Comparison between pre-operative magnetic resonance imaging findings and surgical features in dachshunds suffering from thoracolumbar intervertebral disc extrusion

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Comparison between pre-operative magnetic resonance imaging findings and surgical features in Dachshunds suffering from thoracolumbar intervertebral disc extrusion

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The purpose of this study was to determine whether magnetic resonance imaging (MRI) accurately predicts surgical findings in dachshund dogs with thoracolumbar intervertebral disc extrusions (TLDE). Sixteen dogs presenting with signs of acute TLDE took part in this investigation. MRI was performed on each dog. This was followed by decompressive surgery with the completion of an intra-operative questionnaire documenting the site of the extrusion and spatial distribution of the disc material for each dog. An independent veterinary radiologist evaluated each MRI study, measured and recorded the same parameters from images, utilising 3 sequences (T1-, T2-weighted and Short T1 Inversion recovery) without knowledge of the surgical findings. The imaging findings were compared with the intra-operative

measurements. The specific intervertebral disc (IVD) space from which the material extruded and lateralization of the extruded disc material (EDM) were found to be similar between MRI and surgical observations. Longitudinal distribution of the EDM was described as being cranial, caudal or equally distributed in relation to the affected IVD. A Kappa test showed moderate agreement in longitudinal distribution between MRI and surgery. Circumferential distribution was recorded on transverse images and compared to surgical findings. Recorded distribution only coincided completely in 1 case, although the rest of the cases showed good overlap of findings between the MRI and intraoperative findings. Our results could not demonstrate a statistically significant difference between T1-, T2-weighted or STIR sequences when determining the length of the extruded mass in the vertebral canal. We found that when evaluating the absolute error and range of error for each sequence, that the T2-weighted sequence had a narrower range of errors and was thus more consistent in predicting the size of the lesion pre-surgically. MRI was validated as a very useful imaging modality for neurological disorders in dogs.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Incidence

Canine intervertebral disc disease (IVDD) is a common neurological condition seen in veterinary practice. It is the process of intervertebral disc (IVD) degeneration followed by protrusion or extrusion of disc material into the vertebral canal with focal compression of the spinal cord and/or adjacent nerve roots. Priester[1] published admission figures of 23 IVDD cases per 1000 dogs seen during 1976 at 13 veterinary colleges in the United States and Canada. To put this figure in perspective, allergic dermatitis accounted for 24 new cases per 1000 dogs per year during the same period. Van Niekerk et al[2] found that spinal decompressive surgery (details not specified) made up 5.25% of the surgical caseload of the Onderstepoort Veterinary Academic Hospital in South Africa over a period of 1 year. Dachshunds are 10-12.6 times more likely to suffer from IVDD than any other breed. Priester[1] reported that 65% of the patients suffering from IVDD were dachshunds. Hoerlein[3] reported that dachshunds comprised 24.5% of the breeds affected by IVDD. The incidence of IVDD in the high risk breeds peak between 3 and 6 years of age.

1.2 Anatomy

Intervertebral discs link the vertebrae from the second cervical vertebra (C2) to the sacrum. They are composed of two anatomic regions: the outer *anulus fibrosus* and the inner *nucleus pulposus.* The *anulus fibrosus* is comprised of dense collagen fibres of primarily type I and type II. Collagen is a fibrous structural protein which is the major component of connective tissue and of the extracellular matrix. Type I is found in tendons, muscle, scar tissue and bone. Type II is found predominantly in articular cartilage. The dorsal section of the *anulus fibrosus* is thinner than the ventral part, especially in the thoraco-lumbar region[4]. The *nucleus pulposus* lies eccentrically within the IVD space, further dorsal than ventral. The *nucleus pulposus* is a gelatinous substance originating from the embryonal notochord. This substance consists of notochord cells (which start to degenerate early in life) that are embedded in a well-hydrated, unorganized fibrillar network consisting of collagenous and non-collagenous proteins, glycoproteins and proteoglycan aggregates[5,6]. There are dorsal and ventral longitudinal ligaments that reinforce the IVD dorsally and ventrally respectively. The ligaments run the entire length of the spinal column. Intercapital ligaments cross the dorsal surfaces of each IVD from the second thoracic vertebra (T2) to the tenth thoracic (T10), and make dorsal extrusion or protrusion of discs in this region less likely. The ventral internal vertebral plexus (venous) is situated on the floor of the vertebral canal on either side of the dorsal longitudinal ligament and drains the spinal cord and the vertebrae. The arterial blood supply of the epaxial muscles, fifth thoracic to twelfth thoracic vertebrae and spinal cord, arise directly from the thoracic aorta via the dorsal intercostal arteries. The spinal nerve roots for a given thoracolumbar spinal segment emerge from the spinal cord at a location cranial to their associated intervertebral foramen. Three meningeal layers surround the spinal cord. The outer layer is the dura mater which is lined by an inner thin arachnoid membrane and lastly the pia mater is the innermost layer attached to the spinal cord. The spinal cord is surrounded by cerebrospinal fluid within the subarachnoid space and a thin layer of epidural fat surrounds the dura mater.

1.3 Pathophysiology of IVDD

In non-chondrodystrophic breeds, 75 % of IVD have a normal gelatinous *nucleus pulposus* when tested at 4 years of age but this figure drops to 19 % after 7 years as the *nucleus pulposus* degenerates into a non-gelatinous structure. In chondrodystrophic breeds the aging process is greatly accelerated; the *nucleus pulposus* loses its gelatinous nature before 1 year of age and is usually very advanced by 12-18 months[4,5]. The *nucleus pulposus* loses its gelatinous properties and is replaced by fibrocartilage. The nucleus continues to degenerate and eventually become calcified. The abnormal forces that are transmitted from the *nucleus pulposus* to the *anulus fibrosus* due to loss of shock-absorbing qualities lead to radial fissures and clefts in the anulus and in some instances eventually lead to IVD protrusion or extrusion.

IVDD is the result of IVD degeneration. Hansen described two distinct forms of disc degeneration:

- Type 1 is characterized by chondroid degeneration. During this process the *nucleus pulposus* undergoes loss of water and proteoglycans resulting in an increase in collagen concentration[7]. The matrix disintegrates, with calcification of certain areas. The *anulus fibrosus* also undergoes degeneration with a decrease in the amount of glycosaminoglycans and the formation of radial clefts. The hydro-elastic, shock-absorbing qualities of the *nucleus pulposus* are diminished. As a result, the disc's ability to transmit forces equally and uniformly is lost. Unequal force transmission can further damage the *anulus fibrosus*[6]. This form of disc degeneration is commonly seen in young adult chondrodystrophic breeds and manifests as extrusion of *nucleus pulposus,* through defects in the *anulus fibrosus* into the vertebral canal. This is not the only type of disc degeneration seen in dachshunds and also not seen exclusively in this breed[8].
- Type 2 disc degeneration is characterized by fibroid degeneration of the IVD components. This form is characterized by dorsal displacement of the *nucleus pulposus* while still within the confines of the partially ruptured *anulus fibrosus*; the anulus protrudes dorsally into the vertebral canal. This form of IVDD is most commonly seen in older non-chondrodystrophic breeds[6], although it can occur in the chondrodystrophic breeds as well[8]. This form of disc degeneration will not be discussed further as it was not investigated during this trial.

The thoracolumbar junction (T11 to the second lumbar vertebra (L2)) is the area of the spine most commonly affected by disc extrusion/protrusion, with 65% of all disc protrusions/extrusions in dogs occurring in this region[9]. Approximately 15% of disc protrusions/extrusions occur in the cervical region[10]. A Hansen type I disc extrusion was described after a traumatic event in a dachshund at T1-2. This is a rare case due to the extra stability provided to the *anulus fibrosus* by the intercapital ligament in this region[11].

The extruded disc material is often accompanied by extradural haemorrhage which probably originates from the vertebral sinus when the extruded material lacerates or punctures the sinus[12]. This may be mixed with disc material and/or occur as free haemorrhage or haematomas. The latter may extend some distance from the site of the disc extrusion as shown by Tartarelli et al[12]. They reported on 23 cases of TLDE that had extensive accompanying epidural haemorrhage. These dogs were surgically treated with extended hemilaminectomes. Extent of bone removal was from 3 to 7 vertebrae. Twenty one of these cases regained the ability to ambulate. The only two animals that did not recover were patients that presented with no deep pain sensation pre-operatively.

1.4 Pathophysiology of spinal cord injury

Degenerative changes in the IVD may lead to eventual IVD extrusion or protrusion. Spinal cord injury is the most important consequence of IVD extrusion or protrusion. Physical compression causes the initial spinal cord pathology and initiates a cascade of secondary injury mechanisms that have the potential to further disrupt spinal cord function. This secondary injury can progress after the compression has been removed. One of the most important factors in the pathophysiology of spinal cord injury secondary to disc disease is ischaemia caused by the physical compression of spinal arteries or their branches or possibly venous congestion. This leads to swelling within the spinal cord, local oedema, demyelination, axonal degeneration and neuronal necrosis[6]. Acute disc extrusions have the potential to cause necrosis of grey and white matter.

The secondary mechanisms of injury lead to reduced energy supply to the cells which in turn causes changes in membrane permeability and cell content. This causes cellular swelling. The neurodegenerative process which was initiated by the compression on the spinal cord triggers an inflammatory reaction consisting predominantly of macrophages and fibrous astrocytes [5,6]. Acute thoracolumbar disc extrusion has been reported to precipitate progressive haemorrhagic myelomalacia. The pathogenesis of this condition is unknown but the lesion is characterized by ischemic and haemorrhagic infarction. Neurological symptoms progress in an ascending or descending manner and eventually lead to irreversible paralysis or the animal's death via respiratory failure if the pathology reaches the level of the third cervical vertebra[5,6].

Clinical signs seen with IVDD can also be due to compression of the adjacent nerve roots. This may lead to radicular oedema and accompanying haemorrhage during the acute phase after injury.

The severity of the spinal cord injury is directly affected by the magnitude of the force applied to the spinal cord, the duration that the compression is applied and the ratio of the spinal cord diameter to the vertebral canal[13].

1.5 Clinical signs

The clinical signs observed range from spinal hyperesthesia to hind limb ataxia, non-ambulatory hind limb paraparesis and complete pelvic limb paralysis with and without loss of deep pain perception together with various degrees of loss of sensory and motor function. Twelve % of dogs presented with spinal hyperesthesia alone and 64.2 % presented with pain and paresis[6]. Dachshunds comprise 72.2 % of the dogs presented with signs of thoracolumbar disc disease. When combined with cervical disc disease, this breed represents 70.1 % of affected cases[10].

1.6 Therapeutic Options

Dogs with thoracolumbar disc extrusion can be managed medically by confinement and pain control or treated with surgical decompression and removal of extruded disc material (EDM). Medical therapy is usually attempted in dogs presenting with back pain only or very mild hind limb paresis or when owners decline surgical intervention. The most important feature of medical management is absolute confinement to prevent further disc material extrusion and spinal cord damage while the torn anulus is healing. The disadvantage of medical management is that some cases can deteriorate and then have a prolonged recovery after surgical treatment or no recovery at all.

Surgical therapy is the treatment of choice in most case senarios[1,14,15,16]. These have been subdivided into IVD fenestration and decompression of the spinal cord. **Disc fenestration** aims to evacuate a substantial amount of in situ *nucleus pulposus* through a surgically-created window in the *anulus fibrosus*, in order to indirectly decompress the spinal cord. It has also been used prophylactically to prevent subsequent disc extrusion, both at the site of current extrusion as well as adjacent IVD's. Several surgical approaches have been described in order to achieve direct decompression of the spinal cord. **Dorsal laminectomy** involves extensive bone removal but offers only limited access to the ventral part of the vertebral canal. It does allow access to both the left and right side of the vertebral canal. **Hemilaminectomy** is less destabilizing than dorsal laminectomy and has a reduced risk for cicatrical membrane formation[17]. The **pediculectomy** is the removal of a single pedicle and accessory process and has a minimal destabilizing effect on the vertebral column. A **partial pediculectomy** has been described; the intervertebral foramen does not form part of the bone window created in the pedicle in order to avoid the vertebral artery and spinal nerve. The disadvantage of this is that an unknown amount of disc material can easily be left behind[18].

Surgical candidates require specialized diagnostic imaging to confirm a focal, extradural, cord compression and to anatomically localize the lesion. This enables the surgeon to approach the lesion in the least invasive manner, especially the procedures that provide limited access to the cord.[19,20,21].

The procedure employed at the Ridgemall Veterinary Hospital is the pediculectomy described by Lubbe et al in 1994[16]. This procedure provides an adequate visualization of and access to ventrally and laterally extruded disc material and the spinal cord and causes minimal disruption to the stability of the vertebral column.

1.7 Diagnostic Imaging

1.7.1 Survey Radiography

Survey radiographic localization of extruded disc material was only 60% accurate but improved to 90% after myelography in a study by Schulz et al[22]. The researchers in that study were unable to identify lateralization of EDM on survey radiographs. Clinical lateralization was only 52% accurate.

