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CLINICAL RESEARCH

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Dynamic magnetic resonance imaging of the lumbosacral spine in neutral and flexed position for presurgical assessment of clinically affected dogs with degenerative lumbosacral stenosis

Irenka Baldo Clemot DMV, MRCVS, ECVN-resident[1] | Chiara Briola DVM, MRCVS, Dipl. ECVDI[2] | Abel B. Ekiri BVM, MS, PhD, MPH[3] | Rodolfo Cappello DVM, MRCVS, PhD, DipECVN[4,5] | Riata Marinelly BAnimSci, BVetMed (Hons), MRCVS[1,5] | Josep Brocal Ldo Vet, MRCVS, MVM, DipECVN[6,7] | Alice Prodger MA, VetMB, MRCVS[6,8] | Lorenzo Mari DVM, MRCVS, DipECVN[1]

[1]Neurology Department, The Ralph Veterinary Referral Center, Marlow, UK

[2]Diagnostic Imaging Department, The Ralph Veterinary Referral Center, Marlow, UK

[3]Department of Comparative Biomedical Sciences, School of Veterinary Medicine, University of Surrey, Guildford, UK

[4]South East Veterinary Referrals, UK

[5]North Downs specialist Referrals, Part of Linnaeus Veterinary Limited, Bletchingley, UK

[6]AndersonMoores Veterinary Specialists, Part of Linnaeus Veterinary Limited, Winchester, UK

[7]Veterinary Specialty Hospital of Hong Kong, Wan Chai, Hong Kong

[8]Department of Surgical and Radiological Sciences, College of Veterinary Medicine, University of California, Davis, California, USA

Correspondence
Irenka Baldo Clemot, The Ralph Veterinary Referral Center, Fourth Avenue Globe Business Park, Marlow SL7 1YG, UK.
Email: irenka.balcle@gmail.com

Abstract

Objective: To compare diagnostic findings in neutral and flexed magnetic resonance imaging (MRI) of the lumbosacral joint (LSJ) performed for presurgical assessment in dogs with clinically suspected, diagnostically confirmed degenerative lumbosacral stenosis (DLSS), and to assess if these findings support the need for decompressive dorsal laminectomy/partial discectomy and/or foraminotomy in combination with distraction-stabilization techniques.

Study design: Retrospective, comparative study.

Animals: A total of 24 dogs with clinically suspected, MRI-confirmed DLSS that underwent dynamic LSJ imaging.

Methods: Medical records and MRI findings of included cases from three referral hospitals were reviewed. Quantitative and qualitative assessments of the LSJ (LSJ angle, protrusion ratios, degree of intervertebral disc [IVD] protrusion, ventral bulging of the ligamentum flavum [VBLF], foraminal compression) were compared in neutral and flexed positions. Their correlations with the degree of IVD degeneration or spondylosis was evaluated. Interindividual agreement was assessed among three observers.

Results: Degree of IVD protrusion, foraminal stenosis, VBLF, and protrusion ratios, were significantly reduced in flexion compared with neutral position ($p < .001$ for all comparisons). No dogs had persistent compression of the cauda equina or completely occluded foramina in flexion. The response of IVD

Abbreviations: CSF, cerebrospinal fluid; CT, computed tomography; DLSS, degenerative lumbosacral stenosis; IVD, intervertebral disc; LSJ, lumbosacral joint; MRI, magnetic resonance imaging; OCD, osteochondrosis dissecans; PACR, protrusion to absolute canal ratio; PRCP, protrusion to relative canal ratio; T2W, T2-weighted; VBLF, ventral bulging of the ligamentum flavum.

protrusion to flexion was significantly directly correlated to the degree of IVD degeneration ($p = .004$), but not of spondylosis.
Conclusion: In flexed position, IVD protrusions, VBLF and foraminal stenoses improved in all cases, with resolution of all compression sites.
Clinical significance: With LSJ distraction-stabilization techniques, the need for concurrent decompressive dorsal laminectomy/partial discectomy or foraminotomy should be questioned, unless performed for IVD-spacer placement. Surgical case–control studies are required to investigate this further.

1 | INTRODUCTION

Canine degenerative lumbosacral stenosis (DLSS) is a degenerative disorder affecting the lumbosacral joint (LSJ), which results in narrowing of the vertebral canal and foramina, subsequently causing static and/or dynamic compression of the cauda equina.[1,2] DLSS is a multifactorial condition, where several pathologies contribute to the development of the disease and its clinical signs, including intervertebral disc (IVD) degeneration and protrusion, spondylosis deformans, articular facet hypertrophy, retrolisthesis and subluxation, congenital stenosis of the vertebral canal, vertebral malformations including transitional vertebrae, osteochondrosis-like lesions and hypertrophy of the ligaments (dorsal longitudinal ligament and ligamentum flavum).[1,2] A diagnosis of DLSS is based on history, signalment and clinical signs supported by advanced imaging techniques including computed tomography (CT) and/or magnetic resonance imaging (MRI) confirming the condition.[1,2] Imaging findings need to be correlated with clinical signs, as clinically unaffected dogs can have different degrees of DLSS on advanced imaging.[1,3,4] Considering the dynamic component of DLSS, dynamic imaging techniques have been investigated in recent years. These studies were performed in both normal and DLSS-affected dogs using CT[5–7] and only on clinically normal dogs using MRI.[8] In the CT-based studies, the intervertebral foraminal volume was significantly increased on flexed views compared to extended.[5–7] These studies, however, did not investigate the effect of different positioning on the degree of compression of the cauda equina within the vertebral canal. The research on dynamic MRI[8] also confirmed that the LSJ of clinically unaffected dogs dynamically responds to different positioning, with an increase in foraminal size and a reduction of minor subclinical IVD protrusion in a flexed position. However, it remains unexplored if such results, particularly regarding the compression of the cauda equina within the vertebral canal, can be applied to DLSS clinically affected dogs, and if the degenerative processes affecting the LSJ (for example the presence and degree of spondylosis) may alter such responses. Many different surgical procedures have been described to treat the most severe cases of DLSS, including dorsal laminectomy and discectomy, foraminotomies, multiple distraction and stabilization techniques and combinations of these.[1,2] In most cases that underwent spinal distraction and stabilization reported in the literature, decompressive dorsal laminectomy and partial discectomy have been performed.[9–16] However, if the compression of the cauda equina resolves with distraction, then the role of dorsal laminectomy and partial discectomy in combination with distraction and stabilization techniques may have to be questioned, when not performed to apply an IVD spacer.

