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Description and clinical relevance of the variable conformation of canine spinal arachnoid diverticula

Joao Miguel De Frias[1,2] | **Steven De Decker**[2] | **Alberta De Stefani**[2] | **Francisco Llabres-Diaz**[2]

[1]Hospital for Small Animals, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Midlothian, UK

[2]Department of Clinical Science and Services, Royal Veterinary College, University of London, Hatfield, UK

Correspondence
Joao Miguel De Frias, Hospital for Small Animals, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Midlothian, EH25 9RG, United Kingdom.
Email: joao.frias@ed.ac.uk

Abstract

The conformation of spinal arachnoid diverticula (SAD) and their clinical implications are poorly characterized in dogs. This retrospective cross-sectional study describes different SAD conformations in dogs and aims to identify if there is an association between SAD conformation and clinical features, localization, syringomyelia (SM) presence, concurrent vertebral condition, treatment option, and short as well as long-term outcome. Sixty-two dogs were included (12 cervical and 50 thoracolumbar SAD). All dogs with a cervical SAD had a cranial tethered conformation and were not included in the statistical analysis. Half of the dogs with a thoracolumbar SAD were cranial tethered, and the other half were caudal tethered. SM associated with SAD had a moderate prevalence in the cervical region (58.3%) and a high prevalence in the thoracolumbar region (82%). All dogs with the presence of SM and caudal tethered SAD had a cranial positioned SM, and all dogs with SM and a cranial tethered SAD had a caudal positioned SM. The SM absolute length and SM length/L2 ratio were significantly higher ($P = .018$, respectively) in the caudal tethered SAD compared with the cranial tethered SAD. The short-term outcome was statistically different ($P = .045$) between caudal and cranial tethered thoracolumbar SAD, but not the long-term outcome ($P = .062$). Multivariable logistic regression identified thoracolumbar caudal tethered SAD conformation had a better short-term outcome ($P = 0.017$, OR: 0.043, CI: 0.003–0.563), independently of SM length measurements. SAD conformation in dogs can influence SM formation. A possible link between short-term outcome and SAD conformation was found, but further research is warranted.

KEYWORDS
dog, intradural arachnoid cyst, spinal arachnoid cyst, subarachnoid diverticulum

1 | INTRODUCTION

Spinal arachnoid diverticula (SAD) are characterized by a focal accumulation of cerebrospinal fluid (CSF) in the subarachnoid space, causing spinal cord compression and myelopathic clinical signs.[1–4] SAD can be divided into congenital or acquired, the latter occurring secondary to other disease processes.[1] MRI is considered the diagnostic modality of choice for SAD, with a single-shot turbo spin-echo sequence giving a more than twofold increase in SAD detection compared with a conventional T2-weighted sequence alone.[4] Furthermore, the use of pulse sequences such as three-dimensional (3D) constructive interference in steady state (CISS) has been reported to improve the diagnosis and surgical planning of SAD in dogs.[5] Another case series, looking at the late-onset recurrence of neurological signs after surgery for SAD, has described the direction of tapering of the diverticula, but correlation with clinical signs or outcome was not investigated.[2] There is a lack of description of variations of SAD conformation and their potential clinical implications in dogs. In human medicine, variations in the "dome-capped" conformation of spinal arachnoid cysts, whether cranial or caudal, have been described.[6]

The aims of this study were twofold: (1) to describe variations of SAD conformation in dogs and (2) to identify whether there was an association between SAD conformation and clinical features, localization, syringomyelia (SM) presence, concurrent vertebral condition, treatment option, and short and long-term outcome. It was hypothesized that variations in SAD conformation would be related to the presence of concurrent vertebral diseases at the site of SAD but not to clinical presentation, treatment, or short and long-term outcomes.

2 | MATERIALS AND METHODS

This retrospective cross-sectional study was approved by the Social Science Research Ethical Review Board of the Royal Veterinary College, University of London (URN SR2021-0012).