1.7.2 Myelography

Traditionally, lumbar myelography has been used as the modality of choice to confirm and localize extradural spinal cord compressions in patients with suspected IVD extrusion[20]. This is a technically demanding procedure with various pitfalls. It involves placing a spinal needle in the subarachnoid space between L5 and L6, injecting a non-ionic water-soluble contrast agent and performing radiography to obtain images of the outline of the spinal cord[20]. The animal needs to be under general anaesthesia for the duration of the procedure. Placement of the needle can be aided with the use of fluoroscopy or be performed blindly, the latter requiring considerable experience. Cerebrospinal fluid may be collected from this site. CSF analysis is useful to exclude inflammatory or neoplastic conditions mimicking IVDD. The described limitations associated with myelographic diagnosis of disc disease can be grouped as technical and pathoanatomical[23]. Technical problems relate to radiographic quality, poor contrast distribution and incorrect radiographic views. Pathoanatomical factors are normal anatomical variation, atypical displacement of disc material and spinal cord swelling[23]. Complications associated with myelography are seizures and worsened neurological status after the procedure[20,24]. These complications are not commonly seen due to the use of newer generation contrast agents. Contrast agent can also be deposited into the incorrect space. This could lead to epidurograms (epidural contrast leakage) and canalograms (contrast within the central canal), making image interpretation difficult.

Published reports regarding the accuracy of lumbar myelography are conflicting. Kirberger et al[25] accurately determined the circumferential distribution of disc material in 100% of cases and identified the correct intervertebral space in 97% of cases. Schulz and co-workers could only accurately locate the lesion at the longitudinal site in 90% of cases and circumferentially in 60% of cases[22]. The myelographic technique of the two studies differed. The authors of the latter study concluded that future studies should rather perform computed tomography (CT) or magnetic resonance imaging (MRI) to more accurately locate the position of the extruded disc material. This is especially important when the disc material lateralises in both directions and a decision has to be made whether to perform bilateral surgical decompressions. Oedema of the spinal cord can cause the subarachnoid space to collapse thus affecting myelographic images and complicating localization of disc extrusion.

Spinal cord swelling was evaluated as a prognostic indicator in IVDD using myelography. It was shown that in patients with loss of deep pain perception, the ratio of the total length of attenuation of contrast columns (dorsal plus ventral), to the length of the L2 vertebral body of more than 5 vertebrae, indicated a significantly poorer prognosis than those cases with less than 5 vertebrae of attenuation[26]. Scott and McKee could not prove any prognostic value of myelography in their study in 1999[27]. Myelography can infer cord damage indirectly but it cannot accurately identify pathology within the spinal cord or provide information on the nature or composition of the compression. It can only differentiate between intradural and extradural lesions. The radiographic projections used during myelography can have an important impact on the ability to lateralize EDM. Oblique views are more likely to demonstrate the lateralization of a lesion (93 and 95 %) than ventrodorsal views (59 and 70%). When the two projections were combined, lateralisation was correctly identified in 99% of cases[28].

Myelographic and surgical findings do not always coincide with the clinical signs. Smith and co-workers evaluated 2 groups of dogs classified as suffering from acute and chronic disc extrusion. All demonstrated lateralising extradural compressions on myelography. However, 35 % of the acute cases and 11 % of the chronic cases showed asymmetric clinical signs contralateral to the myelographic and surgically identified cord compression[29].

1.7.3 Computed tomography

The CT appearance of thoracolumbar disc extrusions (TLDE) has been reported in 23 dogs[30]. This study described the successful use of this diagnostic tool for localizing and characterizing extruded disc material. The extruded disc material appeared as a heterogeneous hyperattenuating mass and the degree of attenuation increased as the degree of mineralization increased. These CT findings were correlated to the appearance of the EDM as seen at surgery. No comparison was made with MRI in this study.

In a study that evaluated surgical findings with pre-operative CT and MRI in dogs with degenerative lumbosacral stenosis, it was shown that there was a high degree of agreement between CT and MRI but a lower level of agreement when CT was compared with surgical results and also when MRI was compared to surgery. During surgery the following was recorded: the degree of disc protrusion as none/minimal, slight, moderate or severe; the location of disc protrusion as left, right or central; the position of the dural sac as left, right or central; the amount of epidural fat as absent, reduced, normal or abundant and swelling of the spinal nerve roots as none, left, right or bilateral. These same parameters were recorded as seen on CT and MR images and the degree of disc protrusion was scored as none/minimal, slight (if less than 25% of the spinal canal), moderate (if 25- 50 % of the spinal canal) or severe when more then 50 % of the spinal canal was filled. A Kappa test was used to asses the degree of agreement between CT, MRI and surgical findings. There was near perfect agreement between CT and MRI results as far as degree of disc protrusion, location of disc protrusion, position of dural sac, amount of epidural fat and swelling of spinal nerve roots was concerned. Only moderate agreement was demonstrated between CT and MRI and surgical findings with regard to degree of disc protrusion, location of disc protrusion and swelling of spinal nerve roots. Slight agreement was found with regard to position of the dural sac and amount of epidural fat covering the dural sac when comparing both CT and MRI to surgical findings[31].
CT myelography was evaluated in the thoracolumbar (T11-L2) spine of 8 large breed dogs with clinical signs of degenerative myelopathy (DM). These findings were compared to 3 normal controls. Spinal stenosis, disc protrusions, spinal cord

deformities, attenuation of the subarachnoid spaces, small spinal cords and paraspinal muscle atrophy were regularly found in dogs with suspected DM. Canal diameter ratios were shown to be smaller in dogs with DM at more than one location. These were the ratios of mean spinal cord diameter to dural sac diameter, spinal cord diameter to vertebral canal, dural sac to vertebral canal and vertebral canal to vertebral body diameter. These findings were consistent with findings reported in humans, dogs and horses suffering from stenotic myelopathy[32].

Axlund and Hudson[33] used CT to calculate the percentage of the vertebral canal occupied by a bulging lumbosacral IVD in a group of 22 dogs with no clinical signs of lumbosacral stenosis. They expressed the maximum height of the protrusions as a percentage of the height of the vertebral canal measured at the same location. The mean percentage occupation was found to be 26.89 %.

1.7.4 Magnetic Resonance Imaging

MRI is frequently used in the human medical and the veterinary field for the imaging of a variety of body systems. The principal advantage is enhanced soft tissue imaging with three-dimensional delineation. This imaging modality is non-invasive and safe for the patient. In humans it has been proven as the modality of choice for imaging the nervous system[34,35,36,37,38].

Technical aspects: The body contains positively charged hydrogen ions or protons. These protons spin around their own axes and so create an electromagnetic field. The overall charge is neutral due to the different orientation of the different protons. With MRI, the patient is placed in an external electromagnetic field which aligns protons within this field. A radiofrequency pulse is transmitted through the body and this shifts the proton’s orientation. After the pulse is discontinued, the protons relax and realign their electromagnetic fields with the external field and emit the absorbed energy as a radio signal. A coil surrounding the animal receives these signals, which are reconstructed and portrayed as an anatomical image[39]. T1 relaxation means that the protons relax after the radiofrequency pulse and realign in the same direction as the external magnetic field. This is also known as spin-lattice relaxation. T2 relaxation results when the protons spin out of synchrony and occurs perpendicular to the ambient magnetic field when the protons become out of phase. This is also called transverse or spin-spin relaxation. The hydrogen content of a specific tissue and the interaction between hydrogen protons and surrounding substrates define its intensity on MR images, being more intense with increased content of hydrogen protons. The selection of the most appropriate sequence to use when performing MRI is an area of ongoing debate and research. Studies have compared different techniques to try and find solutions to scanning time and image quality problems[22,40]. The published reports differ slightly with regards to the method employed. This is due to the fact that MRI machines differ, patients and regions of interest differ and researchers are often investigating a variety of conditions. The most commonly used sequences include T1-weighted, T2-weighted and gradient echo susceptibility-weighted sequences.

MRI is potentially more versatile than myelography, as the sequences can be manipulated to enhance certain tissue types and suppress others. MRI can acquire images in virtually any anatomic plane and by using sagital images, one can evaluate multiple vertebral levels at once. This is often performed with the aim to identify the area of pathology and this area can be investigated in detail using transverse or other imaging planes[24,41,42,43,44]. The spinal cord is surrounded by a thin layer of epidural fat which is usually easily visualized on MRI as a hyper-intense area (on T1-weighted images). The spinal cord is usually seen as a homogenously hypo-intense structure on MRI. On T2-weighted sequences it is sometimes possible to visualize the central canal filled with hyper-intense cerebrospinal fluid. Intravenous contrast agents add to the versatility of MRI. Gadolinium–DTPA has the function of enhancing highly vascular structures especially in conjunction with T1-weighted sequences. Neoplastic masses and scar tissue formation usually enhance with the use of this agent. Disc material can enhance but usually the enhancement is inhomogeneous and late (30-45 minutes after injection) [35].

Clinical knowledge : There are a number of reports describing the clinical application of MRI in dogs[12,24,42,43,44,45,46,47,48]. Of these studies, some have looked at the normal spine[7,33,40,45,49,50] while others have looked at degenerative changes in the IVD discs[47,50]. MRI has been validated in the veterinary literature as a reliable diagnostic tool for IVDD[7,24,42,43,45,47,48,49]. Seiler and co-workers[50] proved the accuracy of MRI to characterize IVD degeneration in the lumbar area by comparing MR findings to histopathology. The lumbosacral spine has received particular attention, due to the fact that this area is difficult to interpret with the traditional techniques of myelography, epidurography and discography[42,43,45,51].

Gopal and Jeffery[46] described a case of spinal cord injury which was diagnosed using MRI. An intramedullary lesion was demonstrated as a hyperintense focal area on T2-weighted sagittal images.

Besalti et al[49] performed a retrospective study of 40 dogs of differing breeds. They evaluated the effect of the extruded disc material on neurological status and surgical outcome. MRI was used to diagnose Hansen type 1 disc extrusions. Dogs were grouped into two groups, one group had dispersed disc material that was not in contact with the parent IVD space while the other group had non-dispersed disc material still in contact with the parent disc space. No correlation was found between dispersed or non-dispersed material and pre-operative neurological status or surgical outcome. The MRI findings correlated with surgical observations with regard to localization and degree of dispersion. Horizontal length and vertical height were measured with manual callipers on MRI and ratios were compiled with the vertebral length and the vertebral canal height. No correlation was found between these ratios and surgical outcome. This study also sought to correlate the position of the extruded mass as seen on MR and observed at surgery. They demonstrated complete agreement with regards to left, right or central positioning of the EDM. The size of the extruded mass as seen on MRI was not compared to the actual size seen during surgery. The position of the extruded mass was also not described in relation to the actual IVD space.

A second retrospective publication by Besalti and co-workers evaluated case records of 69 dogs with the objective to classify the different MRI appearances of four types of IVD diseases[7]. Their classification scheme recognized disc degeneration, bulging IVD, disc protrusion and disc extrusion as the four types of pathology seen with IVDD. Disc extrusion was characterised by herniation of the disc through all the layers of the anulus and was present as a focal epidural mass. The extrusions were also sub-classified as dispersed or non-dispersed disc extrusions. The dispersed disc extrusions were noted as disc material which was not in contact with the affected IVD space but spread out along the epidural space. The non-dispersed disc extrusions were seen as disc material in close relation with the affected IVD space and appearing as a focal mass. They noted that all pathological types except disc extrusion can be present without causing clinical symptoms. The extruded material was identified as a mass of low signal intensity in the epidural space on T1- and T2-weighted images. Overall mean degree of vertebral canal narrowing was 49%. This did not correlate with the neurological status score. Twenty-one of the 69 dogs showed areas of increased signal intensity in the spinal cord. Sixty-six percent of these cases also had dispersed disc extrusions. There was significant correlation between the neurological status score and the presence of an area of increased signal intensity in the spinal cord. The increased signal intensity of the spinal cord is associated with oedema, haemorrhage or myelomalacia in acute spinal cord injuries and with gliosis in chronic cases[52].

Ito et al[53] evaluated the prognostic value of MRI in paralysed dogs suffering from TLDE. All dogs with no hyperintensity in the spinal cord on T2-weighted images recovered successfully. Only 55 percent of dogs with focal hyperintensity greater or equal to the length of L2 on T2-weighted images regained the ability to walk. Five out of 16 dogs with no deep pain perception and hyperintensity greater or equal to the length of L2 on T2-weighted images in the spinal cord recovered. This area of hyperintensity could be associated with necrosis, myelomalacia, intra-medullary haemorrhage, inflammation or oedema. Because the onset of clinical signs and the timing of the MRI study differed a lot, the authors could not conclude which pathologic process caused the areas of hyperintensity in their study. They did however suggest that the most likely reason was haemorrhage.

Okada and co-workers reported a case of spontaneous systemic haemorrhage in a dog that presented with tetraplegia. MRI revealed various regions of isointensity intermingled with hyperintensity on T1-weighted images and multiple areas of hyperintensity on T2-weighted images. These regions were all confirmed to be areas of haematomyelia on post mortem examination[54].

Tartarelli[12] reported 23 cases of TLDE accompanied by extensive epidural haemorrhage. In two of these cases, MRI was used to make the diagnosis and correlated accurately to the surgical findings.

The appearance of extradural haematomas associated with IVD extrusion was documented in a single case by Tidwell et al[44]. Their findings (on T1- and T2-weighted images) included partial loss of signal in the disc space with a focal signal void in the vertebral canal. This was confirmed surgically as extruded, mineralized disc material. Additional extradural masses, thought to be a combination of blood and mineralized material were observed.

One case report described a Great Dane dog with faecal incontinence and paraparesis in the pelvic limbs. MRI revealed a T13-L1 IVD extrusion and associated haemorrhage and epidural haematoma. Surgical decompression followed and the removed material was sent for histopathology which confirmed the presence of extruded IVD material with chronic haemorrhage and inflammation. The dog recovered faecal continence by 3 weeks after the surgery[55].