The aim of this study was to describe the diagnostic findings in flexed compared to neutral MRI of the LSJ in dogs with clinically suspected and diagnostically confirmed DLSS. Our hypotheses are that flexed positioning will lead to reduction of the IVD protrusion with no compression of the overlying cauda equina nor occlusion of the foramina; and that this response will be independent of the degree of IVD degeneration and/or spondylosis.

2 | MATERIALS AND METHODS

2.1 | Animals

This was a retrospective, comparative study based on medical records and MRI findings of dogs diagnosed with clinically suspected, MRI-confirmed DLSS from three different referral institutions between September 2020 and March 2024. Inclusion criteria were:

- General, orthopedic and neurologic examination performed by boarded or board-eligible neurology and/or orthopedic veterinary specialists.
- Presenting clinical signs and neurologic examination compatible with lumbosacral disease, including reluctance to jump and/or walk upstairs, pelvic limb lameness, focal LSJ pain and/or neurologic deficits localizing to L6–S3 ± caudal spinal nerves (reduced withdrawal reflexes in one or both pelvic limbs; reduced perineal reflexes; reduced anal tone; lower motor neuron fecal or urinary incontinence; low tail carriage; tail paresis or paralysis).

- MRI findings compatible with degenerative lumbosacral stenosis with any combination of the disease components (e.g., intervertebral disc protrusion; unilateral or bilateral foraminal stenosis; ventral tipping of the dorsal lamina; LSJ subluxation).
- MRI study including a minimum of T2W sagittal and transverse sequences in neutral and flexed positions.

Exclusion criteria were clinical signs not compatible with a lumbosacral localization; presence of concurrent identified neurologic or orthopedic disease that could explain/contribute to the clinical signs, presence of concurrent L7–S1 intervertebral disc extrusion, presence or suspected presence of a concurrent L7–S1 discospondylitis and presence of vertebral malformations aside from transitional L7 or S1 vertebrae.

2.2 | MRI technique and assessments

Dogs were premedicated and maintained with standard anesthetic protocols. MRI examinations were acquired with a 1.5 T MRI (Vantage Elan MR System Canon Medical Systems; Philips Achieva; GE Signa Echospeed). The MRI studies were acquired with the pelvic limbs in neutral and flexed positions in all dogs as previously described.[8] A minimum of T2W sagittal and transverse sequences in neutral and flexed positions were required.

All evaluations and measurements were performed by three independent observers including one ECVN-veterinary neurology resident (IBC), one ECVN-certified veterinary neurology specialist (LM), and one ECVDI-certified veterinary diagnostic imaging specialist (CB) using Horos software (Annapolis, Maryland). The observers were blinded to the presenting clinical signs. Each assessment and measurements were performed by each observer following written instructions as follows:

2.3 | Quantitative measurements

1. Lumbosacral angle: measured on sagittal T2W sequences in neutral and flexed positions. It is the angle formed by the intersection of two lines on midline sagittal plane, one passing through the cranio-dorsal and the caudo-dorsal margins of the L7 vertebral body, and one passing through the cranio-dorsal and the caudo-dorsal margin of S2 vertebral body (Figure 1). S2 was chosen instead of S1 to represent the floor of the sacral canal as the craniodorsal margin of S1 vertebral body could be altered with DLSS.
2. Protrusion ratios: measured on sagittal T2W images in neutral and flexed positions. The measurements were obtained by drawing a first line (line 1) passing through the cranio-dorsal and the caudo-dorsal margins of the L7 vertebral body and a second line (line 2) perpendicular to the first and passing through the top of the protrusion. Along line 2, "A" was identified as the base of the protrusion (intersection between the two lines); "B" the dorsal limit of the protrusion; and "C" the top of the canal (intersection with the ligamentum flavum). A third line (line 3), still perpendicular to line 1 was then drawn, starting from the caudo-dorsal corner of the L7 vertebral body (point "D"), and ending at the intersection with the dorsal lamina of L7 (point "E") (Figure 1). The following ratios were obtained:
   a. *Protrusion-to-relative-canal ratio (PRCR)*: height of the protrusion as a percentage of the height of the canal at the level of the protrusion. This measurement was chosen for its clinical relevance as it considers both ventral and dorsal compressions but is affected by the infolding of the ligamentum flavum. PRCR was calculated as: AB × 100/AC.
   b. *Protrusion-to-absolute-canal ratio (PACR)*: height of the protrusion as a percentage of the height of