Electronic medical records from the Royal Veterinary College - Small Animal Referral Hospital were searched between December 2010 and December 2020 using the following terms: spinal arachnoid diverticulum, spinal arachnoid diverticula, and spinal arachnoid cyst. Inclusion criteria included complete medical records and an MRI study available for review, including a Philips' BALT GRAD (thin-slice 3D balanced turbo field gradient echo) sequence. MRI studies included a Philips' BALT GRAD for post-processing multiplanar reconstructions (MPR) to better appreciate SAD conformation and SM localization in relation to the SAD (Figure 1A, B). The decision for inclusion was made by observers with the following expertise: a veterinary neurology resident (J.M.F.), two board-certified veterinary neurologists (S.D.D., A.d.S.), European College of Veterinary Neurology [ECVN]) and a board-certified radiologist (F.L.D.), European College of Veterinary Diagnostic Imaging [ECVDI]). The following information was retrieved from the medical records: age, sex, body weight, breed, duration of clinical signs, and neurological grade. The outcome was recorded if found in the clinical records. Dogs were classified according to brachycephalic conformation, as previously described,[7] as brachycephalic or nonbrachycephalic breeds. Other potential underlying causes of SAD formation (concurrent vertebral conditions in close anatomic relationship with the SAD, inflammatory CNS disease, previous trauma, or surgery) were recorded. Neurological examination findings were recorded and summarized according to the gait abnormality found for each case. Information was retrieved from the medical records by the first author (J.M.F.).

For this study, a 1.5 Tesla MRI Unit was used (Intera, Philips Medical Systems). Sequences included sagittal and transverse plane T2-weighted (T2-W), T1-weighted (T1-W), sagittal short tau inversion recovery (STIR), as well as transverse Philips' BALT GRAD images. These sequences were evaluated with a digital imaging and communications in medicine (DICOM) viewer (Horos, v3.3.6, Horos Project, Nimble Co LLC d/b/a Purview) by a neurology resident in training (J.M.F.) and used to localize the SAD along the vertebral column, determine its position (dorsal or ventral) and to which vertebrae the SAD was associated with (selecting the ones that would be used to plan surgery), to identify the presence of concurrent vertebral conditions (vertebral malformation/intervertebral disc herniation) in close proximity with the SAD (which was defined as the intervertebral discs and vertebrae adjacent to the SAD), and identify the presence of syringomyelia (SM). The absolute length of SM was measured in millimeters (mm), and a ratio was calculated in the thoracolumbar region as SM length/L2 and the cervical region as SM length/C3. Syringomyelia was defined as an intramedullary lesion with the same signal intensity as CSF.[8] Measurements were obtained on sagittal T2-weighted images. Spinal arachnoid diverticula conformation was defined as caudal or cranial tethered, depending on the direction of the "tail." This was defined by the direction in which the CSF dorsal column was reduced in a linear fashion away from the SAD-associated spinal cord compression (Figure 2A, B). Images were reviewed by a veterinary neurology resident (J.M.F.) under the supervision of two board-certified veterinary neurologists (S.D.D., A.d.S., ECVN) and a board-certified radiologist (F.L.D., ECVDI).

Dogs were classified according to the selected treatment options in medical and surgical groups. Medical treatment consisted of controlled exercise with some receiving analgesia and others receiving medications to decrease the amount of CSF production. Surgical treatment consisted of a dorsal laminectomy or a hemilaminectomy combined with a durectomy and dissection of any present subarachnoid adhesions. Information regarding the outcome was obtained for the short term. The results of the re-examinations between 3 and 8 weeks from diagnosis were reviewed. For the long-term outcome, the telephone communication records or re-examination information during a period of 5 to 12 months from diagnosis were reviewed. The outcome was classified as improvement, static, or deterioration. This classification was made by reviewing the records of the clinician's assessment on re-examination.