There are studies reporting specific measurements of compressive lesions. Mayhew et al[51] measured the degree of lumbosacral compression by calculating a ratio between the dorso-ventral height of the epidural fat at the point of maximum compression and the dorso-ventral height of the epidural fat at the mid body of L6. This was termed the sagital compression ratio. A second compression ratio, namely the cross-sectional compression ratio was calculated by computer software determining the cross sectional area of the vertebral canal at the level of maximum compression, divided by the area determined at the mid body of L6. The authors failed to correlate the degree of compression with the clinical severity.

Cervical spondylomyelopathy of Doberman Pinchers were investigated using MRI and a comparison was made between clinically normal dogs and affected patients. Spinal cord compression, foraminal stenosis, IVD degeneration and protrusion were recorded. Morphometric measurements were made of the vertebral canal and spinal cord in sagital and transverse MR images. Clinically affected dogs had relatively stenotic vertebral canals and wider IVD spaces[56].

The human spine differs from the canine spine in many respects. The human spinal cord ends at the level of L2 and the canine spine at L5-6. IVDD in dogs is most frequently seen at the thoracolumbar junction, where the effects are directly on the spinal cord[3]. In humans the disc extrusions occur mostly in the lower lumbar region where pressure is exerted on the nerve roots and not on the spinal cord. Humans very rarely suffer from acute calcified disc extrusions. Calcified IVD are usually an indication of a more chronic problem[5]. Thus we cannot directly extrapolate the findings to dogs.

1.8 Prognosis of intervertebral disc disease

Black[14] showed that the neurological status of 67.5% of dogs treated surgically for thoracolumbar disc disease improved significantly during the first 72 hours post surgery. All of the dogs in the study were pain free and walking after an average of 2.5 weeks.

Prognostic factors for non-ambulatory dogs with Hansen type I IVD extrusion were evaluated in 308 cases by Ruddle and co-workers[57]. They investigated the specific IVD space as a prognostic factor. The results showed that dogs with disc extrusions from L3-4 caudally were twice as likely to regain the ability to walk sooner than dogs with lesions at T10-L3. Dogs with loss of deep pain sensation pre-operatively were 1.7 times less likely to regain the ability to walk but still showed a 69% recovery rate.

Body weight, body condition score and various body dimensions were investigated to determine if any of these were associated with acute TLDE or protrusion in dachshunds and also if any were linked to severity of clinical signs. The distance from T1 to S1 and from the tuber calcaneus to the patella tendon, were significantly shorter in affected dogs when compared to unaffected dachshunds without signs of IVDD. Height at the withers and pelvic circumference were also associated with clinically affected dogs, with taller height and smaller pelvic measurements seen in unaffected dogs. Body weight and body condition score were not significant factors[58].

Kinzel et al investigated the prognosis and outcome of dogs with thoracolumbar IVDD treated with partial percutaneous discectomy. The technique involved the removal of a 5 mm section of IVD and adjacent vertebral end plate using a Michel trephine introduced over a guiding K-wire. Clinical improvement was seen in 88.8 % of cases with intact deep pain sensation and 38.2 % of cases with no deep pain sensation. This technique was proposed as an alternative to open fenestration and an addition to decompressive surgery when indicated. It was not meant as a substitute for surgical decompression in cases of spinal cord or nerve root compression[59].

In a study of degenerative lumbosacral stenosis, it was found that dorsal decompression yielded favourable results but the presence of faecal and urinary incontinence worsened the prognosis. The duration of urinary incontinence was a further important predictor of prognosis. Faecal incontinence was a poor prognostic indicator, regardless of the duration of the symptoms[60].

Transverse T2-weighted images were used to calculate the degree (percentage) of spinal cord compression at the level of maximum compression compared to the closest non-compressed spinal cord section. These findings were correlated with the neurological grade at presentation, rate of onset of signs, duration of signs and surgical outcome. No significant association could be demonstrated[61].

The degree of neurological dysfunction has been correlated with prognosis. Scott and McKee[27] showed that the most reliable prognostic indicator was the time taken to lose the ability to ambulate. If this time was more than 1 hour, the prognosis was favourable. The recovery rate in their study for dogs with loss of deep pain sensation treated surgically within 72 hours was 62%. Dogs treated surgically with intact deep pain perception showed recovery rates of 80 – 96%[62].

Twenty-seven percent of dogs with surgically treated Hansen type I disc extrusion were diagnosed with lower urinary tract infection. There was a higher incidence of cases with urinary tract infection in dogs unable to walk or voluntarily urinate, dogs not receiving peri-operative cefazolin and those whose body temperature fell under 35°C during anaesthesia[63].

Eight out of 12 working dogs with degenerative lumbosacral stenosis returned to full activity 6 month after decompressive surgery. MRI and CT were used in the diagnostic work up and no significant association was demonstrated between imaging findings and surgical outcome[64].

Sanders and co-workers[65] described a case of intramedullary spinal cord damage secondary to IVD extrusion into the substance of the spinal cord. A good clinical improvement but not a complete recovery, was observed after surgical removal of the extruded disc material[65].

The prognosis for military working dogs with lumbosacral stenosis was reported in 29 dogs after surgical intervention. Forty-one percent of these dogs returned to normal function. Increasing age and severity of neurological status correlated with a poorer surgical result. Other poor prognostic indicators were foraminal narrowing on radiographs and hypertrophic articular facets and interarcuate ligaments as seen in surgery[66].

1.9 Post-operative considerations

"Failed Back Surgery Syndrome" (FBSS) is a well described condition in human beings[35,37,38]. This term implies that the final outcome of surgery did not meet the pre-operative expectations of the patient and/or the surgeon. In humans, lumbosacral spinal surgery has a failure rate of 10 – 40 %. Repeat surgery, in these patients, is only successful in 60 – 82 % of cases. It is therefore very important to accurately diagnose the cause of recurrent signs to avoid unnecessary repeat surgery. Causes range from recurrent disc extrusion, foraminal stenosis and spinal instability[37]. Studies in humans looking at FBSS have found that MRI was the most successful modality to identify and characterize the causes for this condition. Scar tissue can be differentiated from recurrent disc extrusion, and foraminal stenosis was frequently diagnosed. Studies in humans evaluating the early post-operative spine found that some degree of soft tissue compression of the thecal sac was still present in the first month after surgery[34,36]. This mass effect was described as post-operative epidural oedema due to the intermediate signal intensity on T1 weighted images and slightly hyperintensity on T2 weighted images[36]. Post-operative haematomas do not cause a mass effect of the spinal cord[35].

Reoperative neurosurgery in the thoracolumbar region in dogs was investigated by Dhupa et al and published in 1999[67]. The prevalence in dachshunds of recurrent clinical signs following surgery for thoracolumbar disc extrusion/protrusion was reported to be approximately 10%.[67]. Dhupa and co-workers divided patients into an early reoperative group receiving surgery within the first month after initial decompression and a late reoperative group requiring surgery more than 1 month after the first operation. The early cases comprised 17% of the animals undergoing repeat surgery. All the dogs (5 out of 30) in this group had residual extradural spinal cord compression at the same level as the first procedure. The late reoperative group only had 12% with compression at the same level as the first procedure. The rest had a second IVD herniation at a different level. In the majority of cases, extruded disc material was found in the vertebral canal during the second surgery. Neurological status in the late reoperative group was worse in only 12% of cases at the time of the second surgical decompression.

Mayhew and co-workers evaluated risk factors for the recurrence of symptoms related to TLDE. They demonstrated a 25% recurrence rate in dachshunds and 15 % in other breeds. The dogs in this study did not undergo prophylactic fenestration at the initial surgery. An increased number of opacified discs were positively correlated to an increase in risk of recurrence[68].

<u>Conclusion</u>

The literature review identified the following deficiencies in the understanding of MRI in dogs suffering from TLDE:

1. There are no published prospective studies of dogs with TLDE undergoing MRI investigations.
2. No comparison between size of the extruded mass seen on MRI and that found at the time of surgery has been reported.
3. No study has compared different sequences to determine which is the most accurate at determining the size of the extruded mass.
4. No previous case series describing the MRI appearance of TLDE has standardised their patient profile with regards to breed, chronicity of pathology, first time event and level of disc extrusion.

CHAPTER 2

OBJECTIVES

To compare the location/site of the extruded disc material seen on MRI with that recorded intra-operatively for the following variables:

a.) The specific IVD space from which the extruded material originated.
b.) The longitudinal distribution of the extruded material in relation to the identified IVD. Classified as cranial to, caudal to or equidistant from the level of the identified extruding IVD.
c.) The circumferential distribution of the extruded material in relation to the spinal cord. Classified as ventral, ventrolateral, lateral or dorsal to the spinal cord.
d.) The maximum cranio-caudal length in millimetres (mm) of the extruded mass observed on T1-, T2-weighted and Short T1- Inversion Recovery (STIR) images and individually compared to the intra-operative length.

Hypotheses

1. MRI accurately predicts surgical extent and location of extruded IVD material in dachshund dogs with thoracolumbar IVDD.

2. There is no significant difference between three different MRI pulse sequences (T1-, T2-weighted and STIR) when determining the length of extruded IVD material.

CHAPTER 3

MATERIALS AND METHODS

This research project was approved by the Animal Use and Care Committee of the Faculty of Veterinary Science, University of Pretoria.

3.1 Model system

An observational study, using sixteen dachshund dogs, admitted to Ridgemall Veterinary Hospital for treatment of suspected TLDE was performed. Dachshunds of any age, weight or gender were accepted into this trial.

There were strict inclusion/exclusion criteria that needed to be met before a case was entered into this project: The history, according to the owner, of a suspected spinal condition of no longer than 6 weeks. No dog had a history of a previously confirmed spinal condition or of a traumatic incident related to the current clinical symptoms. Patients with symptoms of cervical IVDD were excluded from the trial. Every dog had intact deep pain sensation present in both pelvic limbs and in the tail. All patients were free of additional underlying clinically significant problems unrelated to spinal disease. Survey radiographs of the thoracolumbar spine were negative for discospondylitis, neoplasia, fracture or luxation in every dog. Each patient's pre-operative MRI study confirmed only one IVD extrusion into the thoracolumbar vertebral canal.

3.2 Experimental procedures

3.2.1 History and clinical examination

A detailed history of the current complaint was obtained from every owner, including symptoms observed and duration of problem. The patient's age, weight, gender and whether or not they were sterilized was also recorded. The physical examination included an evaluation of habitus and an observation of the patient's ambulatory status. This was followed by an examination of the head with attention to mucous membrane colour, capillary refill time and other abnormalities. Each dog's rectal temperature was recorded. Thoracic auscultation with pulse evaluation and abdominal palpation was performed. An orthopaedic examination to exclude any joint pain or palpable pathology concluded the clinical assessment. All information was recorded on patient data sheets.

3.2.2 Neurological examination

A full neurological examination was performed on each patient and recorded using the following table:

Table 1: Neurological Examination

Neurological test	**Findings**		
Cranial Nerve Function	Normal	Abnormal	
Neck pain	Yes	No	
Conscious proprioception	Normal(LH, RH,LF,RF)	Delayed(LH,RH,LF,RF)	Absent(LH,RH,LF,RF)
Ambulation	Yes	No	
Ataxia	None	Mild	Severe
Thoracolumbar pain	Yes	No	Site
Motor function	Yes (LH, RH)	No (LH, RH)	
Superficial pain (needle prick)	Yes	No	
Deep pain (Compress digits with haemostat)	Yes (LH, RH)	No (LH, RH)	
Flexor withdrawal reflex	Yes (LH, RH)	No (LH, RH)	
Reflex patella	Hyper (L, R)	Normo (L, R)	Hypo (L, R)

Reflex cranial tibial	Hyper (L, R)	Normo (L, R)	Hypo (L, R)
Reflex Achilles	Hyper (L, R)	Normo (L, R)	Hypo (L, R)
Anal tone	Normal	Depressed	Absent
M cutaneous trunci reflex	Present	Absent	Site

KEY:

Hyper-	Excessive response to testing of reflex
Hypo-	Decreased response to testing of reflex
Normo-	Normal response to testing of reflex
LH-	Left Hind
RH-	Right Hind
LF-	Left Front
RF-	Right Front
L-	Left
R-	Right

The patient's neurological status was scored according to the following scheme (modified from Prata[69]):

Table 2: Neurological classification

1	Normal ambulation with pain on (digitally-applied) dorsal thoracolumbar spinal pressure.
2	Ambulatory with mild ataxia in pelvic limbs (less than 50% of time, dorsal knuckling or feet crossing midline).
3	Ambulatory with severe ataxia in pelvic limbs (more than 50 % of time, dorsal knuckling or feet crossing midline).
4	Non-ambulatory with voluntary motor function present (uni- or bilaterally).
5	Non-ambulatory with no voluntary movement but good deep pain sensation.

3.2.3 Radiography

Lateral and ventrodorsal survey radiographs of the thoracolumbar vertebrae were obtained. Radiographs were only examined for the presence or absence of discospondylitis, neoplasia, fracture or luxation of the thoracolumbar spine. If any of these conditions were found, the animal was excluded from the study.

3.2.4 Magnetic Resonance Imaging

The MRI was performed at a site distant to the Ridgemall Veterinary Hospital. Patients were premedicated prior to transportation via a cephalic catheter using medetomidine (Domitor, Novartis, Kempton Park, SA) at a dosage of 10-20 µg/kg and then transported to Wilgeheuwel Hospital (situated approximately 3 kilometres from the veterinary hospital) by the principle researcher. Each patient received an intravenous infusion of Ringer's lactate (Adcock Ingram Critical Care, JHB, SA) at a rate of 40-60ml/kg/day or 5-10ml/kg/hour. General anaesthesia was then administered using thiopentone sodium 2.5% solution (Intraval sodium, Merial, Halfway House, SA) by slow intravenous injection at 0.1 – 0.5ml/kg and an endotracheal tube was placed. A few patients required a repeat dosage of thiopentone sodium during the procedure.