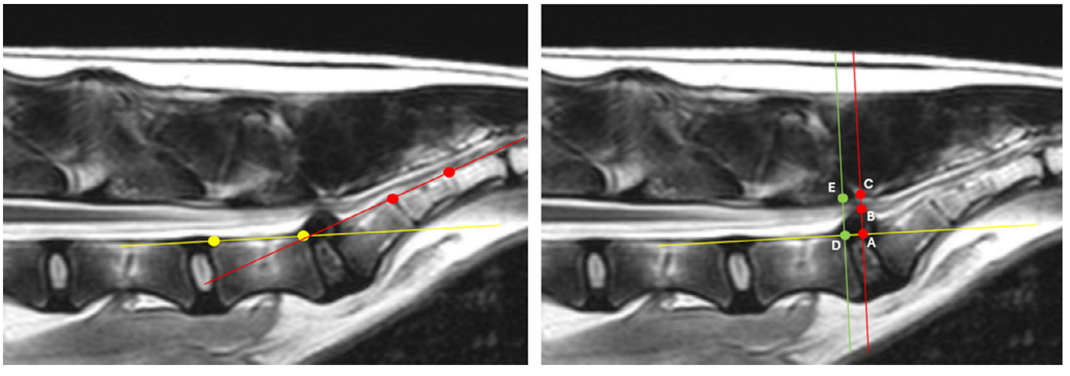

FIGURE 1 Measurement of the lumbosacral junction angle (left) and the protrusion ratios (right) on sagittal T2W magnetic resonance imaging sequences. Protrusion to relative canal ratio was calculated as: AB × 100/AC. Protrusion to absolute canal ratio was calculated as: AB × 100/DE.

the vertebral canal at L7. This measurement was chosen to assess the protrusion itself in comparison to a static structure, independent of the infolding of the ligamentum flavum. PACR was calculated as: AB × 100/DE.

2.4 | Qualitative assessments

1. Degree of intervertebral disc degeneration: assessed in T2W sagittal sequences in the neutral position following Pfirrmann grading system.[17,18] Grade 1, homogeneous and bright white structure with clear margins between nucleus and anulus, hyperintense signal (isointense to cerebrospinal fluid [CSF]), and normal intervertebral disc height; grade 2, heterogeneous structure with or without horizontal bands, with clear margins between nucleus and anulus, still hyperintense signal, and normal intervertebral disc height; grade 3, heterogeneous structure with unclear margins between nucleus and anulus, intermediate signal intensity, and normal to slightly decreased intervertebral disc height; grade 4, heterogeneous structure with lost margins between nucleus and anulus, intermediate to hypointense signal intensity compared to CSF, and normal to moderately decreased intervertebral disc height; grade 5, heterogeneous and black structure with lost margins between nucleus and anulus, completely hypointense signal, and collapsed disc space (Figure 2).
2. Degree of spondylosis: presence of ventral spondylosis with or without bridging assessed in T2W sagittal and transverse images. Bridging is defined as continuous tissue joining L7 and S1 vertebral bodies ventrally. This was graded as follows: grade 0, no spondylosis; grade 1, spondylosis without bridging; grade 2, spondylosis with bridging.
3. Degree of intervertebral disc protrusion: degree of contact/compression of the cauda equina by the intervertebral disc protrusion in T2W sagittal images assessed at the point of maximal protrusion, in both neutral and flexed positions. This was graded as follows: grade 0, no protrusion and intact adipose tissue column ventral to the cauda equina; grade 1, protrusion with no contact with the cauda equina but with indentation of the ventral CSF/fat signal column; grade 2, protrusion in contact with the cauda equina causing effacement of the ventral adipose tissue column without dorsally displacing the cauda equina; grade 3, protrusion causing a dorsal displacement of the cauda equina, but with adipose tissue signal still present between the cauda equina and the roof of the vertebral canal; grade 4, compression of the cauda equina with effacement of both dorsal and ventral adipose tissue columns by the protrusion (Figure 3).
4. Ventral bulging of the ligamentum flavum (VBLF) at L7–S1: assessed in T2W sagittal sequences in neutral and flexed positions. Drawing a line connecting the dorsal lamina of L7 and S1, this variable was graded as follow: grade 0, the ligament does not bulge below the line; grade 1, the ligament bulges ventrally below the line without making contact with the cauda equina; grade 2, the ligament bulges ventrally below the line and is in contact with the cauda equina, causing effacement of the dorsal CSF/fat signal column (Figure 4).
5. Vertebral canal occlusion: based on the evaluation of the degree of intervertebral disc protrusion and the degree of VBLF, the vertebral canal was defined as completely occluded when the degree of protrusion was scored grade 4, or when the degree of

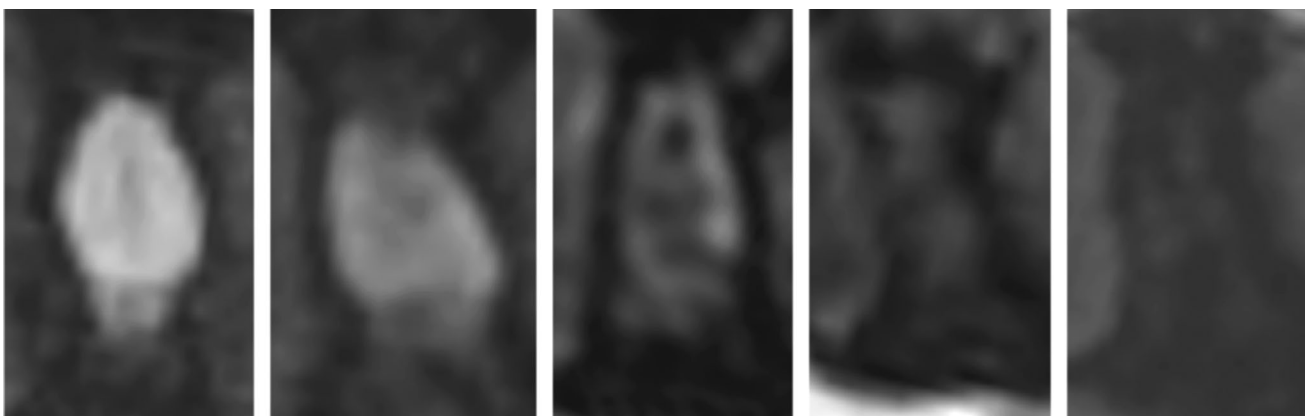

FIGURE 2 Sagittal T2W magnetic resonance imaging images of the lumbosacral intervertebral disc (IVD) in five cases showing, from left to right, IVD degeneration scores from 1 to 5, respectively.

