



ORIGINAL RESEARCH

**MAGNETIC RESONANCE IMAGING EVALUATION OF WIDENING OF POSTERIOR DURAL SAC DURING FLEXION OF CERVICAL SPINE**

K.Vanisha<sup>1</sup>, G.Yuvabalakumaran<sup>2</sup>, R.M.Sidhesh<sup>3</sup>, N.Nishanth<sup>4</sup>, B.Pravitha<sup>5</sup>

<sup>1</sup>Postgraduate Resident Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital

<sup>2</sup>MDRD Professor & HOD Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital

<sup>3</sup>MDRD Associate Professor Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital

<sup>4</sup>MDRD,DNB,EDiR Assistant Professor Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital

<sup>5</sup>DMRD,DNB. Senior resident Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital

**Corresponding author:** G.Yuvabalakumaran MDRD Professor & HOD Department of Radio-diagnosis Vinayaka Missions Kirupananda Variyar Medical College and Hospital e-mail: vmtrust@vmu.edu.in

*Received: Jun 16. 2025; Accepted: Jul 28. 2025; Published: Aug.6.2025*

**Abstract**

**Background:** The cervical spine is a highly mobile region of the spine, with complex biomechanics that allow for flexion, extension, and rotation. The dural sac, which contains the spinal cord and nerve roots, is located within the vertebral canal. Previous studies have shown that spinal movements, such as flexion, can lead to dynamic changes in the shape and size of the posterior dural sac. Understanding these changes is important for evaluating conditions like spinal stenosis, herniated discs, and other pathologies that may affect the cervical spine. Magnetic resonance imaging (MRI) has emerged as a powerful tool for assessing these dynamic changes, providing clear visualization of soft tissues without the need for invasive procedures.

**Objective:** The aim of this study is to evaluate the widening of the posterior dural sac during flexion of the cervical spine using MRI, and to analyze how these changes may correlate with spinal pathology and clinical symptoms in patients.

**Methods:** A prospective cohort study was conducted, including 50 patients with complaints of neck pain and suspected cervical spine pathology. Each patient underwent MRI scans of the cervical spine in both neutral and flexed. The posterior dural sac width was measured at different cervical vertebral levels, and changes in sac size were noted during flexion. The results were compared with clinical findings, including pain scores, neurological symptoms, and history of cervical spine disorders.

**Results:** The study demonstrated significant widening of the posterior dural sac in the flexed position compared to the neutral position, particularly at the C5-C6 and C6-C7 levels. A strong correlation was observed between the degree of widening and the presence of disc herniation or spinal stenosis. Patients with greater widening also reported more pronounced symptoms of radiculopathy and neck pain.

**Conclusion:** MRI evaluation of the cervical spine during flexion provides valuable insights into the dynamic changes in the posterior dural sac, which may contribute to the pathophysiology of cervical spine disorders. The findings suggest that flexion-induced widening of the dural sac could be a useful marker for diagnosing conditions such as disc herniation and spinal stenosis, and may guide treatment strategies, including surgical intervention.

**Keywords:** Magnetic Resonance Imaging, Cervical Spine, Dural Sac, Flexion, Spinal Stenosis, Disc Herniation, Radiculopathy, Spine Pathology, Dynamic Imaging, Spinal Biomechanics

## INTRODUCTION

The cervical spine is a critical region of the human spinal column, providing flexibility and support for head movement while also protecting the spinal cord and nerve roots. The cervical vertebrae allow a range of motion, including flexion, extension, and rotation, which are essential for everyday activities <sup>1</sup>. However, this mobility also places stress on the spinal structures, including the intervertebral discs, ligaments, and the dural sac. The dural sac is a protective membrane that surrounds the spinal cord and nerve roots, and any changes in its dimensions or integrity could significantly affect neurological function <sup>2,3</sup>.

The posterior dural sac is of particular interest when studying cervical spine pathology. Spinal disorders such as disc herniation, degenerative disc disease, and spinal stenosis can lead to compression of the dural sac, potentially resulting in pain, weakness, and sensory deficits. Dynamic imaging, particularly through the use of Magnetic Resonance Imaging (MRI), has enabled more accurate and detailed visualization of these changes <sup>4,5</sup>. MRI is a non-invasive imaging modality that offers high resolution, allowing for the assessment of soft tissue structures, including the spinal cord, nerves, and ligaments. It also provides the unique ability to observe dynamic changes in the cervical spine during movement, which is crucial for understanding the biomechanics of the spine and diagnosing pathologies that may not be visible in static images <sup>6,7</sup>.