For statistical analysis, dogs were divided into cervical and thoracolumbar SAD groups. Each group was further divided into caudal and cranial tethered SAD conformations. Statistical analysis was performed using commercially available statistical software (SPSS Statistics for OSx, Version 26, IBM Corp.). Statistical analysis was performed by a veterinary neurology resident (J.M.F.) in consultation with a Senior Lecturer in statistics (Dr. Ruby Chang, Royal Veterinary College). Age, body weight, time from first clinical signs recorded to referral, SM absolute length, and SM length/L2 ratio or SM length/C3 ratio were tested for normality using the Kolmogorov–Smirnov test. Only body weight and SM length/C3 were normally distributed, and data was reported as mean ± standard deviation, and a Student's *T*-test was used to compare body weight between the dogs with caudal

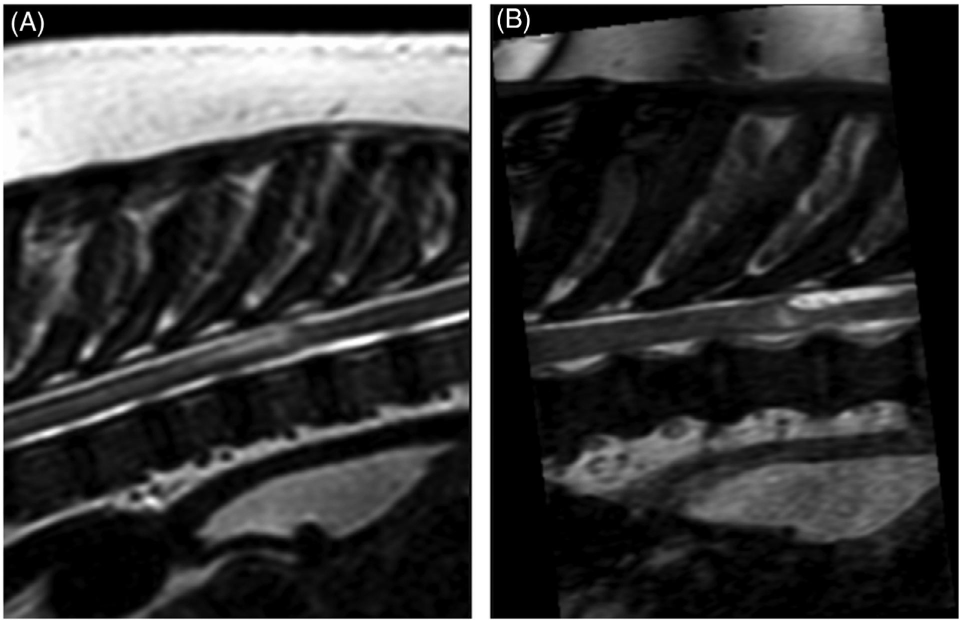

FIGURE 1 MRI images of the thoracolumbar region of a 5-year-old male entire French Bulldog with a caudal tethered dorsal spinal arachnoid diverticulum (SAD) at the level of T8/T9. Sagittal T2-W (A) and comparable sagittal BALT GRAD reconstruction (B). Figures demonstrate how BALT GRAD can be helpful to appreciate the SAD conformation.

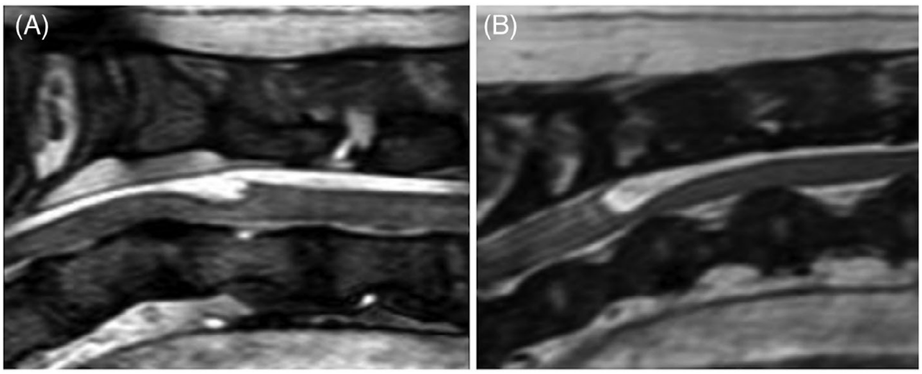

FIGURE 2 MRI images (sagittal BALT GRAD reconstructions) of the thoracolumbar region of the two different spinal arachnoid diverticula (SAD) conformations identified: cranial tethered dorsal SAD at the level of T10/T11 in a 10-year-old female neutered Pug (A) and a caudal tethered dorsal SAD at the level of T11/T12 in an 8-year-old male neutered Staffordshire Bull Terrier (B).