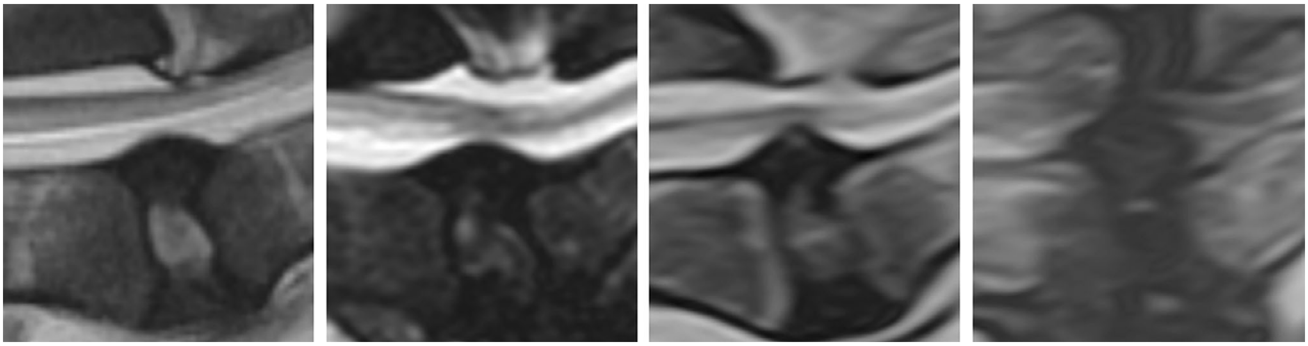

FIGURE 3 Sagittal T2W magnetic resonance imaging images of the lumbosacral junction in four cases showing, from left to right, intervertebral disc protrusion scores from 1 to 4, respectively.

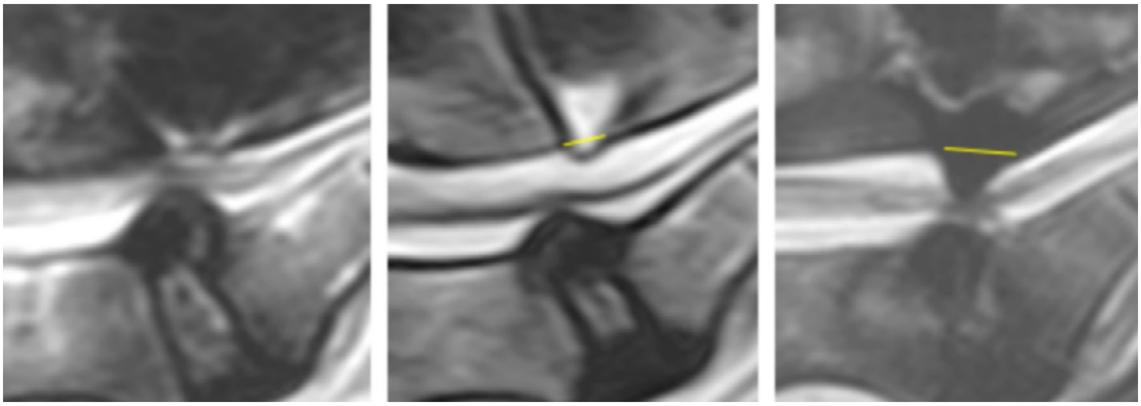

FIGURE 4 Sagittal T2W magnetic resonance imaging images of the lumbosacral junction in three cases showing, from left to right, ventral bulging of the ligamentum flavum scores from 0 to 2, respectively. The yellow line connects the dorsal lamina of L7 and S1.

protrusion was scored grade 2 or 3 and the degree of VBLF was scored 2.

6. Degree of foraminal stenosis: assessed in the parasagittal slices of the T2W sequences in neutral and flexed positions. Starting from the midline and moving parasagittally, the assessment was made on the first image showing a complete bony perimeter around L6–L7 and L7–S1 foramina. If there was no slide matching the above criteria, the foramen was not assessed. The degree of L7–S1 foraminal compression was graded as follows: grade 0, there is abundant hyperintense adipose tissue signal in the L7–S1 foramen, which is more than the hypointense content of the foramen; grade 1, there is still adipose tissue signal in the L7–S1 foramen, but only in similar or less volume compared to the hypointense content of the L7–S1 foramen; grade 2, there is no obvious normal adipose tissue signal in the L7–S1 foramen (Figure 5).
7. Other assessments: other assessments included presence or absence of any of the following: transitional L7 vertebra; transitional S1 vertebra; osteochondrosis dissecans (OCD) of the sacrum; L7–S1 subluxation.

2.5 | Statistical analysis

The interobserver agreement (kappa statistic) for the three clinicians was determined using Fleiss' multi-rater kappa for variables with ordinal data and using Intraclass correlation coefficient for variables with continuous data. The interobserver agreement was defined as "poor" (<0.2), "fair" (0.21–0.4), "moderate" (0.41–0.6), "good" (0.61–0.8) or "very good" (0.81–1).

Following interobserver agreement analysis, for continuous data the mean value between the three observations was calculated for each dog, and the result was used for comparative analysis between the neutral and flexed position assessment. For variables with ordinal data, the value chosen with the highest frequency by the three observers was then selected as the final agreed score for each dog, and used for comparative analysis between the neutral and flexed position assessment (for example, if a variable was scored grade 2 by two observers and grade 3 by one observer, that variable was given a final agreed score of grade 2). In the event of three different scores, a final agreement was obtained via collegial discussion.