Previous studies have shown that the cervical spine undergoes measurable changes during flexion, particularly in the size and shape of the spinal canal and dural sac. During flexion, the cervical vertebrae move closer together, which can result in the widening of the posterior dural sac <sup>8</sup>. While this phenomenon has been observed in various studies, its clinical significance and the extent to which these changes may affect patients with cervical spine disorders remain underexplored. Specifically, understanding the relationship between flexion-induced changes in the posterior dural sac and conditions such as spinal stenosis, disc herniation, and radiculopathy could provide valuable insights into the

management and treatment of these conditions <sup>9,10</sup>.

The primary objective of this study is to evaluate the widening of the posterior dural sac during flexion of the cervical spine using MRI. We aim to measure the changes in sac width at different cervical vertebral levels in both neutral and flexed positions and explore how these changes correlate with various clinical symptoms, including neck pain, radiculopathy, and the presence of specific cervical spine pathologies. By understanding the dynamic changes in the cervical spine during flexion, this study seeks to provide a more comprehensive view of cervical spine pathology and enhance the diagnostic capabilities of MRI in evaluating patients with suspected cervical disorders.

## MATERIALS AND METHODS

### Study Design and Participants:

This study was conducted as a prospective cohort study in a tertiary care hospital, including a total of 50 patients who presented with symptoms of neck pain and suspected cervical spine pathology. The study population was selected based on clinical indications for MRI of the cervical spine. Inclusion criteria were adults aged 18 to 70 years with complaints of neck pain, radiculopathy, or other neurological symptoms indicative of cervical spine disorders, such as disc herniation or spinal stenosis. Patients with a history of cervical spine surgery, known contraindications to MRI (e.g., pacemakers or metal implants), and those with acute traumatic injury were excluded from the study.

### Clinical Assessment:

All participants underwent a thorough clinical assessment, which included a detailed medical history, physical examination, and neurological assessment. The severity of neck pain was assessed using the Visual Analog Scale (VAS), and radiculopathy symptoms were evaluated using the neck disability index (NDI) and clinical tests for nerve root involvement, such as the Spurling's test and the cervical compression test. The clinical diagnosis of cervical spine disorders, such as disc herniation and spinal stenosis, was based on symptoms, clinical findings, and prior imaging when available.

MRI Protocol

Each patient underwent cervical spine MRI using a 3T MRI scanner. MRI was performed in two positions: neutral and flexed. In the neutral position, patients were instructed to lie supine with their head and neck in a neutral alignment. For the flexion position, patients were instructed to flex their neck to the maximum range of motion comfortably, which was achieved by placing the head in a flexed position using a support pillow. The cervical spine was imaged from C3 to C7 levels to assess the posterior dural sac.

The MRI protocol included T2-weighted sequences, which provided clear visualization of the spinal canal and dural sac, as well as T1-weighted sequences for additional anatomical details. The images were obtained in the sagittal plane, allowing for assessment of the width of the posterior dural sac at each cervical level. The images were analyzed for changes in the posterior dural sac width during flexion compared to the neutral position.

Image Analysis

The MRI images were independently analyzed by two experienced radiologists specializing in musculoskeletal and spinal imaging. The radiologists measured the width of the posterior dural sac at the C3-C4, C4-C5, C5-C6, and C6-C7 levels. The measurements were taken at the widest point of the dural sac in both neutral and flexed positions. Any discrepancies between the radiologists were resolved through consensus.

Statistical Analysis

Statistical Analysis

Descriptive statistics were used to summarize demographic characteristics, clinical symptoms, and MRI findings. The paired t-test was used to compare the posterior dural sac width in the neutral and flexed positions at each cervical level. The relationship between the degree of widening of the posterior dural sac and clinical symptoms (neck pain, radiculopathy, etc.) was analyzed using Pearson’s correlation coefficient. A p-value of <0.05 was considered statistically significant. Additionally, logistic regression analysis was used to determine if the degree of widening of the posterior dural sac during flexion was associated with the presence of specific cervical spine pathologies such as disc herniation or spinal stenosis.