and cranial tethered thoracolumbar SAD conformation. For age, time to referral, SM absolute length, and SM length/L2 ratio data were reported as median, minimum, and maximum values, and a Mann–Whitney *U* test was used to compare the dogs with caudal and cranial tethered thoracolumbar SAD. The proportion of each sex, brachycephalic conformation, SAD localization, SM presence, neurological examination findings, treatment option, presence of concurrent vertebral conditions, and short and long-term outcomes were compared between the two groups using a Fisher's exact test. Then, a univariate and multivariable logistic regression (including odds ratio and 95% confidence interval) was used to compare caudal and cranial tethered conformation for the statistically significant differences found in the descriptive statistical analysis. Statistical significance was defined as $P < .05$.

3 | RESULTS

Of the 87 dogs with SAD found in the electronic records, 62 met the inclusion criteria. The MRI studies of the 25 excluded dogs did not include BALT GRAD sequences. Twelve dogs had a cervical SAD (19.4%), and 50 dogs had a thoracolumbar SAD (80.6%).

3.1 | Cervical spinal arachnoid diverticula

Information regarding the group with cervical SAD (C-SAD) can be found in Table 1. All 12 dogs had a cranial tethered C-SAD. As no differences in C-SAD conformation were detected in this group, these dogs were excluded from the statistical analysis. Only 1/12 (8.4%)

TABLE 1 Comparison of the age, body weight, sex, breed, duration of clinical signs, neurological grade, syringomyelia (SM) presence, and spinal arachnoid diverticula (SAD) localization/position between group of dogs with cervical and thoracolumbar SAD.

	Cervical spinal arachnoid diverticula (*n* = 12)	Thoracolumbar spinal arachnoid diverticula (*n* = 50)
Age	31.4 months (3–107 months)	90.5 months (7–164 months)
Body weight	21.3 kg (±14.9)	11.6 kg (±5.2)
Sex	1 female entire – 8.4% 11 males – 91.6% (1 neutered)	16 females – 36.4% (6 neutered) 34 males – 68% (16 neutered)
Breed	Pug (*n* = 3) Rottweiler (*n* = 2) Miniature Dachshund (*n* = 1) Shih Tzu (*n* = 1) Bull Mastiff (*n* = 1) French Bulldog (*n* = 1) Labrador (*n* = 1) American Bulldog (*n* = 1) Crossbreed (*n* = 1)	Pug (*n* = 19) French Bulldog (*n* = 14) Staffordshire Bull Terrier (*n* = 6) Crossbreed (*n* = 3) Shih Tzu (*n* = 2) Bichon Frise (*n* = 1) English Bulldog (*n* = 1) Cocker Spaniel (*n* = 1) Jack Russel Terrier (*n* = 1) Miniature Schnauzer (*n* = 1) Toy Poodle (*n* = 1)
Duration of clinical signs	10.2 weeks (4.4–449.3 weeks)	13.2 weeks (0.14–113 weeks)
Neurological examination—gait assessment	12 (100%) ambulatory tetraparetic	48 (96%) ambulatory paraparetic 1 (2%) nonambulatory paraparetic 1 (2%) was normal
SM presence	7 dogs (58.3%)	41 dogs (82%)
SAD localisation	Dorsal C2/C3 – 10 (83.2%) Dorsal C3/C4 – 1 (8.4%) Ventral C6/C7 – 1 (8.4%)	Dorsal T11/T12 – 12 (24%) Dorsal T12/T13 – 7 (14%) Dorsal T13/L1 – 6 (12%) Dorsal T8/T9 – 5 (10%) Dorsal T10/T11 – 5 (10%) Dorsal T9/T10 – 5 (10%) Ventral T9/T10 – 2 (4%) Dorsal T7/T8 – 2 (4%) Dorsal T5/T6 – 2 (4%) Dorsal T3/T4 – 1 (2%) Dorsal T4/T5 – 1 (2%) Dorsal T6/T7 – 1 (2%) Ventral T8/T9 – 1 (2%)