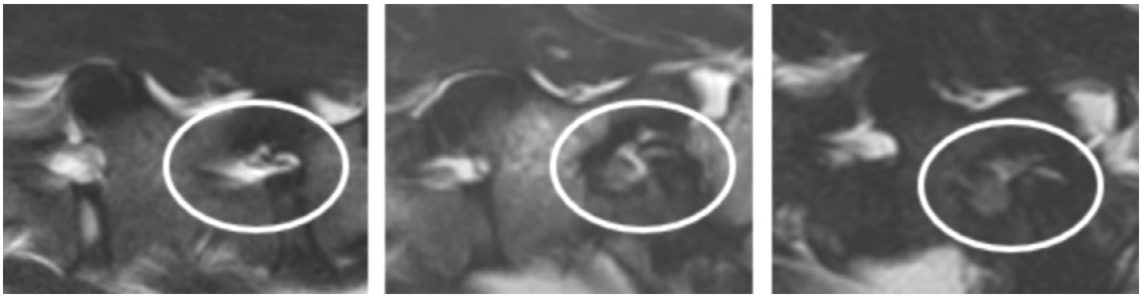

FIGURE 5 Sagittal T2W magnetic resonance imaging images of the L6–L7 and L7–S1 lumbosacral foramen in three cases showing, from left to right, foraminal stenosis scores from 0 to 2, respectively. The white circle highlights the L7–S1 foramen.

The mean values for continuous data and the final agreed score for ordinal data were compared between neutral and flexed position using Mann–Whitney U test. The *p*-values were reported for each comparison.

Correlation analysis between paired variables was performed using Spearman's correlation for the paired variables with continuous data and for the paired variables with ordinal data. Spearman's Rho and *p*-values were reported. If in the paired variable one had ordinal and the other had continuous data, to logically assess correlations the continuous variables were initially transformed into ordinal variables based on quartiles (25, 50, 75).

For all analyses, a *p*-value of .05 or lower was considered statistically significant.

3 | RESULTS

3.1 | Animals

A total of 32 dogs matched the inclusion criteria in terms of clinical presentation and acquired MRI studies. Of these 32 cases, eight were excluded due to lack of MRI findings consistent with DLSS, suspected concurrent discospondylitis, suspected concurrent intervertebral disc extrusion or presence of more complex vertebral malformations. Ultimately, 24 dogs met all the inclusion criteria and underwent MRI assessment and statistical analysis.

3.2 | Signalment

The study population included 16 female dogs (66.6%), two entire and 14 neutered, and eight males (33.3%), one entire and seven neutered. The median age at presentation was 6 years (1 to 11 years). Crossbreeds were the most prevalent ($n = 4$, 16.6%), followed by Labrador Retriever (3/24, 12.5%), German Shepherd dog (3/24, 12.5%), Cocker Spaniel (2/24, 8.3%) and Dalmatian (2/24, 8.3%). Other breeds were represented by a single case each and included: Alaskan Malamute, Cavalier King Charles Spaniel, English Springer Spaniel, French Bulldog, German Short-Haired Pointer, Golden Retriever, Hungarian Vizsla, Lurcher, Staffordshire Bull Terrier and Yorkshire Terrier.

3.3 | History and clinical presentation

The duration of clinical signs before presentation was: 1–2 weeks ($n = 2$, 8.3%), 2–4 weeks ($n = 1$, 4.1%), 1–3 months ($n = 8$, 33.3%), 3–6 months ($n = 6$, 25%), up to 1 year ($n = 6$, 25%), longer than a year ($n = 1$, 4.1%). A total of 10 dogs had progressive neurologic signs (41.6%), 11 had waxing and waning signs (45.8%), one had static signs (4.1%) and two were reported as improving by the time of presentation (8.3%).

The most common complaints reported by the owner were reluctance to jump ($n = 16$, 66.6%), reluctance to exercise ($n = 15$, 62.5%), vocalization episodes ($n = 14$, 58.3%) and pelvic limb lameness ($n = 13$, 54.1%), being unilateral in 11 cases (84.6%) and bilateral in two dogs (15.3%). Other signs described by the owner included: reluctance to climb stairs ($n = 9$, 37.5%), reluctance to sit and/or stand ($n = 4$, 16.6%), change of the tail carriage ($n = 3$, 12.5%), urinary incontinence ($n = 1$, 4.1%) and fecal incontinence ($n = 1$, 4.1%).

At the time of presentation, the most common findings on neurologic examination were lumbosacral pain ($n = 19$, 79.1%) and pelvic limb lameness ($n = 9$, 37.5%; of which 7 were unilateral and 2 bilateral). Other findings included: reduced pelvic limb withdrawal reflex ($n = 5$, 20.8%; 3 unilateral and 2 bilateral), lumbosacral kyphosis ($n = 3$, 12.5%), low tail carriage ($n = 3$, 12.5%) and reduced perineal reflex bilaterally ($n = 1$, 4.1%).

3.4 | Other diagnostic investigations

Other diagnostic investigations included hematology ($n = 13$, 54.1%), serum biochemistry ($n = 14$, 58.3%), radiographs of the pelvic limbs ($n = 9$, 37.5%) and spine ($n = 13$, 54.1%), CT scan of the pelvic limbs ($n = 1$, 4.1%) or spine ($n = 7$, 29.1%) and CSF analysis ($n = 1$, 4.1%). These revealed a mild degree of hip dysplasia in one case (not deemed responsible for the clinical signs) and no other relevant findings aside from those affecting the lumbosacral joint.

3.5 | Interobserver agreement analysis

Interobserver agreement on the evaluated MRI variables was good to very good for the quantitative measurements and fair to moderately good for the qualitative assessment (Table 1). In no cases the three observers provided three different qualitative scores for any variable.

3.6 | Evaluations of quantitative and qualitative variables

All the results from the assessment of each MRI variable in neutral and flexed positions are summarized in Table 2.

The median degree of intervertebral disc degeneration based on Pfirrmann's classification was 4 (range: 2–5). The median degree of spondylosis was 1 (range: 0–2).