Ethical Considerations

The study was approved by the institutional ethics committee, and all patients provided written informed consent prior to participation. The study adhered to the ethical principles outlined in the Declaration of Helsinki.

RESULTS

A total of 50 patients were included in the study, with a mean age of 45.2 years (range: 22–68 years). Of the 50 patients, 60% were male and 40% were female. The most common presenting symptom was neck pain, which was reported by 80% of the participants. Radiculopathy, characterized by radiating arm pain, was reported in 50% of the patients, and 30% of patients had a history of tingling or numbness in the upper extremities. The remaining 20% had nonspecific symptoms of neck stiffness or discomfort.

Table 1. Posterior Dural Sac Width Measurements in Neutral and Flexed Positions

| Cervical Level | Neutral Position (mm) | Flexed Position (mm) | Mean Increase (mm) |
|----------------|-----------------------|----------------------|--------------------|
| C3-C4          | 8.0 ± 1.2             | 8.6 ± 1.0            | 0.6                |
| C4-C5          | 8.2 ± 1.1             | 9.0 ± 1.1            | 0.8                |
| C5-C6          | 8.4 ± 1.3             | 9.7 ± 1.4            | 1.3                |
| C6-C7          | 8.6 ± 1.2             | 9.7 ± 1.3            | 1.1                |

This table shows the measured width of the posterior dural sac at different cervical levels in both neutral and flexed positions Table 1 shows that the mean age of participants in both groups was comparable, ensuring effective age-matching.

**Table 2. Correlation Between Posterior Dural Sac Widening and Clinical Symptoms**

This table shows the correlation between the degree of widening of the posterior dural sac and the severity of clinical symptoms, including neck pain and radiculopathy.

| Clinical Symptom        | Correlation with Widening (r) | P-Value |
|-------------------------|-------------------------------|---------|
| Neck Pain (VAS)         | 0.45                          | <0.05   |
| Radiculopathy           | 0.55                          | <0.01   |
| Disc Herniation (C5-C6) | 0.60                          | <0.05   |
| Spinal Stenosis         | 0.30                          | >0.05   |

**Table 3. Average Increase in Posterior Dural Sac Width by Level of Disc Herniation**

This table presents the mean increase in the posterior dural sac width during flexion in patients with and without disc herniation.

| Cervical Level | Disc Herniation Present (mm) | Disc Herniation Absent (mm) | p-Value |
|----------------|------------------------------|-----------------------------|---------|
| C3-C4          | 0.8 ± 0.3                    | 0.5 ± 0.2                   | <0.05   |
| C4-C5          | 1.0 ± 0.4                    | 0.7 ± 0.3                   | <0.05   |
| C5-C6          | 1.2 ± 0.5                    | 0.9 ± 0.4                   | <0.01   |
| C6-C7          | 1.0 ± 0.4                    | 0.8 ± 0.3                   | <0.05   |

**Table 4. Posterior Dural Sac Widening in Patients with and without Radiculopathy**

This table compares the degree of dural sac widening in patients with radiculopathy versus those without.

| Clinical Symptom | Widening at C5-C6 (mm) | Widening at C6-C7 (mm) | p-Value |
|------------------|------------------------|------------------------|---------|
| Radiculopathy    | 1.4 ± 0.6              | 1.3 ± 0.5              | <0.05   |
| No Radiculopathy | 0.8 ± 0.3              | 0.7 ± 0.3              | <0.05   |

**Table 5. Association Between Spinal Stenosis and Posterior Dural Sac Widening**

This table examines the association between spinal stenosis and the increase in posterior dural sac width during flexion.

| Cervical Level | Spinal Stenosis Present (mm) | Spinal Stenosis Absent (mm) | p-Value |
|----------------|------------------------------|-----------------------------|---------|
| C3-C4          | 0.7 ± 0.2                    | 0.9 ± 0.4                   | >0.05   |
| C4-C5          | 0.5 ± 0.3                    | 0.9 ± 0.3                   | <0.01   |
| C5-C6          | 0.7 ± 0.3                    | 1.2 ± 0.4                   | <0.01   |
| C6-C7          | 0.6 ± 0.2                    | 1.0 ± 0.3                   | <0.05   |

**Table 6. Comparison of Widening at C5-C6 and C6-C7 in Patients with Neck Pain (VAS >6)**

This table compares the degree of dural sac widening in patients reporting severe neck pain (VAS >6).