The MRI examination was performed by a qualified radiographer, using a 1.5 tesla MRI unit (Philips Gyroscan Intera T15). Patients were positioned in dorsal recumbency with the hind limbs in a flexed position. All attempts were made to position the animal as straight as possible.

Scanning protocol:
Thoracolumbar vertebral column was investigated from T10-L7. The following sequences were performed on every case. T1-weighted, T2-weighted and STIR* sequences were obtained in the sagital plane. Balance-Turbo field echo (B-TFE) sequences in the transverse plane, at the level of the extruded IVD material was performed after the sagital series. An MRI myelogram was generated by the software of the MRI-unit.

* (An inversion recovery pulse sequence is a spin echo pulse sequence preceded by a 180° radiofrequency pulse)

MRI settings :
T1: FOV (Field of view) 275, Matrix 304 x 512, TE 10, Flip angle 90°, TR 400, 2mm slices with 2mm slice gaps.
T2: TE 120, TR 3500 (rest as for T1)
STIR: IR delay 170 ms, TR 2500, TE 10, Matrix 256 x 512
B-TFE: FOV 225, Matrix 352 x 512, Flip Angle 45°, TR 5.3, TE 2.7, Slice thickness: 1.2mm with 1.2mm slice gap
All images were stored digitally. Hard copies were also available for examination of each sequence performed.

3.2.5 Surgery

Surgery was started within 45 minutes of completion of the MRI and completed within the following 90 minutes. Anaesthesia was maintained with halothane inhalation agent. All dogs received morphine sulphate (Fresenius Kabi, PE, SA) subcutaneously at 0,3mg/kg and amoxicillin/clavulanate (Augmentin, Aspen Pharmacare) intravenously at 20mg/kg pre-operatively. The surgical site was shaved using Oster clippers and prepared aseptically following accepted published methods[50].

A pediculectomy was performed at the location determined by the MRI study. A bone window was created marginally bigger than the outline of extruded disc material as observed from lateral images. The extruded material was carefully removed once the various measurements had been made. The herniated IVD was fenestrated using a number 11 scalpel blade and a blunt curette. All patients were under anaesthesia for less than 3 hours in total.
Post-operative pain control consisted of morphine sulphate subcutaneously at a dosage of 0,3 – 0,5 mg/kg administered every 4hrs during the first 24 – 48 hrs, as well as carprofen (Rimadyl, Pfizer Animal Health, Sandton, SA) administered orally at a dosage of 4 mg/kg once a day for the first 7 days after surgery. Animals were

caged in a heated ward until full recovery. Intravenous fluids were continued until the patient ate. Amoxycillin/clavulanate was repeated at 4 and 12 hours post-operatively. Patients were discharged from hospital once they could walk unassisted and void urine and faeces unaided. All patients were hospitalized for at least 72 hours.

3.2.6 Measurements and observations

Intra-operative findings (Appendix 1):

The operating surgeon (SHN) recorded the following measurements during the pediculectomy: The total length (in millimetres) of the extruded mass was measured in a cranio-caudal direction using a sterile manual calliper. The position of the extruded mass in relation to the IVD space was recorded as distributed more cranially, more caudally or equidistant to the extruding disc space. The position of the extruded mass was recorded in relation to the spinal cord as situated dorsal, lateral, ventral or ventrolateral thereof. The position of the EDM with regards to lateralization was also recorded as situated left or right of the spinal cord, or central midline.

Magnetic resonance imaging findings and measurements (Appendix 2):

Measurements were performed on the MRI unit computer by an independent, board-certified (ECVDI) radiologist, who had no knowledge of the intra-operative findings. The recorded data started with identifying the specific herniating IVD space. The maximum length of the extruded mass as seen on sagital T1-weighted, T2-weighted and STIR sequences in a cranio-caudal direction was measured and recorded. This was performed by using the digital calliper of the MRI computer. Two measurements on each sequence were recorded in millimetres. The average of these two measurements was used during the statistical analysis. The distribution of the extruded mass as seen on the sagital sequence, in relation to the disc space was recorded as distributed cranially, caudally or equally cranially and caudally relative to the identified disc space. Transverse B-TFE sequences (gradient echo) were used to evaluate the circumferential distribution of the extruded IVD material and recorded as dorsal, lateral, ventral or ventro-lateral. The transverse images were also used to categorize the material as situated left or right of the spinal cord or exactly central in the vertebral canal

3.3 Data analysis

3.3.1 Statistical analysis

Descriptive statistics were calculated for the patient's age, weight, gender and duration of clinical signs.

Frequency tables and/or cross-tabulations were compiled for the neurological score and the specific herniating IVD site on MRI and compared to the intra-operative findings. The lateralization of the EDM, the longitudinal distribution and the circumferential distribution of the material were all presented in frequency tables or cross-tabulations.

Kappa statistics were calculated to assess agreement between each MRI sequence and intra-operative findings with respect to location of the herniated disc, lateralization of the extruded mass and longitudinal distribution of the extruded mass. For the latter, a weighted Kappa statistic was used in which cranial vs. equal and caudal vs. equal were each regarded as 50% agreement, and cranial vs. caudal as disagreement.

Agreement between cranio-caudal length of the compressive mass obtained by each MRI sequence and that obtained intra-operatively was assessed using scatter plots, correlation coefficients, and calculation of absolute errors for each patient. Paired *t*-tests were used to compare mean lengths obtained by each MRI sequence with that obtained during surgery. Mean bias, with 95% confidence intervals, was calculated for each sequence, and 95% limits of agreement were then calculated for each sequence vs. intra-operative measurement. Absolute errors were also compared between MRI sequences using repeated-measures analysis of variance.

The first hypothesis, that MRI accurately predicts the length of the extruded IVD mass as seen during surgery, was tested. The paired *t*-tests were used to compare mean lengths obtained by each MRI sequence with that obtained during surgery.

The second hypothesis, that there was no significant difference between three different MRI pulse sequences (T1-, T2-weighted and STIR) when determining the length of extruded IVD material, was tested using a repeated measures analysis of variance. Mean error, with 95% confidence intervals, was calculated for each sequence and 95% limits of agreement were calculated for each sequence vs. intra-operative measurement, and presented graphically. Statistical analyses were done using Stata 8.2 (StataCorp, College Station, TX, U.S.A.) and NCSS 2004 (NCSS, Kaysville, UT, U.S.A.) statistical software.

CHAPTER 4

RESULTS

4.1 Description of sample population

4.1.1 Age and body weight

The summarised results for patient age and body weight are presented in Table 3. The individual signalment details are recorded in Appendix 3.

Table 3: Patient age and body weight

Variable (n=16)	Mean	Median	Standard deviation	Range
Age (years)	5.9	5	1.843	3-10
Weight (kg)	7.56	7.3	1.682	4-11

4.1.2 Gender

The summarised results for patient gender are presented in Table 4. The individual patient gender detail is recorded in Appendix 4.

Table 4: Patient Gender

Gender	Frequency (n=16)	Percentage (%)
Female intact	0	0
Female spayed	5	31.25
Male intact	4	25

Male neutered	7	43.75
Total	16	100

4.2 Clinical history – duration of clinical signs

The summarised results for the duration of clinical signs are presented in Table 5. The individual patient details are presented in Appendix 5.

Table 5: Duration of clinical signs

Variable (n=16)	Mean	Median	Standard deviation	Range
Duration of clinical signs (days)	8.8125	5	10.46	1 - 42

4.3 Clinical signs – neurological score

The summarised results for neurological status are presented in Table 6. The individual patient details are recorded in Appendix 6. No patient scored 4 or 5 in the neurological category.

Table 6: Neurological score

Neurological score	Frequency (n=16)	Percentage (%)
1	6	37.5
2	3	18.75
3	7	43.75
Total	16	100

4.4 Characteristics of intervertebral disc extrusion

4.4.1 Specific extruded intervertebral disc space

The summarised results of the localization of the extruded IVD as seen on MRI and during surgery, is presented in Table 7. The individual patient details are recorded in Appendix 7.

The objective was to compare the specific IVD space from which the EDM originated, as seen on MRI, with that recorded during surgery. There was complete agreement (Kappa = 1.0) between the MRI images and the specific extruded IVD as found intra-operatively. The null hypothesis that MRI estimates of disc length were similar to surgical estimates of disc length was thus not rejected.

There was no difference in the number of correct predictions for any of the pulse sequences, as tested using a repeated measures analysis of variance. This finding was expected because the results of MRI were used for surgical planning.

Table 7: Extruding IVD space

Extruded IVD	Frequency (n=16)	Percentage (%)
T 11-12	3	18.75
T 12-13	6	37.5
T 13 – L1	2	12.5
L 1-2	3	18.75
L 2-3	0	0
L 3-4	2	12.5
Total	16	100

4.4.2 Lateralization of extruded mass

The summarised results of the lateralization of the extruded mass as seen on MRI and during surgery are presented in Table 8. The individual patient details are recorded in Appendix 7.

The objective was to compare the lateralization of the EDM as seen on each of the three MRI pulse sequences with that recorded during surgery. There was complete agreement (Kappa = 1.0) between MRI images and findings intra-operatively with respect to the lateralization of the extruded mass. There was no difference in the number of correct predictions for any of the pulse sequences. This finding was expected because the results of MRI were used for surgical planning.

Table 8: Lateralization

Lateralization of extruded mass	Frequency (n=16) on T1	Frequency (n=16) on T2	Frequency (n=16) on STIR	Frequency (n=16) during surgery	Percentage (%)
Right	8	8	8	8	50
Left	8	8	8	8	50
Total	16	16	16	16	100

4.4.3 Longitudinal distribution of extruded mass

The longitudinal distribution as recorded from the MRI images and as observed during surgery, are cross-tabulated in Table 9. The patient details are displayed in Appendix 8. Each cell of the table represents the number of patients recorded as having extruded disc material at a specific location (cranial, caudal or equidistant from the affected disc space) using MRI and surgical exploration. The individual patient details are recorded in Appendix 8. The weighted Kappa statistic for agreement between MRI and intra-operative findings was 0.59, indicating moderate agreement. In eleven of the sixteen cases we found agreement between the surgical and MRI findings. In 2 cases where MRI indicated equidistant distribution, disc material was found cranial to the disc space. Two other cases found the opposite. An additional case had disc material distributed equidistant in relation to the disc space but MRI showed a predominant caudal distribution.

Table 9: Longitudinal distribution

		SURGERY			
		Cranial	**Equidistant**	**Caudal**	**Total**
MRI	**Cranial**	6	2	0	8
	Equidistant	2	3	0	5
	Caudal	0	1	2	3
	Total	8	6	2	16

The highlighted cases in the above table represent the five cases where there was no agreement MRI and surgery with regards to the longitudinal distribution.

4.4.4 Circumferential distribution of the extruded mass

The circumferential distributions of the extruded mass as seen on MRI and intra-operatively are presented in Table 10. Each marked cell indicates the position in which each specific observer (surgeon and radiologist) found the extruded material to be located.

Table 10: Circumferential distribution

Patient	Ventral	Ventro-lateral	Lateral	Dorsal
1 Surgery		♦		
MRI	O			
2 Surgery	♦			
MRI	O	O	O	
3 Surgery		♦	♦	
MRI	O	O	O	
4 Surgery		♦		
MRI		O	O	
5 Surgery	♦	♦		

MRI	**O**	**O**	**O**	
6 Surgery	♦			
MRI	**O**	**O(L + R)**		
7 Surgery	♦	♦		
MRI	**O**	**O**	**O**	
8 Surgery	♦	♦		
MRI	**O**	**O**	**O**	
9 Surgery	♦	♦	♦	
MRI	**O**	**O**	**O**	**O**
10 Surgery		♦	♦	
MRI		**O**	**O**	**O**
11 Surgery		♦		
MRI	**O**	**O**	**O**	**O**
12 Surgery			♦	
MRI		**O**	**O**	
13 Surgery	♦		♦	
MRI	**O**	**O (L + R)**	**O**	
14 Surgery	♦	♦	♦	
MRI	**O**	**O**	**O**	
15 Surgery		♦		
MRI	**O**	**O**		
16 Surgery			♦	
MRI		**O**	**O**	**O (L + R)**

4.5 <u>Length of extruded mass</u>

The intra-operatively measured length of extruded disc material was taken as a standard against which each MRI sequence was compared. The aim was to firstly determine if any significant difference exist between the average lengths measured for each sequence when compared to the measured intra-operative length using a paired *t*-test. Secondly we compared the absolute error measured from each MRI pulse sequences using ANOVA.

All collected data is presented in Appendix 9-11. Where data is not entered into a certain cell, the radiologist could not accurately measure or define the boundaries of a specific IVD extrusion. Scatter plots are used to illustrate the data collected for each sequence.