When comparing neutral and flexed positioning, the mean LSJ angle from neutral to flexed position increased by 30.5°. The intervertebral disc protrusion from neutral to flexed position was reduced on both quantitative and qualitative assessment ($p < .001$). Mean PRCR and PACR reduced by 49.3% and 53.1%, respectively. The median degree of protrusion reduced from 3 in neutral (range: 1–4) to 1 in flexed (range: 0–3). There were no dogs with IVD protrusion grade 4 in flexed position, compared to

TABLE 1 Interobserver agreement analysis for each assessed variable.

Variable	Overall agreement	95% CI	*p*-value
Neutral position			
LSJ angle	0.887	0.781, 0.947	<.001
IVD protrusion measure AB	0.811	0.606, 0.914	<.001
IVD protrusion measure AC	0.83	0.699, 0.916	<.001
IVD protrusion measure DE	0.748	0.403, 0.895	<.001
Degree of IVD degeneration	0.45	0.309, 0.591	<.001
Degree of IVD protrusion	0.39	0.252, 0.527	<.001
Degree of spondylosis	0.46	0.294, 0.621	<.001
Degree of right foraminal stenosis	0.451	0.266, 0.636	<.001
Degree of left foraminal stenosis	0.45	0.278, 0.621	<.001
Degree of VBLF	0.492	0.327, 0.656	<.001
Flexed position			
LSJ angle	0.823	0.688, 0.912	<.001
IVD protrusion measure AB	0.674	0.457, 0.831	<.001
IVD protrusion measure AC	0.826	0.685, 0.915	<.001
IVD protrusion measure DE	0.73	0.453, 0.876	<.001
Degree of IVD protrusion	0.456	0.314, 0.598	<.001
Degree of right foraminal stenosis	0.219	0.012, 0.426	.038
Degree of left foraminal stenosis	0.361	0.143, 0.58	.001
Degree of VBLF	0.206	−0.025, 0.437	.081

Note: The interobserver agreement is defined as "poor" (<0.2), "fair" (0.21–0.4), "moderate" (0.41–0.6), "good" (0.61–0.8) or "very good" (0.81–1). Statistical significance was set at $p \leq .05$.
Abbreviations: IVD, intervertebral disc protrusion; LSJ, lumbosacral junction; VBLF, ventral bulging of the ligamentum flavum.

Variable	Neutral position Mean (± SD) or n	Flexed position Mean (± SD) or n	*p*-value
LSJ angle	152.2° (± 7.2°)	182.7° (± 7.6°)	<.001
PRCR	52.1% (± 13.7%)	25.7% (± 9.9%)	<.001
PACR	45.0% (± 13.7%)	23.9% (± 9.6%)	<.001
Degree of IVD degeneration	Cases	Cases	
Grade 1	0	N/A	
Grade 2	3		
Grade 3	5		
Grade 4	11		
Grade 5	5		
Degree of spondylosis	Cases	Cases	
Grade 0	8	N/A	
Grade 1	7		
Grade 2	9		
Degree of IVD protrusion	Cases	Cases	
Grade 0	0	7	<.001
Grade 1	3	7	
Grade 2	6	8	
Grade 3	8	2	
Grade 4	7	0	
Degree of VBLF	Cases	Cases	
Grade 0	7	23	<.001
Grade 1	6	1	
Grade 2	11	0	
Degree of right foraminal stenosis	Cases	Cases	
Grade 0	9	23	<.001
Grade 1	10	1	
Grade 2	5	0	
Degree of left foraminal stenosis	Cases	Cases	
Grade 0	7	22	<.001
Grade 1	9	2	
Grade 2	8	0	

Abbreviations: IVD, intervertebral disc; LSJ, lumbosacral junction; N/A, non-applicable; PACR, protrusion to absolute canal ratio; PRCR, protrusion to relative canal ratio; VBLF, ventral bulging of the ligamentum flavum.

TABLE 2 Results and comparison of the assessment of each quantitative and qualitative variables in neutral and flexed position. Statistical significance was set at $p \leq .05$.

seven dogs in neutral position. When combining the invasion of the vertebral canal by the intervertebral disc ventrally and the ligamentum flavum dorsally, 10 dogs had complete occlusion of the vertebral canal in a neutral position, while no dogs displayed complete occlusion of the vertebral canal in a flexed position (Figure 6). The median VBLF was 1 in neutral (range: 0–2) and 0 in flexed (range: 0–1).

The median degree for both right and left foraminal stenosis was 1 in neutral (range: 0–2) and 0 in flexed (range: 0–1). Of the 48 foramina assessed in both neutral and flexed views, there were 19 narrowed foramina (grade 1) and 13 completely occluded foramina (grade 2) in a neutral position, while in a flexed position there were only three narrowed foramina (decreased from grade 2 to grade 1) and no completely occluded foramen.

No transitional L7 vertebrae or OCD-like lesions were detected, one case had a transitional S1 vertebra, and two cases had LS subluxation.