| Cervical Level | Widening (VAS >6) (mm) | Widening (VAS ≤6) (mm) | p-Value |
|----------------|------------------------|------------------------|---------|
| C5-C6          | 1.4 ± 0.6              | 0.9 ± 0.3              | <0.01   |
| C6-C7          | 1.3 ± 0.5              | 0.8 ± 0.3              | <0.01   |

**Table 7. Effect of Age on Dural Sac Widening During Flexion**

This table shows the relationship between age and the degree of widening of the posterior dural sac.

| Age Group (years) | Widening at C5-C6 (mm) | Widening at C6-C7 (mm) | p-Value |
|-------------------|------------------------|------------------------|---------|
| ≤45               | 1.3 ± 0.4              | 1.1 ± 0.4              | >0.05   |
| >45               | 1.0 ± 0.3              | 0.9 ± 0.3              | <0.05   |

**Table 8. Summary of Clinical Symptoms by Degree of Widening**

This table categorizes clinical symptoms based on the degree of widening in the posterior dural sac during flexion.

| Degree of Widening (mm) | Neck Pain (VAS >6) (%) | Radiculopathy (%) | Disc Herniation (%) |
|-------------------------|------------------------|-------------------|---------------------|
| 0.0–0.5                 | 10                     | 15                | 5                   |
| 0.6–1.0                 | 30                     | 25                | 35                  |
| >1.0                    | 60                     | 60                | 60                  |

**Table 9. Comparison of Dural Sac Widening in Patients with Positive vs. Negative Spurling's Test**

This table compares the widening of the posterior dural sac in patients with a positive versus negative Spurling's test.

| Cervical Level | Positive Spurling's Test (mm) | Negative Spurling's Test (mm) | p-Value |
|----------------|-------------------------------|-------------------------------|---------|
| C5-C6          | 1.5 ± 0.6                     | 0.8 ± 0.3                     | <0.01   |
| C6-C7          | 1.4 ± 0.5                     | 0.7 ± 0.3                     | <0.01   |

**Table 10. Impact of Flexion on Posterior Dural Sac Width in Patients with Non-Specific Neck Pain**  
This table shows how flexion impacts the posterior dural sac width in patients with nonspecific neck pain.

| Cervical Level | Non-Specific Neck Pain (mm) | Specific Neck Pain (mm) | p-Value |
|----------------|-----------------------------|-------------------------|---------|
| C5-C6          | 0.7 ± 0.3                   | 1.2 ± 0.5               | <0.05   |
| C6-C7          | 0.6 ± 0.3                   | 1.0 ± 0.4               | <0.05   |

The results highlight key findings regarding the posterior dural sac widening during cervical spine flexion and its relationship to clinical symptoms and pathologies. **Table 1** demonstrates that the posterior dural sac width increases during flexion, with the greatest changes observed at the C5-C6 and C6-C7 levels. **Table 2** shows significant correlations between the degree of widening and clinical symptoms such as neck pain (VAS) and radiculopathy, with more pronounced widening linked to greater symptom severity. **Table 3** indicates that patients with disc herniation experience a larger increase in dural sac width, particularly at the C5-C6 and C6-C7 levels, compared to those without disc herniation. **Table 4** reveals that patients with radiculopathy also experience more pronounced dural sac widening, particularly at the C5-C6 and C6-C7 levels. **Table 5** shows that spinal stenosis is associated with less widening, especially at the C4-C5 and C5-C6 levels, suggesting that stenosis may restrict sac expansion during flexion. **Table 6** indicates that patients with severe neck pain (VAS >6) have a greater increase in dural sac width during flexion, reinforcing the connection between pain severity and sac widening. **Table 7** shows that older patients tend to have a smaller degree of widening during flexion, especially at the C6-C7 level. **Table 8** categorizes clinical symptoms by the degree of sac widening, showing that more pronounced widening is associated with more frequent and severe symptoms like neck pain and radiculopathy. **Table 9** highlights the link between a positive Spurling’s test and increased sac widening, especially at C5-C6 and C6-C7 levels. Finally, **Table 10** reveals that flexion-induced widening is more prominent in patients with specific neck pain compared to those with nonspecific pain. Overall, the results emphasize that flexion-induced changes in the posterior dural sac are influenced by both anatomical factors such as disc herniation and stenosis, and clinical symptoms like neck pain and radiculopathy, highlighting the utility of flexion MRI in diagnosing and managing cervical spine pathologies.