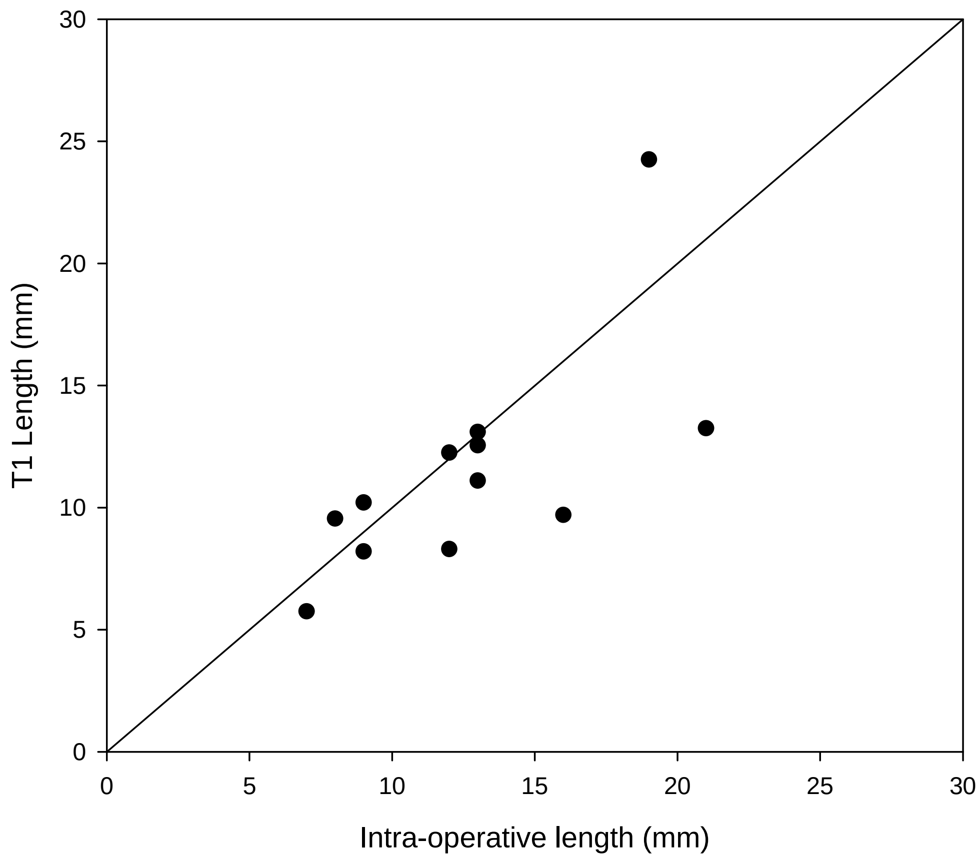

Figure 1: Scatter plot of maximum length of extruded mass observed on T1 vs. that measured intra-operatively. The diagonal is the line of perfect agreement. The vertical distance between each point and the diagonal is the T1 measurement error. r^2 = 0.478.

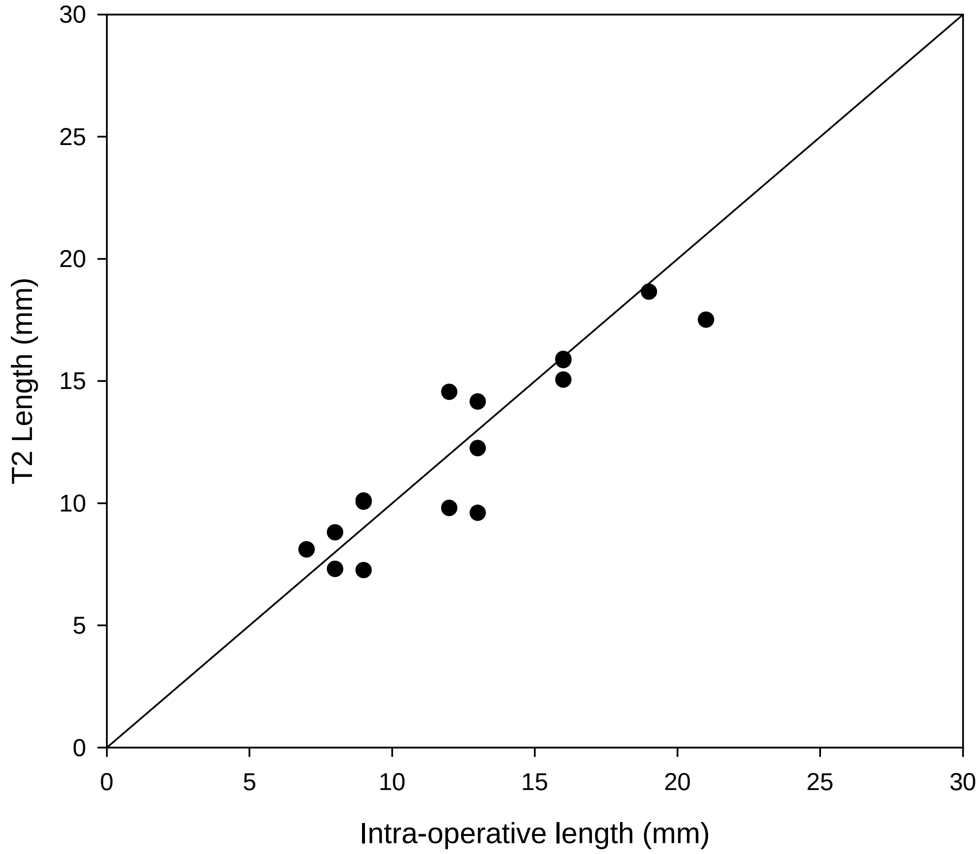

Figure 2: Scatter plot of maximum length of extruded mass observed on T2 vs. that measured intra-operatively. The diagonal is the line of perfect agreement. The vertical distance between each point and the diagonal is the T2 measurement error. $r^2 = 0.833$.

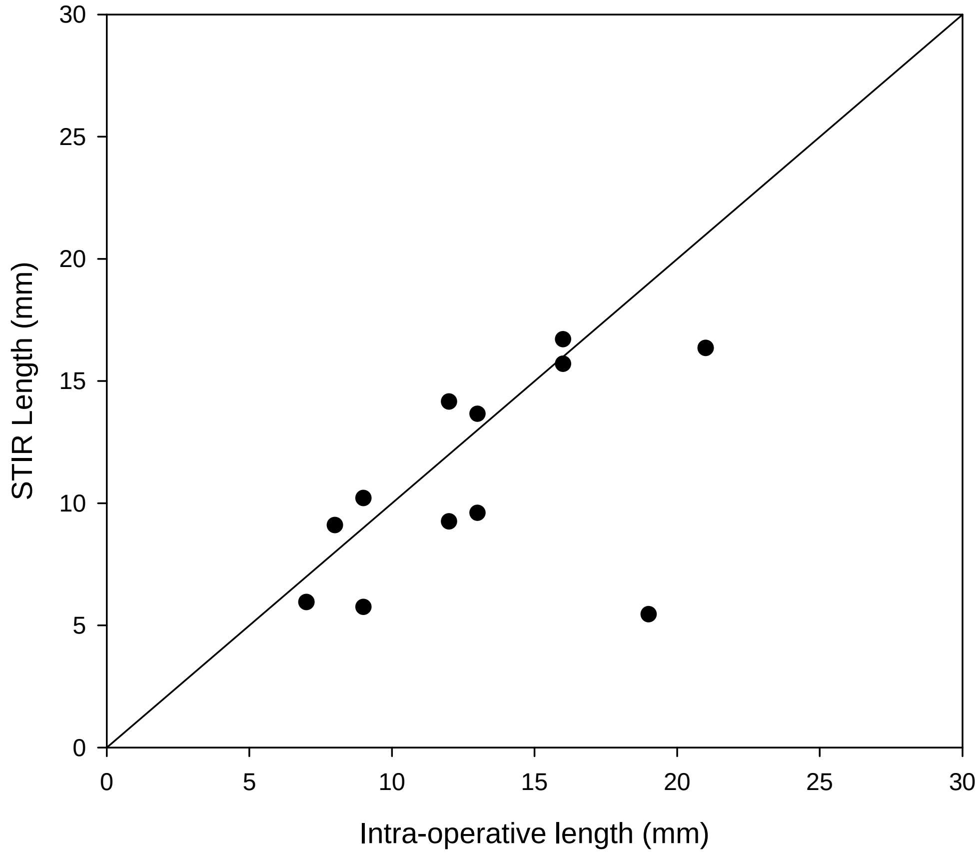

Figure 3: Scatter plot of maximum length of extruded mass observed on STIR vs. that measured intra-operatively. The diagonal is the line of perfect agreement. The vertical distance between each point and the diagonal is the STIR measurement error. $r^2 = 0.259$.

The preceding scatter plots display the actual measured length for each MRI sequence compared to the surgical measurement, which is represented by the diagonal line. The distance of each point from the diagonal line is the difference between the MRI measurement and the intra-operative measurement. If a point is on the diagonal line, it presents an exact correlation between the MRI finding and the surgical finding.

Table 11: Range of measured lengths and range of mean lengths

Measurement	Range of measured lengths (mm)	Range of mean lengths (mm)
Surgery	7 – 21	No mean (single measurement)
T1	5.6 – 25.5	5.75 – 24.25
T2	7 – 18.9	7.25 – 18.65
STIR	5.3 – 17.1	5.45 – 16.7

The following 3 scatter plots display the 95 % limits of agreement for each MRI sequence measurement when compared to the intra-operative measurements. These demonstrate the range in which 95 % of all future measurements will fall if compared to the surgical findings.

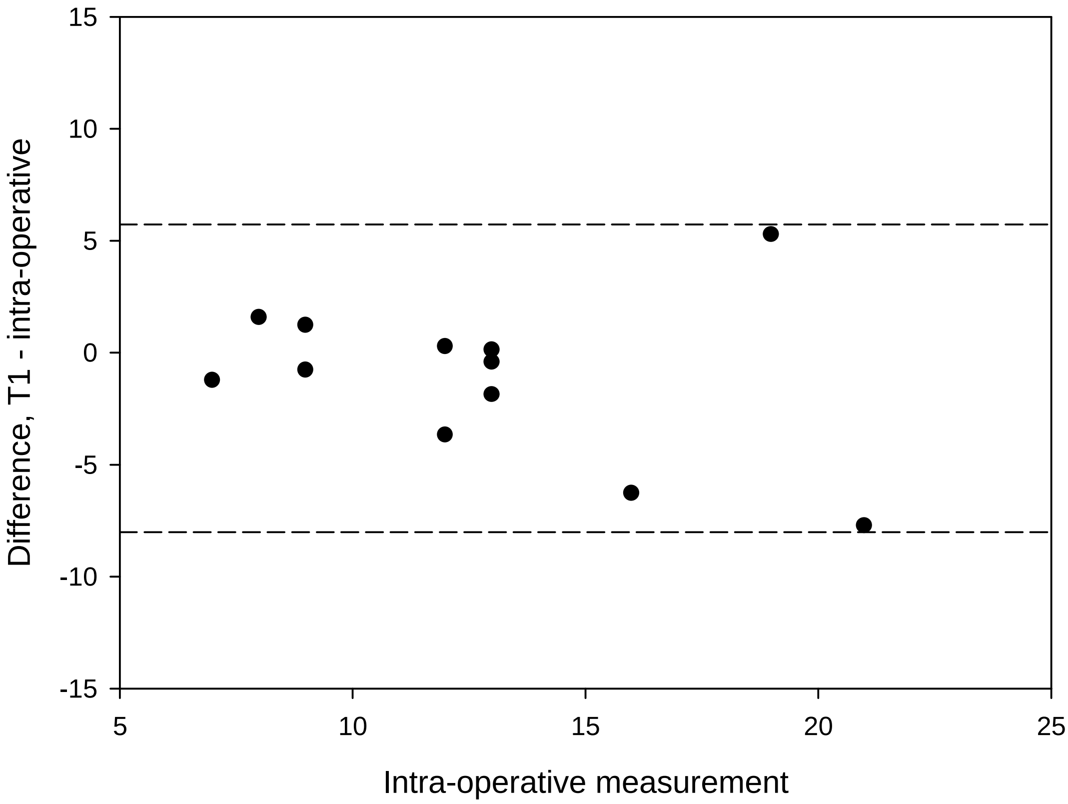

Fig 4: 95 % limits of agreement for T1 measurements compared to intra-operative measurements

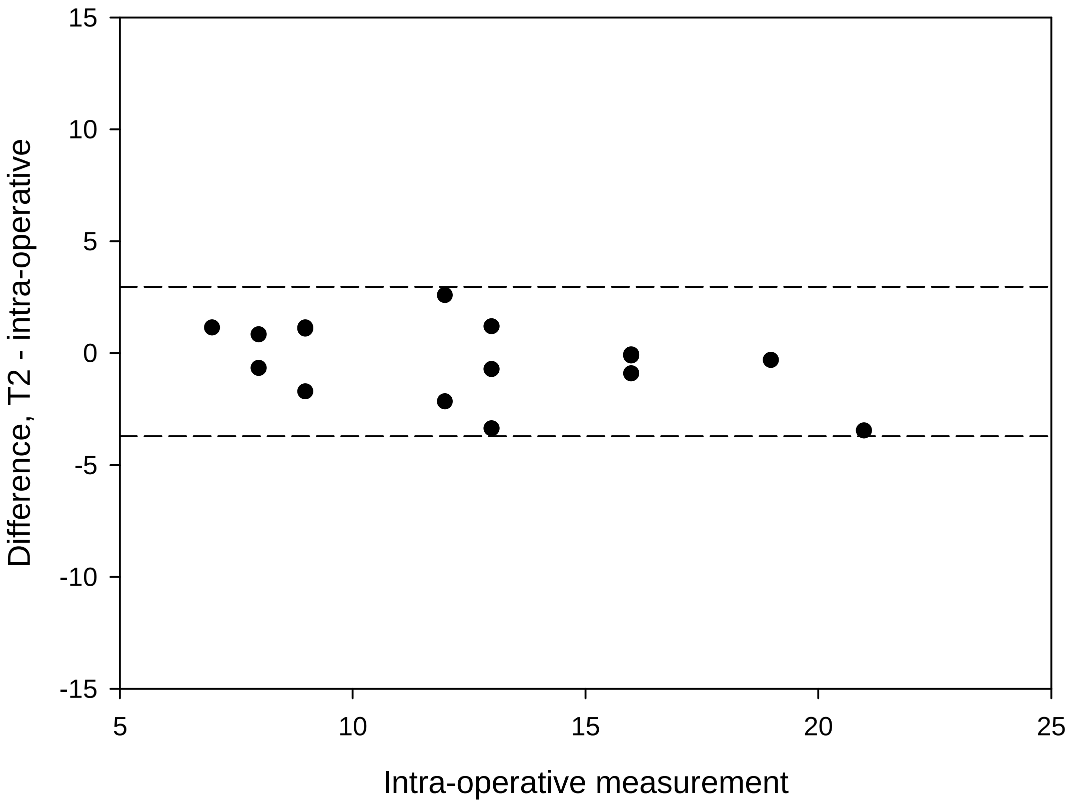

Fig 5: 95 % limits of agreement for T2 measurements compared to intra-operative measurements