dogs had a ventral SAD location, while the others were all dorsal. An SM associated with C-SAD was present in 7/12 cases (58.3%), and they were all caudal to the C-SAD location. The SM absolute median length was 22.1 mm (7.26–57.5 mm) and the mean SM length/C3 ratio was 1.18 ± 0.83. Four dogs (33.3%) were treated medically, with three dogs receiving nonsteroidal anti-inflammatory drugs (meloxicam or carprofen) and one dog receiving corticosteroids (prednisolone). Eight dogs (66.7%) underwent surgery. Short-term outcomes were not available for the dogs treated medically. For short-term outcomes in the surgery group, 7 (87.5%) dogs had improved at the re-examination visit, ranging from 4 to 8 weeks after surgery. One dog (12.5%) had deteriorated after surgery, becoming nonambulatory, and given failure to improve over a period of 7 weeks, the owners elected for euthanasia. Regarding longer-term outcomes within the remaining surgical group cases, one continued to improve with an acute deterioration 30 months after surgery, and another case had improved 10 months after surgery, despite a mild deterioration 4 months postsurgery.

3.2 | Thoracolumbar spinal arachnoid diverticula

Information regarding the group with thoracolumbar SAD (TL-SAD) can be found in Table 1. Regarding the SAD conformation, there were 25 of 50 (50%) caudal tethered TL-SAD and 25 of 50 (50%) cranial tethered TL-SAD. An SM associated with TL-SAD was present in 41 of 50 cases (82%), and they were caudal to the cranial tethered TL-SAD and cranial to the caudal tethered TL-SAD. The median SM absolute length was 18.3 mm (6.2–82.6 mm), and the median SM length/L2 ratio was 1.3 (0.3–6.2). The presence of concurrent vertebral condition in close proximity with the SAD was found in 32 of 50 (64%) dogs. The cranial tethered group included eight vertebral body malformations (i.e., hemivertebra), six intervertebral disc herniation (IVDH), and two IVDH associated with caudal articular process (CAP) dysplasia. The caudal tethered group included seven IVDH, four vertebral body malformations, and five IVDH associated with CAP dysplasia.

Twenty-eight (56%) dogs were treated medically and 22 (44%) were treated surgically. Medical treatment consisted of corticosteroids

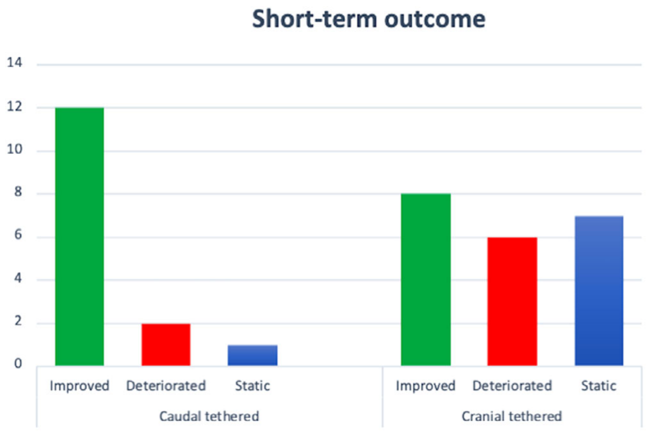

FIGURE 3 Bar chart showing difference between short-term outcomes between caudal and cranial TL-SAD dogs (absolute number of dogs for each group). Note that other factors possibly contributing to the difference in outcome are not included in this chart.