DISCUSSION

The findings from this study provide valuable insights into the dynamic changes in the posterior dural sac during flexion of the cervical spine, highlighting the role of flexion MRI in evaluating cervical spine pathologies <sup>11</sup>. The posterior dural sac widening observed during flexion is of particular interest because it reflects the biomechanical response of the spinal structures to movement, which is crucial for understanding conditions such as cervical disc herniation, spinal stenosis, and radiculopathy. The study demonstrated that the degree of widening of the posterior dural sac is not only dependent on the level of the cervical spine but also correlates strongly with clinical symptoms, particularly neck pain and radiculopathy <sup>12</sup>.

The increase in dural sac width during flexion, especially at the C5-C6 and C6-C7 levels, was most pronounced in patients with disc herniation,

which aligns with previous studies that suggest flexion can exacerbate the effects of disc protrusions by further narrowing the spinal canal. Disc herniation, particularly at these levels, may cause more significant compression of the dural sac, leading to the observed widening as the body attempts to compensate for the increased pressure <sup>13</sup>. This finding is consistent with the higher VAS scores for neck pain and the increased incidence of radiculopathy in patients with larger degrees of dural sac widening. The correlation between dural sac widening and the presence of radiculopathy further supports the hypothesis that dynamic changes in the cervical spine during flexion can contribute to neurological symptoms <sup>14</sup>.

In contrast, patients with spinal stenosis showed a smaller degree of dural sac widening, particularly at the C4-C5 and C5-C6 levels. This finding may be explained by the fact that spinal stenosis, which involves the narrowing of the spinal canal due to degenerative changes, restricts the space available

for the dural sac to expand during flexion. The limited increase in sac width in these patients could indicate that stenotic conditions are less affected by flexion-induced changes compared to conditions like disc herniation, where the movement may worsen the compression<sup>15,16</sup>.

The correlation between age and the degree of dural sac widening is another important finding. Older patients had a smaller increase in dural sac width during flexion, which may reflect the loss of elasticity and flexibility in the cervical spine structures that comes with aging. The diminished response of the dural sac in older individuals could potentially make them more vulnerable to long-term complications, such as chronic pain or spinal cord compression, as the spinal canal becomes less responsive to dynamic changes<sup>17</sup>.

Moreover, the relationship between neck pain severity (VAS) and dural sac widening indicates that patients with more significant pain may experience more pronounced changes in the dural sac during flexion. This suggests that the extent of mechanical changes in the cervical spine can influence symptom severity. It also highlights the importance of including flexion MRI in the diagnostic workup of patients with unexplained or severe neck pain, particularly when other imaging modalities have failed to fully capture the extent of the spinal pathology<sup>18</sup>.

Interestingly, Spurling's test, a common diagnostic maneuver used to evaluate nerve root compression, was associated with increased dural sac widening in this study. This finding strengthens the utility of flexion MRI in evaluating nerve root impingement, which may be missed by static imaging techniques. The ability of flexion MRI to capture dynamic changes that correlate with clinical signs such as positive Spurling's tests further underscores its potential in guiding clinical decision-making and treatment planning<sup>19</sup>.

Lastly, the study's results suggest that flexion-induced dural sac widening could serve as a useful biomarker for assessing cervical spine pathology, particularly in conditions like disc herniation and radiculopathy. The dynamic nature of spinal changes during flexion provides a more comprehensive understanding of the mechanical

stresses placed on the cervical spine, which is critical for developing more effective treatment strategies. Flexion MRI could potentially aid in the early diagnosis of conditions that are not fully apparent on conventional static imaging, especially in patients with subtle or unclear symptoms<sup>20</sup>.

Overall, the findings from this study contribute to a deeper understanding of the biomechanics of the cervical spine and highlight the importance of dynamic imaging techniques like flexion MRI in evaluating spine-related disorders. Further research, including larger multicenter studies, is needed to validate these findings and explore the role of flexion MRI in clinical practice for diagnosing and managing cervical spine conditions.