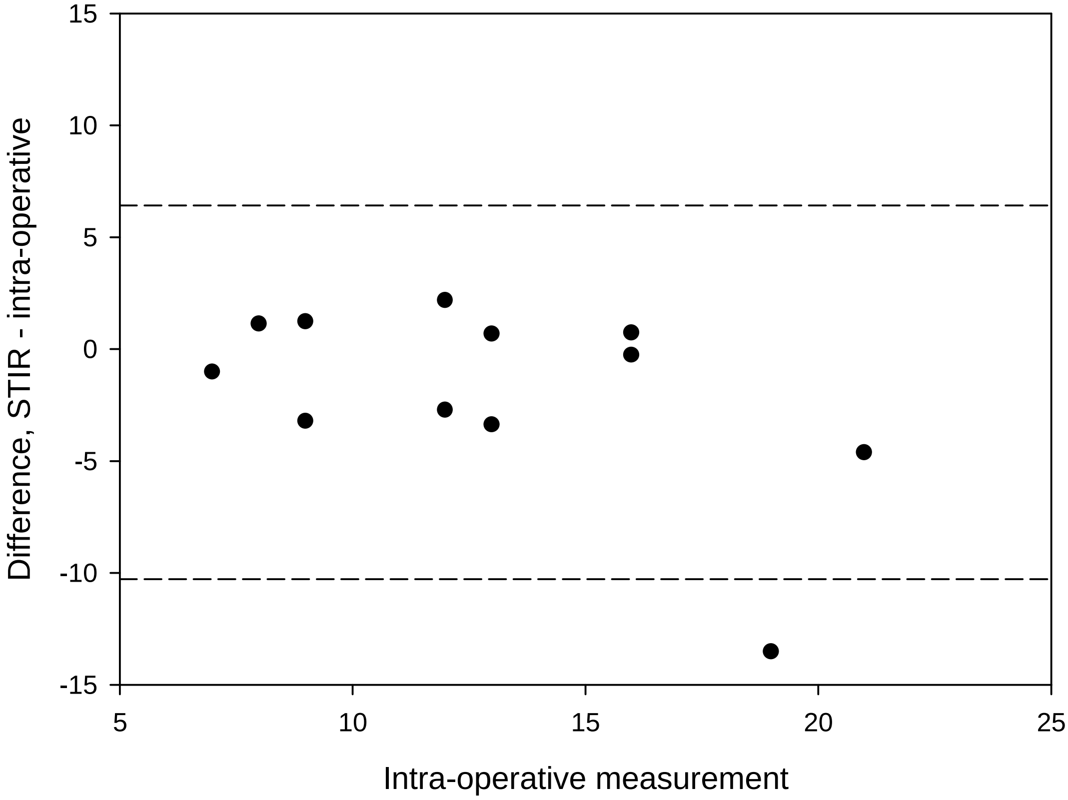

Fig 6: 95 % limits of agreement for STIR measurements compared to intra-operative measurements

The summarised average error, range of errors, absolute error averages, 95% confidence limits for the average error, 95% limits of agreement and P-values for the *t*-tests are presented in Table 12

Table 12: Summary of statistical findings

MRI sequence	Mean absolute error	Mean error	Range of errors	95% CL*	95% LOA#	P-values for *t*-tests@
T1	2.583	-1.15	-7.75;5.25	-3.38;1.08	-8.02;5.72	0.28
T2	1.054	-0.38	-3.4;2.55	-1.12;0.53	-3.72;2.96	0.385
STIR	3.61	-1.93	-13.55;2.15	-4.64;0.78	-10.28;6.42	0.145

* - Confidence limits for the average error

- Limits of agreement

@ - Test comparing length on MRI to surgical findings

Using paired *t*-tests, there were no significant differences in the mean length of the extruded mass between each of the MRI sequences and surgery.

Using repeated-measures ANOVA, there were no significant differences between the absolute errors obtained using the three MRI sequences ($p = 0.420$).

Our results show that measurements performed on the T2-weighted images had a narrower range of errors and the lowest average error when compared to the T1-weighted and STIR sequences

CHAPTER 5

DISCUSSION

Context

IVD extrusion has been extensively reported on in the veterinary literature, indicating that the condition is common and that many questions still exist with regards to its diagnosis, treatment and prognosis. The main aim of this study was to evaluate the accuracy of MRI in localising the extruded disc material in dachshund dogs suffering from disc extrusion in the thoracolumbar region. We also set out to determine if any one of the three MRI sequences investigated (T1-, T2-weighted and STIR) was superior in predicting the actual length of the extruded IVD material.

Methodology

This project describes the MRI findings and surgical observation for sixteen (16) dachshunds admitted to Ridgemall Veterinary Hospital (RSA) for diagnostic work up and surgical decompression of a suspected TLDE. All patients had a history of spinal pain or pelvic limb neurological deficits for no longer than 6 weeks prior to admission and all of them presented for their first clinical episode of disc disease.

Previous studies[7,45,49,53] investigated a range of breeds with different durations of clinical symptoms and a large variation in anatomical position of disc extrusion. This study was purposefully designed to minimize the number of variables and maximize the ability to isolate effects and thus compensate for a small sample size. This was a preliminary observational study which will have to be followed up by larger case numbers to critically test our findings.

Results

The average age of the study group was 5.9 years and average weight was 7.56 kg, which is representative of previously described study populations. Average age in Besalti's two reports were 5.8 and 6.6 years respectively[7,49]. Kirberger et al[25] had a group of dachshunds with an average age of 5.25 years and an average weight of

7.05 kg. Five of the dogs in our study were spayed females, four were intact male dogs and the remaining seven were neutered males. As in previous studies, no sex predilection was found[7,25,49].

The average duration of clinical signs prior to admission was 8.8 days. One patient had a history of 42 days and if this dog is omitted from statistical evaluation, the average duration of clinical signs is only 6.6 days for the remaining 15 animals. We suspect that the majority of dogs suffering from Hansen type 1 disc extrusion will present for surgical decompression within 2 weeks from the start of clinical signs. However, this assumption is based on low case numbers and disregards the possibility that other referring veterinarians might be more inclined to treat these cases conservatively for longer periods before referring them to a specialist facility for surgery.

Dogs were scored according to their neurological status as described in Table 2. No dog in this study was non-ambulatory. Thus only group 1-3 dogs (neurological score) were part of this investigation, which was incidental and was not a requirement of the trial. This was due to the fact that our hospital policy is to treat non-ambulatory patients as emergencies and to delay treatment due to the unavailability of the MRI facility is deemed poor practice. We could only perform the MRI investigations at set times, so the procedure was inadvertently reserved for patients where surgical intervention could be delayed. We inadvertently created some selection bias for mild to moderate neurological dysfunction and our results could have been different if dogs with more severe symptoms had been included. However, this case selection is consistent with study populations of other studies[49]. We do not feel that this bias in selection of patients affected our findings as our study did not attempt to evaluate prognosis or recovery times but was concerned with the comparison of the imaging findings and the surgical information.

We examined IVD extrusions between the eleventh thoracic and the fourth lumbar vertebrae. The majority of cases, 37.5 %, had IVD extrusions at T12-T13. No extrusions were seen at L2-3. The percentages of IVD lesions at different anatomical locations were presented by Hoerlein[9] in 1979 as documented at Auburn University over a 23 year period. Extrusions originated from T11-12 in 9.9% of cases, T12-13 in 22.8% of cases, 21.9% for T13-L1, 11% for L1-2, 7% for L2-3 and 6.3% for the L3-4 IVD space. Disc extrusions were equally divided between the left and right sides. No centrally located disc extrusions were found in the trial reported here. This differs from a previous report, which had 15 % central disc extrusions[49].

Comparison between the MRI findings and the intra-operative observations were made for various dimensional categories. The intra-operative findings used for comparison could not be seen as a true standard because the vertebral canal was only viewed through a limited bone window. However, no other standard would have been practical. The only absolute gold standard would have been post mortem evaluation and measurement which is obviously not ethical or possible for this investigation.

It was easier than expected to perform the intra-operative measurements. The disadvantage of the intra-operative examination is that visibility is reduced with concurrent haemorrhage, limited access to the vertebral canal due to the size of the created bone window and disturbance of the extruded mass on entering the vertebral canal. It is the author's opinion that MRI improved the quality of the surgery because the extent of the extruded mass as observed on the images corresponded closely to that seen during the surgical procedure. Myelography can be difficult to interpret if spinal cord swelling due to oedema is severe or when extensive epidural haemorrhage is present[12]. Computed tomography is also used extensively for imaging of IVDD. Non-contrast CT has the disadvantage of not being accurate enough to diagnose IVD extrusions of a soft tissue nature but only mineralized material will be seen[30]. Computed tomography is able to show epidural haemorrhage where myelography is inadequate[30]. Despite spinal cord swelling, epidural haemorrhage and extrusion of unmineralized disc material, MRI is able to accurately identify extradural spinal cord compression secondary to IVD extrusion[12]. This will save vital time in a clinical situation by eliminating the uncertainty in determining the level of the pathology.

Complete agreement (Kappa = 1.0) was found to exist between MRI and surgical records with regards to the specific IVD that extruded into the vertebral canal. There was also complete agreement for the lateralization findings. These data confirm what previous studies have shown; that MRI is very reliable in directing the surgeon to the correct location of the pathology[7,49].

The longitudinal distribution of the extruded disc material was categorised as being situated either predominantly cranial to the specific IVD space, predominantly caudal to the disc or equally distributed cranial and caudal to the affected IVD. There was agreement between MRI and surgical findings in 68.8 % of cases, as in five cases the distribution did not coincide. It is possible that the demarcation between the three distribution categories were not well enough defined, resulting in an overlap of descriptions, as we only attempted to record the region where most of the extruded mass was situated and not the entire mass. In addition, the MRI image used for the recording of the longitudinal distribution could have missed some part of the extruded mass due to the slice thickness and the gap between consecutive slices. This could potentially lead to both an under- and an over-estimation of the extent of the material. This did not impede our ability to access and remove the extruded material, as we created a marginally larger bone window than the imaged extremes, to avoid disturbing the extruded material for this study. For this reason, the authors recommend that the size of the bony window be slightly larger than the margins of the extruded disc material defined by the MRI study, in order to reach all extruded material. Thinner slices could be more accurate in delineating the extruded IVD material, although this would result in decreased signal-to-noise ratio and less well-defined images. It is of clinical importance to determine the distribution of the extradural compression as accurately as possible. This will lead to shorter surgical times and thus safer anaesthesia with a shorter time of hypotension, which may have a sparing effect on the already compromised spinal cord. A further advantage is that the surgeon can work more accurately and cause less tissue trauma.

The circumferential distribution of the extruded disc material observed during the MRI and surgical examinations, was not statistically compared, but reported in Table 10. The position of the material was described in four different locations in relation to the spinal cord, as seen on transverse sections of the MRI, and compared to what the surgeon observed intra-operatively. The four positions were classified as ventral, ventro-lateral, lateral or dorsal. If material was present in any of these locations, this was recorded accordingly. Only one case showed complete agreement between MRI findings and intra-operative observations. The majority of cases showed some overlap in the respective locations of the material. Various reasons exist for these discrepancies: The surgeon only had a limited view of the lateral aspect of the spinal cord and had to try and determine where all the extruded material was situated before and during evacuating the material. Suctioning during surgery could have displaced some extruded material and this could have made interpretation of the original location difficult. It is also possible that not all disc material was removed during surgery. Although these cases were not classified as dispersed or non-dispersed extrusions, it is possible that some material was separated from the main body of extruded material and situated in such position so that the observer could not locate it. A follow up MRI performed during the early post-operative period would have been helpful to prove or disprove this, but was not part of this investigation. We recommend that this be done in some future investigation. Such a study could help determine how completely the extruded material is removed from the vertebral canal. At this stage it is not known whether removing all extruded material leads to a faster or better outcome than in cases where some material is inadvertently left behind.