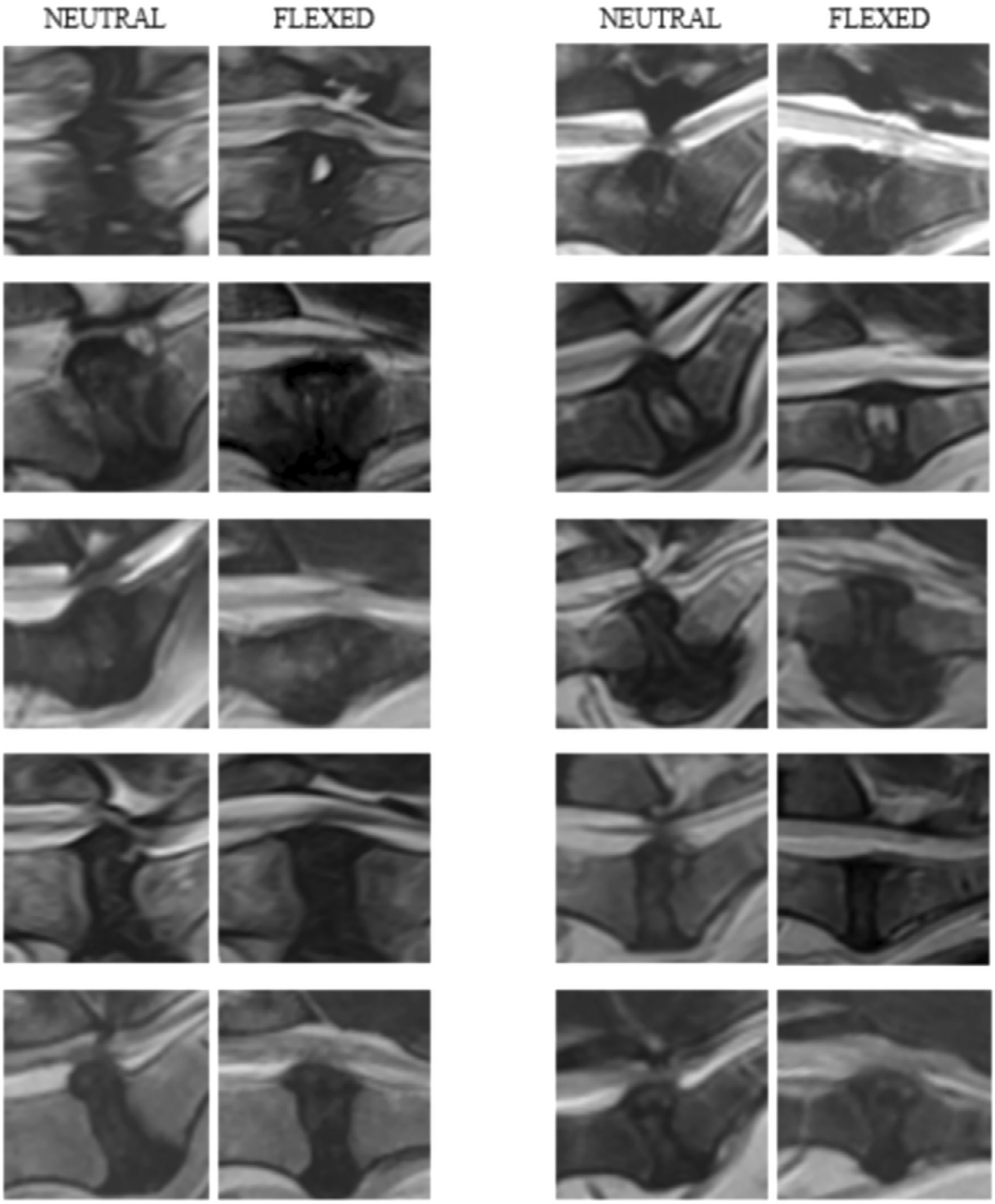

FIGURE 6 Sagittal T2W magnetic resonance imaging images of the lumbosacral junction in neutral and flexed position in 10 cases with completely occluded vertebral canal in a neutral position. The figure shows the resolution of the compression in flexion in all cases.

3.7 | Correlation analysis between paired variables

The variation in degree of IVD protrusion from neutral to flexed was correlated with the degree of variation in the LSJ angle (Spearman's correlation coefficient = 0.589, $p = .002$) and the degree of IVD degeneration (Spearman's correlation coefficient = 0.565, $p = .004$). A correlation was also found between the degree of IVD protrusion in neutral position and the degree of intervertebral disc degeneration (Spearman's correlation coefficient = 0.479, $p = .018$).

There was no correlation between PRCR or PACR variation and the degree of LSJ angle variation ($p = .756$ and $p = .506$, respectively) or the degree of IVD degeneration ($p = .362$ and $p = .307$, respectively).

The degree of spondylosis was not correlated with the degree of LSJ angle variation ($p = .113$), the change in the IVD protrusion grade ($p = .261$), or the variation in PRCR (p = .113) or PACR ($p = .356$).

4 | DISCUSSION

The results of this study confirmed that the degree of IVD protrusion was statistically significantly reduced in flexed views on both quantitative and qualitative assessments, with the proportion of the dorsoventral height of the vertebral canal occupied by the IVD protrusion in flexed views decreasing by an average of approximately 50% (PRCR and PACR) compared to neutral position. The same was true for the qualitative assessment of the degree of compression at the L7–S1 intervertebral foramina. These results support the hypothesis that when the LSJ is flexed, the compression of the cauda equina detectable on MRI, within either the vertebral canal or the intervertebral foramina resolves in all cases, at least in our population. Larger studies are recommended to support these findings even further. Our findings echo the results obtained by previous studies[5–7] reporting an enlargement of the intervertebral foramina in dogs with DLSS assessed on CT comparing flexed to neutral positioning. These studies performed on CT, however, did not assess simultaneously the effect of dog positioning on the degree of IVD protrusion and its impact on the cauda equina within the vertebral canal. For such assessment, an MRI study is likely to be more reliable in identifying neural structures and the degree of their displacement/compression. The only study that evaluated the lumbosacral spine using dynamic MRI was performed only on clinically normal dogs.[8]

In our population, the results of this study also revealed no correlation between the degree of spondylosis and the variation in the degree of IVD protrusion from a neutral to flexed position, whether assessed qualitatively or quantitatively. Similarly, no correlation was also found between the degree of spondylosis and the degree of change in the LSJ angle obtained when flexing the LSJ, therefore, supporting the hypothesis that spondylosis does not appear to limit the ability to flex the LSJ or reduce the compression of neural structures in flexion. The only correlations detected were between the variation of the LSJ angle and the variation in the degree of protrusion, which is quite intuitive and not unexpected, as reported by Lampe and colleagues,[8] and between the degree of degeneration of the IVD and the degree of variation of the IVD protrusion from neutral to flexed, suggesting that a more degenerated IVD could be more responsive to flexion. However, when investigating this further, a correlation between the degree of IVD degeneration and the degree of IVD protrusion in neutral view was revealed, suggesting that the more degenerated an IVD was, the more prominent was the protrusion in neutral positioning. Therefore, the greater response to flexion of the more degenerated IVD might simply reflect that such IVD were more protruded to begin with, allowing a wider gap in the scoring of the degree of protrusion from a neutral to flexed position.