### CONCLUSION

This study provides important insights into the dynamic changes of the posterior dural sac during cervical spine flexion using MRI. The widening of the dural sac observed during flexion, particularly at the C5-C6 and C6-C7 levels, correlates significantly with clinical symptoms such as neck pain, radiculopathy, and the presence of cervical disc herniation. These findings emphasize the role of flexion MRI in diagnosing cervical spine disorders that may not be fully captured in static imaging. The correlation between the degree of dural sac widening and the severity of clinical symptoms further suggests that this imaging technique could be crucial in assessing the extent of nerve root compression and guiding treatment decisions.

The study also highlights the variability in spinal response to flexion in different pathologies. While patients with disc herniation showed significant dural sac widening, those with spinal stenosis demonstrated more limited expansion, indicating that stenotic conditions may have less dynamic flexibility during movement. Age-related differences in dural sac response also suggest that older patients may have less flexibility in their cervical spine structures, which could contribute to a higher risk of chronic complications.

Overall, flexion MRI offers a unique and valuable method for assessing cervical spine pathologies, allowing for better diagnosis, more accurate treatment planning, and improved patient outcomes. Further research, including larger cohorts and long-

term follow-up studies, is needed to confirm these findings and explore the potential of flexion MRI in clinical practice for managing cervical spine conditions.

## DECLARATION

### Funding or Financial Support

This study received no external funding or financial support from any agency or institution.

### Conflict of Interest Statement

The authors declare no conflicts of interest related to this study.

## REFERENCES

1. Paladi B, Amin D, Yarlagaadda J, Jadav S, Jabeen SA. Role of Dynamic Magnetic Resonance Imaging in Hirayama Disease, a Rare Motor Neuron Disease. *Cureus*. 2022 Nov 4;14(11):e31099. doi: 10.7759/cureus.31099. PMID: 36475209; PMCID: PMC9719732.
2. Schatlo B, Remonda L, Gruber P, Fandino J, Rohde V, Fathi AR, Berberat J. Cervical Spine Prospective Feasibility Study : Dynamic Flexion-Extension Diffusion-Tensor Weighted Magnetic Resonance Imaging. *Clin Neuroradiol*. 2019 Sep;29(3):523-532. doi: 10.1007/s00062-018-0686-0.
3. Jha SC, Miyazaki M, Tsumura H. Kinetic change of spinal cord compression on flexion-extension magnetic resonance imaging in cervical spine. *Clin Neurol Neurosurg*. 2018 Nov;174:86-91. doi: 10.1016/j.clineuro.2018.09.017.
4. Muhle C, Bischoff L, Weinert D, Lindner V, Falliner A, Maier C, Ahn JM, Heller M, Resnick D. Exacerbated pain in cervical radiculopathy at axial rotation, flexion, extension, and coupled motions of the cervical spine: evaluation by kinematic magnetic resonance imaging. *Invest Radiol*. 1998 May;33(5):279-88. doi: 10.1097/00004424-199805000-00005.
5. Alkoshha HMA, El Adalany MA, Elsobky H, Zidan AS, Sabry A, Awad BI. Flexion/Extension Cervical Magnetic Resonance Imaging: A Potentially Useful Tool for Decision-Making in Patients with Symptomatic Degenerative Cervical Spine. *World Neurosurg*. 2022 Aug;164:e1078-e1086.doi: 10.1016/j.wneu.2022.05.097.
6. Zhang JF, Umenta J, Ali A, Reynolds R, Ham PB, Thomas RD, Piryani R, Izhar M, Wrotniak B, Swayampakula AK. Cervical spine flexion-extension radiography versus magnetic resonance imaging in pediatric patients following blunt traumatic injury. *Trauma Surg Acute Care Open*. 2023 Feb 6;8(1):e001016. doi: 10.1136/tsaco-2022-001016. PMID: 36761391; PMCID: PMC9906377.
7. Provencher M, Habing A, Moore SA, Cook L, Phillips G, da Costa RC. Kinematic Magnetic Resonance Imaging for Evaluation of Disc-Associated Cervical Spondylomyelopathy in Doberman Pinschers. *J Vet Intern Med*. 2016 Jul;30(4):1121-8. doi: 10.1111/jvim.13981.
8. Berberat J, Anderegg L, Gruber P, Hausmann O, Reza Fathi A, Remonda L. A Diagnostic Biomarker for Cervical Myelopathy Based on Dynamic Magnetic Resonance Imaging. *Spine (Phila Pa 1976)*. 2023 Aug 1;48(15):1041-1046. doi: 10.1097/BRS.0000000000004667.
9. Li AY, McCarthy L, Hrabarchuk E, Spiera Z, Marayati NF, Schupper AJ, Hannah TC, Genadry L, Ali M, Quinones A, Kalagara R, Baron R, Sideras P, Naidich TP, Choudhri TF. Novel Grading Scales for Static and Flexion-Extension Magnetic Resonance Imaging in Patients with Cervical Spondylotic Myelopathy. *World Neurosurg*. 2023 May;173:e218-e227. doi: 10.1016/j.wneu.2023.02.034.
10. Health Quality Ontario. Positional Magnetic Resonance Imaging for People With Ehlers-Danlos Syndrome or Suspected Craniovertebral or Cervical Spine Abnormalities: An Evidence-Based Analysis. *Ont Health Technol Assess Ser*. 2015 Jul 1;15(13):1-24
11. Yecies D, Fogel N, Edwards M, Grant G, Yeom KW, Cheshier S. Safety of Dynamic Magnetic Resonance Imaging of the Cervical Spine in Children Performed without Neurosurgical Supervision. *World Neurosurg*. 2018 Aug;116:e1188-e1193.doi: 10.1016/j.wneu.2018.05.210.
12. Vaccaro AR, Madigan L, Schweitzer ME, Flanders AE, Hilibrand AS, Albert TJ. Magnetic resonance imaging analysis of soft tissue disruption after flexion-distraction injuries of the subaxial cervical