Statistical analysis

Table 12 displays the average error, range of errors and standard deviations for each sequence when compared to the physical intra-operative measurement. The average error for T1-weighted sequences was -1.15 mm, for T2-weighted sequences -0.38 mm and for the STIR images -1.9292 mm. This indicates that in this study, all the MRI sequences underestimated the surgical size of the extruded material. The range for T1-weighted errors was -7.75 – 5.25 mm, for the T2-weighted -3.4 – 2.55 mm and for the STIR sequence -13.55 – 2.15 mm. It appears as if the T2-weighted images showed the narrowest range and smallest average error when compared to the other sequences. However this may have been due to the larger number of samples for the T2 images; measurements could not be made in 25% of T1 and STIR images. The average absolute error was used to statistically compare the accuracy of the different MRI sequences. It is clinically more relevant how accurate or inaccurate the measurements are, and not if they are greater or smaller than the true value. If we evaluated the average error, negative and positive values would have cancelled each other out and given us a false sense of accuracy. T2-weighted sequence had the lowest average absolute error of 1.35 mm, however there was no statistically significant difference between the average absolute errors of the different sequences on the ANOVA test (p=0.420). The T2-weighted sequence also had the lowest standard deviation of 1.054 when compared to T1-weighted of 2.583 and STIR-images of 3.61.

Using paired *t*-tests, there were no significant differences in the mean length of the extruded mass between each of the MRI sequences and surgery. We also reported the 95% confidence limits for the average errors (Table 12). This gives the range of average errors, which would usually get narrower with higher case numbers because the more values used to determine an average, the closer the individual averages become to the group average.

The 95% limits of agreement (Table 12) gives us an idea of the extent of errors overall and would stay the same even if case numbers increased. Only one measurement fell outside of these limits. These limits may be useful for further investigations in that we can predict the variability of the measurements for each sequence.

Limitations of study

The measurement of the length of the extruded mass during surgery could have been a problem in this study due to the fact that the sterile calliper had to be placed within the surgical wound and possibly interfered with the task of recording an accurate measurement. There was also a concern that the extruded material could be disturbed or displaced on surgically entering the vertebral canal. The possibility also existed that we measured the most lateral aspect of the extruded material and not necessarily the maximum distribution in a cranio-caudal direction. The bone window created was done as carefully as possible and larger (increased width and height) than the suspected size of the extruded mass as seen on MRI.

The surgeon was shown the sagital images so he knew the specific herniated IVD space, the lateralization and he had some subjective idea about the length of the EDM but no actual measurement. This introduced a major bias in this investigation. Although acceptable for a preliminary study, it does reduce the credibility of our statistical analysis. In future trials the surgeon must be completely blinded to the extent of the EDM but will still need to know the level of extrusion and the lateralization. A radiologist could read the MRI results and supply the surgeon with the site of maximum compression.

After removing the pedicles of the vertebrae, a small probe was inserted to palpate the cranio-caudal margins of the extruded material (where the disc material ended and where the epidural fat started). A sterile manual calliper was then used to measure the observed length in a cranio-caudal direction as seen from the lateral aspect. This was recorded to the nearest millimetre. All sixteen cases proved relatively easy to measure intra-operatively. With adequate exposure the calliper could be positioned correctly with no interference by any anatomical structure. The calliper used had slightly broad pincers and this method could be improved using a specially designed device with thin and elongated pincers, which could be positioned with the measuring section away from the surgical wound and only the pincers in position in the vertebral canal. Alternatively, it may be possible to measure the distribution of extruded disc material using intra-operative ultrasound[70].

Measurements performed on the MRI unit computer with the digital tracker proved to be difficult to execute, due to the fact that the tracker was superimposed over parts of the pathology, making it difficult to get the exact measurement. The MRI images were measured twice to reach an average reading and the readings were not performed concurrently. The readings for each case rarely differed by more than 1-2 millimetres and a third set of measurements was not deemed necessary. The radiologist could not accurately measure cases 6, 7, 10 and 15 on T1-weighted sequences as well as cases 6, 10, 15 and 16 on the STIR sequences. This was due to the fact that it was very difficult to define the cranial and caudal borders of the EDM and to decide exactly where the mass was positioned. T2-weighted images showed a clearer distinction between the EDM and the surrounding tissues. Measurements were not recorded if no accurate reading could be taken using the digital tracker on the MRI unit. Thus, 25 % of the T1-weighted and STIR sequences respectively could not be used for measurements but all T2-weighted images could be measured. We therefore recommend using the T2-weighted images for surgical planning.

Value of study

This study supported what previous research has shown, when comparing the results of MRI with surgical location of IVD pathology. Besalti et al[49] found complete agreement between MRI and surgical findings when evaluating affected IVD space, lateralization and nature of extruded disc material as either dispersed or non-dispersed in the vertebral canal. Our results showed complete agreement between MRI and surgical findings regarding the localization of the affected IVD space and lateralization of extruded disc material. Our study was more concerned about the accuracy of the imaging findings, whereas Besalti and co-workers[49] concentrated on relating these findings to surgical outcome and recovery.

Comparison of the intra-operative measured length of the extruded material with that measured on MRI images revealed information not previously reported. This is the first time that these types of measurements were employed. These methods were repeatable and could be used in future studies. As described earlier it is possible to improve the method of performing the intra-operative measurement. Our results show that T2-weighted images had a narrower range of error when compared to the T1-weighted and STIR sequences. The cases that could not be measured on MRI were due to the fact that no clear margin was visible to define the cranial and caudal borders of the EDM. The fact that 4/16 cases in the T1- and STIR group could not be measured accurately also makes T2-weighted images the preferred sequence to use when determining the length of the extruded disc material although there was no statistically significant difference between the average absolute errors of the different sequences using ANOVA.

This study confirmed that MRI is an extremely accurate imaging modality for use in dogs with IVD extrusion. We could possibly use this information for other types of pathology and determine very accurately the location and surgical extent of a specific lesion or abnormality e.g. a neoplastic mass or a haematoma. Thus, our first hypothesis was found to be true in that MRI was shown to be extremely accurate in determining the localization and extent of IVD extrusions in dachshund dogs. The second hypothesis was not disproved in that we could not demonstrate a statistically significant difference between the sequences when determining the length of the extruded IVD material.

Future studies

Follow up studies should have larger case numbers with the surgeon completely blinded to the MRI findings. Further research in this field should focus on using MRI to evaluate the effects of surgical intervention on the structures in and around the vertebral canal. The accuracy of MRI in defining the nature of the compressive material e.g. uncalcified disc material, cartilage, bone, blood, admixtures of these structures should be investigated to give more pre-operative information to the clinician. Determining the appearance of the post-operative spine will add to the existing knowledge and it could help with treatment in cases where dogs do not recover from decompressive surgery by supplying reasons for this non-recovery or deterioration. This has been extensively evaluated in the human medical literature by using MRI as the modality of choice.

Conclusion

Determining the location and extent of IVD extrusions prior to surgical intervention is a critical factor for a successful outcome. The information provided by this study will help surgeons to remove the maximum amount of disc material with the minimum amount of nerve tissue manipulation and surgical time. The more information we can gather before surgery, the more prepared we can be for these procedures and this can only benefit our patients.

REFERENCES

1. Priester WA. Canine intervertebral disc disease – occurrence by age, breed and sex among 8117 cases. *Theriogenology* 1976; 6:293-301.
2. Van Niekerk LJ, Verstraete FJM, Odendaal JSJ. A comparison of the surgical caseloads of selected companion animal hospitals and a veterinary academic hospital in South Africa. *J South African Vet Assoc* 2002;73:115-118
3. Hoerlein BF. Intervertebral disc disease. In: *Canine Neurology: Diagnosis and treatment.* Philedelphia: WB Saunders 1978;321-341
4. Hansen HJ. A pathologic-anatomical study on disc degeneration in dog. *Acta Orthop Scand Suppl* 1952;11:1-117
5. Braund KG. Intervertebral disc disease. In: Bojrab MJ, Smeak DD, Bloomberg MS, eds. *Disease Mechanisms in Small Animal Surgery*. Philadelphia: Lea & Febiger, 1993;960-970
6. Coates JR. Intervertebral disk disease. *Vet Clin North Am Small Anim Pract* 1988;18:77-110
7. Besalti O, Pekcan Z, Sirin S et al. Magnetic resonance imaging findings in dogs with thoracolumbar intervertebral disc disease: 69 cases (1997-2005). *J Am Med Vet Assoc* 2006;228:902-908
8. Bray JP, Burbridge HM. The canine intervertebral disk Part two : Degenerative changes – nonchondrodystrophoid versus chondrodystrophoid disks. *J Am Anim Hosp Assoc* 1998;34:135-144
9. Hoerlein BF. Comparative disc disease: Man and dog. *J Am Anim Hosp Assoc* 1979;15:535-545
10. Gage ED. Incidence of clinical disc disease in the dog. *J Am Anim Hosp Assoc*1975;11:135-138
11. Liptak JM, Watt PR, Thomson MJ et al. Hansen type I disk disease at T1-2 in a Dachshund. *Aust Vet J* 1999;3:156-159

12. Tartarelli CL, Baroni M, Borghi M. Thoracolumbar disc extrusion associated with extensive epidural haemorrhage: a retrospective study of 23 dogs. *J Small Anim Pract* 2005;46:485-490

13. Colter S, Rucker NC. Acute injury to the central nervous system. *Vet Clin North Am Small Anim Pract* 1988;18:545-563

14. Black AP. Lateral spinal decompression in the dog : A review of 39 cases. *J Small Anim Pract* 1988;29:581-588

15. Jeffery ND. Treatment of acute and chronic thoracolumbar disc disease by 'mini' hemilaminectomy. *J Small Anim Pract* 1988;29:611-616

16. Lubbe AM, Kirberger RM, Verstraete FJM. Pediculectomy for thoracolumbar spinal decompression in the dachshund. *J Am Anim Hosp Assoc* 1994;30:233-238

17. Hill TP, Lubbe AM, Guthrie AJ. Lumbar spine stability following hemilaminectomy, pediculectomy, and fenestration. *Vet Comp Orthop Traumatol* 2000;13:165-171

18. McCartney W. Partial pediculectomy for the treatment of thoracolumbar disc disease. *Vet Comp Orthop Traumatol* 1997;10:117-121

19. Hara Y, Tagawa M, Ejima H et al. Usefulness of computed tomography and myelography for surgery on dogs with cervical intervertebral disc protrusion. *J Vet Med Sci* 1994;56:791-794

20. Kirberger RM. Recent developments in canine lumbar myelography. *Comp Cont Edu Prac Vet* 1994;16:847-853

21. Yamada K, Nakagawa M, Kato T et al. Application of short time magnetic resonance examination for intervertebral disc disease in dogs. *J Vet Med Sci* 2001;63:51-54

22. Schulz KS, Walker M, Moon M et al. Correlation of clinical, radiographic and surgical localization of intervertebral disc extrusion in small breed dogs: A prospective study of 50 dogs. *Vet Surg* 1998;27:105-111

23. Lamb CR. Common difficulties myelographic diagnosis of acute thoracolumbar disc prolapse in the dog. *J Small Anim Pract* 1994;35:549-558

24. Penderis J, Dennis R. Use of traction during magnetic resonance imaging of caudal cervical spondylomyelopathy (“wobbler syndrome”) in the dog. *Vet Radiol Ultrasound* 2004;45:216-219

25. Kirberger RM, Roos CJ, Lubbe AM. The radiological diagnosis of thoracolumbar disc disease in the dachshund. *Vet Radiol Ultrasound* 1992;33:255-261

26. Duval J, Dewey C, Roberts R et al. Spinal cord swelling as a myelographic indicator of prognosis: A retrospective study in dogs with intervertebral disc disease and loss of deep pain perception. *Vet Surg* 1996;25:6-12

27. Scott HW, McKee WM. Laminectomy for 34 dogs with thoracolumbar disc disease and loss of deep pain perception. *J Small Anim Pract* 1999;40:417-422

28. Gibbons SE, Macias C, De Stefani A et al. The value of oblique versus ventrodorsal myelographic views for lesion lateralization in canine thoracolumbar disc disease. *J Small Anim Pract* 2006;47:658-662

29. Smith JD, Newell SM, Budsberg SC et al. Incidence of contralateral versus ipsilateral neurological signs associated with lateralised Hansen type I disc extrusion. *J Small Anim Pract* 1997;38:495-497

30. Olby NJ, Munana KR, Sharp NJH et al. The computed tomographic appearance of acute thoracolumbar intervertebral disc herniations in dogs. *Vet Radiol Ultrasound* 2000;41:396-402

31. Suwankong N, Voorhout G, Hazewinkel H et al. Agreement between computed tomography, magnetic resonance imaging and surgical findings in dogs with degenerative lumbosacral stenosis. *J Am Vet Med Assoc* 2006;229:1924-1929

32. Jones CJ, Inzana KD, Rossmeisl JH et al. CT myelography of the thoraco-lumbar spine in 8 dogs with degenerative myelopathy. *J Vet Sci* 2005;6:341-348

33. Axlund TW, Hudson JA. Computed tomography of the normal lumbosacral intervertebral disc in 22 dogs. *Vet Radiol Ultrasound* 2003;44:630-634

34. Annertz M, Jonsson B, Stromqvist B et al. Serial MRI in the early postoperative period after lumbar discectomy. *Neuroradiol* 1995;37:177-182

35. Djukic S, Lang P, Roberts R. The postoperative spine- Magnetic resonance imaging. *Orthop Clin North Am* 1990;21:603-622

36. Floris R, Spallone TY, Aref A et al. Early postoperative MRI findings following surgery for herniated lumbar disc. *Acta Neurochir (Wien)* 1997;139:169-175

37. Jinkins JR, Van Goethem JWM. The postsurgical lumbosacral spine. *Rad Clin North Am* 2001;39:1-29

38. Schofferman J, Reynolds J, Herzog R et al. Failed back surgery : etiology and diagnostic evaluation. *Spine J* 2003;3:400-403