As stated previously, in most published cases where LSJ distraction and stabilization were performed, dorsal laminectomy and partial discectomy were also performed simultaneously.[9–16] In these cases, these procedures were only aimed to achieve decompression and not to place IVD spacers. Our study revealed that, in our population of dogs with clinical DLSS, once the LSJ was flexed, there was no persistent compression of the cauda equina in any case, suggesting that performing dorsal laminectomy and partial discectomy could be unnecessary if a good distraction is achieved. The same appears to be true regarding the need for a concurrent foraminotomy. If this is the case, this would reduce surgical time and remove the risks associated with opening the vertebral canal and operating around the cauda equina or the foramina, when an IVD spacer is not positioned as part of the technique. Clearly, further prospective case–control surgical studies are still needed to confirm this hypothesis. In humans, indirect decompression (decompression achieved via distraction and stabilization alone) is well described as a surgical technique to address lumbosacral stenosis. In a study including 419 patients undergoing this treatment at L5–S1, 95.6% did not require a second intervention to add direct decompression.[19] In a systematic review and meta-analysis comparing indirect and direct decompression and fusion techniques for lumbar spinal stenosis, both approaches were equally successful in treating the condition. However, indirect decompression resulted in shorter surgical time and less intraoperative blood loss.[20]

Among veterinary surgeons, different preferences exist in terms of how to obtain LS distraction in surgery, whether operating with the dog positioned with the LSJ flexed or with the dog in neutral position via applying linear distraction. Because of the design of the present study, our results are applicable only to flexed positioning and may not be applicable to linear distractions in a neutral position. However, in an ex vivo study evaluating the craniocaudal disc height changes with distraction and stabilization in neutral or in flexed positions, this value equally increased with all techniques.[21] This suggests that it is likely that the degree of protrusion should have similar responses to both type of distractions. Future studies evaluating the lumbosacral joint with linear traction on MRI would be useful to confirm this hypothesis, if reliable linear traction techniques for imaging are developed.

A final consideration based on the results of the study is related to the usefulness of flexed position MRI studies as a standard procedure in all DLSS cases. Indeed, if such MRI studies in flexed position are performed with the goal to define if the condition is traction/flexion-responsive, then our study seems to suggest that this may be the case in all dogs, both at the foramina and on the midline, without being correlated to factors such as the degree of spondylosis. If this is confirmed in larger studies, then the prolonged anesthetic time needed to obtain flexed views on top of the neutral views, with the potential risks and costs associated, might not be justified. However, we cannot exclude that in specific cases with more complex vertebral malformations and/or doubt of concurrent intervertebral disc extrusion, a dynamic imaging study could still be useful to assess the disease.

This study presents several limitations. First, due to its retrospective nature, 3D MRI sequences were not obtained as a standard protocol in both positions in all dogs, which would have reduced the disadvantage in using MRI compared to CT when assessing foraminal anatomy. Considering this, it was the authors' decision to avoid attempting quantitative measurements of the foraminal volume in our study and instead limiting the evaluation to a simpler qualitative assessment that was considered more reliable with the MRI sequences available. The small sample size is another limitation to consider. However, although increasing the sample size can always be beneficial, the very low *p*-value detected for all the comparisons between the variables investigated suggests that it is quite likely that the same results would be replicated in larger populations. Another limitation is that the presence of more complex LS malformation aside from L7 or S1 transitional vertebrae, was considered an exclusion criterion. Although this decision was made to create a more homogenous study population, it may limit the ability of our results to be applied to cases with more complex malformations.

In conclusion, this study confirms that in dogs with clinical DLSS, in flexed position the degree of IVD protrusion and foraminal stenosis improves in all cases, with no dog presenting persistent compression of the cauda equina or complete foraminal stenosis. When applied to surgical planning, these results suggest that the need for combining dorsal laminectomy and partial discectomy or foraminotomy in association with distraction stabilization techniques should be questioned, if a good distraction is achieved and when placement of an IVD spacer is not part of the chosen technique. Further surgical case–control studies are needed to confirm this hypothesis.

AUTHOR CONTRIBUTIONS

Baldo Clemot I, DMV, MRCVS, ECVN-resident: Study design, identified medical records (8 cases), recorded demographic information, compiled all data, assessed MRI-studies, interpreted data, drafted and revised the manuscript. Briola C, DVM, MRCVS, Dipl.ECVDI: Study design, identified medical records, recorded demographic information, compiled all data, assessed MRI-studies, interpreted data, revised manuscript. Ekiri AB, BVM, MS, PhD, MPH: Study design, statistical analysis, interpreted data, revised manuscript. Cappello R, DVM, MRCVS, PhD, DipECVN: Study design, interpreted data, revised manuscript. Marinelly R, BAnimSci, BVetMed (Hons), MRCVS: Identified medical records (10 cases), recorded demographic information, compiled all data, revised manuscript. Brocal J, Ldo Vet, MRCVS, MVM, Dip.ECVN: Study design, interpreted data, revised manuscript. Prodger A, MA, VetMB, MRCVS: Identified medical records (6 cases), recorded demographic information, compiled all data, revised manuscript. Mari L, DVM, MRCVS, DipECVN: Study design, identified suitable medical records, recorded demographic information, compiled all data, assessed MRI-studies, statistical analysis, interpreted data, drafted and revised the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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