(prednisolone) in 13 (46.4%) dogs, with one dog additionally receiving omeprazole; nonsteroidal anti-inflammatory drugs were administered (meloxicam or carprofen) in 2 (7.1%) dogs, and gabapentin in 1 (3.7%) dog. Twelve (42.8%) dogs did not receive any medications. A combination of controlled exercise and physiotherapy was recommended for all dogs undergoing medical treatment. Short-term outcomes were available for 16 dogs in the medical treatment group; 5 (31.3%) had improved, 5 (31.3%) had deteriorated, and 6 (37.4%) remained static at the time of re-examination. Short-term outcomes were available for 20 dogs in the surgery group; 15 (75%) had improved, 3 (15%) had deteriorated, and 2 (10%) remained static at the time of re-examination. Long-term outcomes were available for 7 dogs in the medical treatment group; 1 (14.2%) had improved, 3 (42.9%) had deteriorated, and 3 (42.9%) remained static, ranging from 6 to 24 months after diagnosis. Long-term outcomes were available for 6 dogs in the surgery group; 1 (16.7%) had a sustained improvement, and 5 (83.3%) deteriorated, ranging from 5 to 37 months after surgery.

3.3 | Comparison of caudal tethered vs. cranial tethered TL-SAD dogs

Median SM absolute length was significantly longer in dogs with caudal tethered TL-SAD (21.1 vs. 13.5 mm; $P = .018$) compared with dogs with cranial tethered TL-SAD. Caudal tethered TL-SAD dogs had a significantly increased SM length/L2 ratio median (1.4 vs. 1.1; $P = .018$), compared with the cranial tethered TL-SAD. Furthermore, a statistical difference in the short-term outcome ($P = .045$) between the caudal and cranial tethered TL-SAD was found (Figure 3) with better short-term outcomes in the caudal tethered group. No significant differences between the caudal and cranial tethered TL-SAD were found for any of the other variables (Table 2).

Univariate logistic regression revealed that caudal tethered TL-SAD had an improved short-term outcome ($P = .017$, OR: 0.154, CI: 0.033–0.719) compared with a cranial tethered TL-SAD. Multivariate logistic regression demonstrated that caudal tethered TL-SAD could predict an improved short-term outcome ($P = .017$, OR: 0.043, CI: 0.003–0.563), independently of the SM length/L2 ratio or SM length median.

4 | DISCUSSION

This study provides insight into the SAD conformation in dogs and its potential clinical implications. The pathophysiology of SAD is not completely understood.[1] A possible explanation is a CSF-flow disturbance resulting in a functional one-way valve that allows CSF to flow into a pocket but not be released in response to changes in CSF pressure.[1,2] However, a novel explanation of thoracic spinal arachnoid cysts in humans may also explain TL-SAD in dogs, with the CSF flow dynamics within the subarachnoid space and the *septum posticum* playing a role.[6,9] The *septum posticum* is a thick membrane connecting the pia to the arachnoid membrane that is thought to provide additional dorsal stability to the spinal cord.[9] This theory hypothesizes that fast CSF velocities can cause a “dissection” in the dorsal subarachnoid space where the *septum posticum* is, leading to the formation of a cyst with a ball-valve inlet.[6] The difference in CSF velocities within the spinal arachnoid cyst would define the direction of the polar cap.[6] The *septum posticum* is mentioned and described in a recent canine veterinary neuroanatomy book.[10] In dogs, it has been identified in the cervical and thoracolumbar regions.[10] It is plausible that an underlying pathology could cause injury and thickening of these leptomeningeal trabeculae.[10] This could lead to fibrous tissue formation, leading to the formation of SAD, and even contribute to the tethering direction. However, this ligament does not explain the development of arachnoid diverticula in other locations, such as in the ventral region or intracranial formation, and the absence of different conformations in the cervical region.[10,11] In veterinary medicine, spinal arachnoid diverticula are not considered true cysts as they have no epithelial cell lining and appear to communicate freely with the subarachnoid space.[12] An attempt has been made to classify SAD in dogs, like in human medicine, according to their localization: type I (extradural meningeal cysts without involvement of the nerve root), type II (extradural meningeal cysts with involvement of the nerve root), and type III (intradural meningeal cysts).[6,12] However, only the intradural spinal arachnoid cysts (type III) show some similarities to what is found in dogs.[6,12] Moreover, a new updated human classification has emerged, highlighting the misleading “cyst” terminology and focusing on the etiology of the intradural arachnoid cyst, dividing them into primary (i.e., idiopathic) and secondary (i.e., acquired following vertebral disease).[13,14] In veterinary medicine, an attempt has also been made to classify SAD as primary and secondary.[1,3,15] Further studies focusing on the anatomical variations in these cases are warranted to clarify the role of the *septum posticum* in the formation of SAD, the contribution to the conformation of SAD, and possible underlying aetiologies.