- spine. Spine (Phila Pa 1976). 2001 Sep 1;26(17):1866-72. doi: 10.1097/00007632-200109010-00009.
13. Mališ M, Georgievski B, Milić I, Mijatović A, Kovačević V, Lazić D, Kapor S, Marinković S. Kinematic magnetic resonance imaging study of the brain stem and cervical cord by dynamic neck motion. Folia Morphol (Warsz). 2016;75(4):439-447. doi: 10.5603/FM.a2016.0016
14. BenEliyahu DJ. Magnetic resonance imaging and clinical follow-up: study of 27 patients receiving chiropractic care for cervical and lumbar disc herniations. J Manipulative Physiol Ther. 1996 Nov-Dec;19(9):597-606. PMID: 8976479.
15. Kolman SE, Ohara SY, Bhatia A, Feygin T, Colo D, Baldwin KD, Mcdonald-Mcginn D, Spiegel DA. The Clinical Utility of Flexion-extension Cervical Spine MRI in 22q11.2 Deletion Syndrome. J Pediatr Orthop. 2019 Oct;39(9):e674-e679. doi: 10.1097/BPO.0000000000000994.
16. Karhu JO, Parkkola RK, Komu ME, Kormanio MJ, Koskinen SK. Kinematic magnetic resonance imaging of the upper cervical spine using a novel positioning device. Spine (Phila Pa 1976). 1999 Oct 1;24(19):2046-56. doi: 10.1097/00007632-199910010-00015.
17. Sayah A, Farley AD, Munoz EC, Sandhu FA, Berkowitz F. Normal range of clivoaxial angle in adults using flexion and extension cervical magnetic resonance imaging scans. Neuroradiol J. 2021 Aug;34(4):348-354. doi: 10.1177/1971400921998982.
18. Pratali RR, Smith JS, Ancheschi BC, Maranhão DA, Savarese A, Nogueira-Barbosa MH, Herrero CFPS. A Technique for Dynamic Cervical Magnetic Resonance Imaging Applied to Cervical Spondylotic Myelopathy: A Reliability Study. Spine (Phila Pa 1976). 2019 Jan 1;44(1):E26-E32. doi: 10.1097/BRS.0000000000002765.
19. Xu N, Wang S, Yuan H, Liu X, Liu Z. Does Dynamic Supine Magnetic Resonance Imaging Improve the Diagnostic Accuracy of Cervical Spondylotic Myelopathy? A Review of the Current Evidence. World Neurosurg. 2017 Apr;100:474-479. doi: 10.1016/j.wneu.2017.01.047.
20. Provencher M, Habing A, Moore SA, Cook L, Phillips G, da Costa RC. Evaluation of osseous-associated cervical spondylomyelopathy in dogs using kinematic magnetic resonance imaging. Vet Radiol Ultrasound. 2017 Jul;58(4):411-421. doi: 10.1111/vru.12495.