39. Thompson CE, Kornegay JN, Burn RA et al. Magnetic resonance imaging – A general overview of principles and examples in veterinary neurodiagnosis. *Vet Radiol Ultrasound* 1993;34:2-17

40. Miyabashi T, Smith M, Tsuruno Y. Comparison of fast spin echo and conventional spin echo MR spinal imaging technique in 4 normal dogs. *Vet Radiol Ultrasound* 2000;41:308-312

41. Adams WH. The spine. *Clin Tech Small Anim Pract* 1999;14:148-159

42. Chambers JN, Selcer BA, Sullivan SA et al. Diagnosis of lateralized lumbosacral disc herniation with magnetic resonance imaging. *J Am Anim Hosp Assoc* 1997;33:296-299

43. De Haan JJ, Shelton SB, Ackerman N. Magnetic resonance imaging in the diagnosis of degenerative lumbosacral stenosis in four dogs. *Vet Surg* 1993;22:1-4

44. Tidwell AS, Specht A, Blaeser L et al. Magnetic resonance imaging features of extradural haematomas associated with intervertebral disc herniation in a dog. *Vet Radiol Ultrasound* 2002;43:319-324

45. Adams WH, Daniel GB, Pardo AD et al. Magnetic resonance imaging of the caudal lumbar and lumbosacral spine in 13 dogs (1990-1993). *Vet Radiol Ultrasound* 1995;36:3-13

46. Gopal MS, Jeffery ND. Magnetic resonance imaging in the diagnosis and treatment of a canine spinal cord injury. *J Small Anim Pract* 2001;42:29-31

47. Karkkainen M, Punto LU, Tulamo RM. Magnetic resonance imaging of canine degenerative lumbar spine disease. *Vet Radiol Ultrasound* 1993;34:399-404

48. McConnel JF, Garosi LS. Intramedullary intervertebral disk extrusion in a cat. *Vet Radiol Ultrasound* 2004;45:327-330

49. Besalti O, Ozak A, Pekcan Z et al. The role of extruded disk material in thoracolumbar intervertebral disk disease : A retrospective study in 40 dogs. *Can Vet J* 2005;46:814-820

50. Seiler G, Hani H, Scheidegger J et al. Staging of lumbar intervertebral disc degeneration in non-chondrodystrophic dogs using low field magnetic resonance imaging. *Vet Radiol Ultrasound* 2003;44:179-184

51. Mayhew PD, Kapatkin AS, Wortman JA et al. Association of cauda equina compression on magnetic resonance images and clinical signs I ndogs with degenerative lumbosacral stenosis. *J Am Anim Hosp Assoc* 2002;38:555-562

52. Czervionke LF, Haughton VM. Degenerative disease of the spine. In: Atlas SW, ed. *Magnetic resonance imaging of the brain and spine 3rd ed* Philadelphia: Lippencott-Raven 2002;1633-1713

53. Ito D, Matsunaga S, Jeffery ND et al. Prognostic value of magnetic resonance imaging in dogs with paraplegia caused by thoracolumbar intervertebral disc extrusion: 77 cases (2000-2003). *J Am Vet Med Assoc* 2005;227:1454-1460

54. Okada M, Koie H, Kitagawa M et al. MRI findings in a dog with spontaneous systemic haemorrhage. *Aust Vet J* 2006;84(9):332-335

55. Cerda-Gozales S, Olby NJ. Fecal incontinence associated with epidural spinal hematoma and intervertebral disk extrusion in a dog. *J Am Vet Med Assoc* 2006;228(2):230-235

56. Da Costa RC, Parent J, Partlow G. Morphologic and morphometric magnetic resonance imaging features of Doberman Pinschers with and without clinical signs of cervical spondylomyelopathy. *Am J Vet Res* 2006;67:1601-1612

57. Ruddle TL, Allen DA, Schertel ER et al. Outcome and prognostic factors in non-ambulatory Hansen Type I intervertebral disc extrusions: 308 cases. *Vet Comp Orthop Traumatol* 2006;1:29-34

58. Levine JM, Levine GJ, Kerwin SC et al. Association between various physical factors and acute thoracolumbar intervertebral disk extrusion or protrusion in Dachshunds. *J Am Vet Med Assoc* 2006;229:370-375

59. Kinzel S, Wolff M, Buecker A et al. Partial percutaneous discectomy for treatment of thoracolumbar disc protrusion: Retrospective study of 331 dogs. *J Small Anim Pract* 2005;46:479-484

60. De Risio L, Sharp NJH, Olby NJ et al. Predictors of outcome after dorsal decompressive laminectomy for degenerative lumbosacral stenosis in dogs: 69 cases (1987-1997). *J Am Vet Med Assoc* 2001;219:624-628

61. Penning V, Platt SR, Dennis R et al. Association of spinal cord compression seen on magnetic resonance imaging with clinical outcome in 67 dogs with thoracolumbar intervertebral disc extrusion. *J Small Anim Pract* 2006;47:644-650

62. Toombs JP, Waters DJ. Intervertebral disc disease. In:Slatter DA, Sharp NJH, eds. *Textbook of Small Animal Surgery*. 3rd Edition Saunders, 2003;1193-1209

63. Stiffler KS, McCrackin Stevenson MA, Sanchez S et al. Prevalence and characterization of urinary tract infections in dogs with surgically treated Type I thoracolumbar intervertebral disc extrusion. *Vet Surg* 2006;35:330-336

64. Jones JC, Banfield CM, Ward DL. Association between postoperative outcome and results of magnetic resonance imaging and computed tomography in working dogs with degenerative lumbosacral stenosis. *J Am Vet Med Assoc* 2000;216:1769-1774

65. Sanders SG, Bagley RS, Gavin PR. Intramedullary spinal cord damage associated with intervertebral disk material in a dog. *J Am Vet Med Assoc* 2002;221:1594-1596

66. Linn LL, Bartels KE, Rochat MC et al. Lumbosacral stenosis in 29 military working dogs : Epidemiological findings and outcome after surgical intervention (1990-1999). *Vet Surg* 2003;32:21-29

67. Dhupa S, Glickman N, Waters DJ. Reoperative neurosurgery in dogs with thoracolumbar disc disease. *Vet Surg* 1999;28:421-428

68. Mayhew PD, McLear RC, Ziemer LS et al. Risk for recurrence of clinical signs associated with thoracolumbar intervertebral disc herniation in dogs: 229 cases (1994-2000). *J Am Vet Med Assoc* 2004;225:1231-1236

69. Prata RG. Neurosurgical treatment of thoracolumbar disks: The rationale and value of laminectomy and concomitant disk removal. *J Am Anim Hosp Assoc* 1981;17:17-26

70. Navai B, Lyman R, Bichsel P. Intraoperative use of ultrasonography during continous dorsal laminectomy in two dogs with caudal cervical vertebral instability and malformation ("wobbler syndrome"). *Vet Surg* 2006;35(3):465-469

Appendix 1

Intra-operative Questionnaire:

IVD space affected	
Lateralization of EDM	
Length of EDM (mm)	
Longitudinal distribution : Equal	
Cranial	
Caudal	
Circumferential distribution : Ventral	
Lateral	
Ventro-lateral	
Dorsolateral	
Dorsal	

Appendix 2

MRI – Questionnaire

Patient :

Pathologic IVD :

Longitudinal distribution in relation to disc space (circle) :

Cranial Equal Caudal

Circumferential distribution (circle) :

Dorsal Ventral Lateral Dorso-lateral Ventro-lateral

Length (mm) :

T1 :	**1-)**	
	2-)	
	3-)	
T2 :	**1-)**	
	2-)	
	3-)	
STIR :	**1-)**	
	2-)	
	3-)	

Transverse views : Left Right Centre

Oedema of spinal cord : Yes No

Composition of disc material :

a.) Disc or Disc and blood or Blood

b.) Bone and cartilage or Disc or Bone/cartilage and disc

Additional MRI findings:

Survey radiographs:

Appendix 3

Age and body weight

Case (n=16)	Age (years)	Body weight (kg)
1	10	7
2	6	11
3	9	9
4	4	8.3
5	5	6.5
6	3	6.7
7	5	6.5
8	7	7.3
9	6	7
10	5	10.5
11	7	8.1
12	5	6.8
13	8	7.6
14	5	8.3
15	5	4
16	5	6.3

Appendix 4

Gender

Case (n=16)	Gender
1	FS
2	MN
3	FS
4	MN
5	MN
6	FS
7	MI
8	MN
9	MI
10	FS
11	FS
12	MI
13	MN
14	MI
15	MN
16	MN

Key : FS - Female sterilized
MI - Male intact
MN - Male neutered

Appendix 5

Duration of clinical signs

Case (n=16)	Duration (days)
1	42
2	14
3	10
4	10
5	12
6	4
7	6
8	3
9	3
10	7
11	21
12	1
13	1
14	3
15	2
16	2

Appendix 6

Neurological score

Case (n=16)	Neurological score
1	1
2	3
3	2
4	3
5	1
6	1
7	3
8	3
9	3
10	2
11	1
12	1
13	3
14	1
15	2
16	3

Neurological classification

1	Normal ambulation with pain on (digitally-applied) dorsal thoracolumbar spinal pressure.
2	Ambulatory with mild ataxia in pelvic limbs (less than 50% of time, dorsal knuckling or feet crossing midline).
3	Ambulatory with severe ataxia in pelvic limbs (more than 50 % of time, dorsal knuckling or feet crossing midline).
4	Non-ambulatory with voluntary motor function present (uni- or bilaterally).
5	Non-ambulatory with no movement but deep pain sensation.

Appendix 7

Extruded disc site and lateralization at surgery and on MRI

Case (n=16)	Extruded disc space	Lateralization
1	T11-12	R
2	T13-L1	R
3	T12-13	L
4	L1-2	L
5	T12-13	R
6	L3-4	R
7	T12-13	R
8	T12-13	R
9	L1-2	L
10	L3-4	L
11	L1-2	R
12	T13-L1	L
13	T12-13	L
14	T11-12	L
15	T11-12	R
16	T12-13	L

Appendix 8

Longitudinal distribution of disc material

Case (n=16)	Position on MRI	Position in surgery
1	Equal	Cranial
2	Cranial	Cranial
3	Cranial	Cranial
4	Cranial	Cranial
5	Cranial	Equal
6	Equal	Cranial
7	Cranial	Cranial
8	Caudal	Caudal
9	Cranial	Equal
10	Cranial	Cranial
11	Caudal	Equal
12	Equal	Equal
13	Equal	Equal
14	Equal	Equal
15	Cranial	Cranial
16	Caudal	Caudal

Appendix 9

Length of extruded material: Surgery vs T1-weighted images

Case number	**Intra-operative length (mm)**	**T1 – 1st**	**T1 – 2nd**	**T1 – average**	**T1 – absolute error**
1	8	10	9.1	9.55	1.55
2	7	5.9	5.6	5.75	1.25
3	12	9.6	7	8.3	3.7
4	16	9.9	9.5	9.7	6.3
5	19	25.5	23	24.25	5.25
6	8	-	-	-	-
7	16	-	-	-	-
8	13	11.4	10.8	11.1	1.9
9	21	13.5	13	13.3	7.75
10	16	-	-	-	-
11	9	7.3	9.1	8.2	0.8
12	13	12.7	13.5	13.1	0.1
13	12	11.5	13	12.3	0.25
14	9	11.1	9.3	10.2	1.2
15	9	-	-	-	-
16	13	12.4	12.7	12.6	0.45

Blocks with no data represent cases where the radiologist was unable to accurately measure the length of the EDM

Appendix 10

Length of extruded material: Surgery vs T2-weighted images

Case number	Intra-operative length (mm)	T2 – 1st	T2 – 2nd	T2 – average	T2 – absolute error
1	8	9	8.6	8.8	0.8
2	7	8	8.2	8.1	1.1
3	12	9.9	9.7	9.8	2.2
4	16	14.4	17.4	15.9	0.1
5	19	18.9	18.4	18.65	0.35
6	8	7.1	7.5	7.3	0.7
7	16	14.7	15.4	15.05	0.95
8	13	13.7	14.6	14.15	1.15
9	21	17.6	17.4	17.5	3.5
10	16	16.2	15.5	15.85	0.15
11	9	10.2	10	10.1	1.1
12	13	9.7	9.5	9.6	3.4
13	12	14.4	14.7	14.55	2.55
14	9	7	7.5	7.25	1.75
15	9	9.6	10.5	10.05	1.05
16	13	12	12.5	12.25	0.75

Appendix 11

Length of extruded material: Surgery vs STIR images

Case number	Intra-operative length (mm)	STIR 1st	STIR 2nd	STIR – average	STIR – absolute error
1	8	9.3	8.9	9.1	1.1
2	7	5.6	6.3	5.95	1.05
3	12	8.9	9.6	9.25	2.75
4	16	16.3	17.1	16.7	0.7
5	19	5.3	5.6	5.45	13.55
6	8	-	-	-	-
7	16	15.8	15.6	15.7	0.3
8	13	9	10.2	9.6	3.4
9	21	16.1	16.6	16.35	4.65
10	16	-	-	-	-
11	9	5.6	5.9	5.75	3.25
12	13	13.6	13.7	13.65	0.65
13	12	16.3	12	14.15	2.15
14	9	9.9	10.5	10.2	1.2
15	9	-	-	-	-
16	13	-	-	-	-

Blocks with no data represent cases where the radiologist was unable to accurately measure the length of the EDM