A recent study found a 50% prevalence of SM in association with a diagnosis of SAD in dogs[16]; however, in humans, SM formation associated with spinal arachnoid cysts seems to be less prevalent (30%).[6]

TABLE 2 Comparison of the age, body weight, sex, brachycephalic conformation, duration of clinical signs, neurological grade, syringomyelia (SM) presence, length and ratio, and spinal arachnoid diverticula (SAD) localization/position, treatment option, and short-term as well as long-term outcome between group of dogs with caudal and cranial thoracolumbar SAD.

	Caudal tethered TL-SAD	Cranial tethered TL-SAD	*P*-value
Age (*n* = 50)	97 months (11—123 months)	71 months (7–164 months)	.258
Body weight (*n* = 50)	11.5 kg (±4.4)	11.9 kg (±6.1)	.819
Sex (*n* = 50)	9 Females – 36% 16 Males – 64%	7 Females – 28% 18 Males – 72%	.762
Brachycephalic conformation (*n* = 50)	Yes – 20 (80%) No – 5 (20%)	Yes – 16 (64%) No – 9 (36%)	.345
Duration of clinical signs (*n* = 50)	13.4 weeks (0.14 – 113 weeks)	13 weeks (0.14 – 34 weeks)	.572
Neurological examination—gait assessment (*n* = 50)	24 (96%) Ambulatory paraparetic 1 (4%) Nonambulatory paraparetic	24 (96%) Ambulatory paraparetic 1 (4%) Normal	1
SAD localisation (*n* = 50)	T11/T12 – 4 (16%) T12/T13 – 5 (20%) T13/L1 – 3 (12%) T8/T9 – 1 (4%) T10/T11 – 4 (16%) T9/T10 – 4 (16%) T5/T6 – 2 (8%) T4/T5 – 1 (4%) T6/T7 – 1 (4%)	T11/T12 – 8 (32%) T12/T13 – 2 (8%) T13/L1 – 3 (12%) T8/T9 – 5 (20%) T3/T4 – 1 (4%) T9/T10 – 3 (12%) T7/T8 – 2 (8%) T10/T11 – 1 (4%)	.086
SAD position (*n* = 50)	Dorsal – 24 (96%) Ventral – 1 (4%)	Dorsal – 23 (92%) Ventral – 2 (8%)	1
Concurrent vertebral condition (*n* = 50)	Yes – 16 (64%) No – 9 (36%)	Yes – 16 (64%) No – 9 (36%)	1
SM presence (*n* = 50)	Yes – 22 (88%) No – 3 (12%)	Yes – 19 (76%) No – 6 (24%)	.463
SM absolute length (*n* = 41)	21.05 mm (6.2–82.8 mm)	13.5 mm (8.6–60.9 mm)	**.018***
SM length/L2 ratio (*n* = 41)	1.44 (0.33–6.23)	1.09 (0.64–3.83)	**.018***
Treatment (*n* = 50)	Medical – 13 (52%) Surgical – 12 (48%)	Medical – 15 (60%) Surgical – 10 (40%)	.776
Short-term outcome (*n* = 36)	Improved – 12 (80%) Deteriorated – 2 (13.3%) Static – 1 (6.7%)	Improved – 8 (38.1%) Deteriorated – 6 (28.6%) Static – 7 (33.3%)	**.045***
Long-term outcome (*n* = 13)	Improved – 1 (16.7%) Deteriorated – 5 (83.3%)	Improved – 1 (14.2%) Deteriorated – 3 (42.9%) Static – 3 (42.9%)	.062

In this study population, an SM associated with SAD had a moderate prevalence in the cervical region (58.3%) and a higher prevalence in the thoracolumbar region (82%). The reason for the discrepancy in prevalence from previous publications is unknown. However, it may be related to different definitions of syringomyelia (here, choosing to use previously published criteria for syringomyelia diagnosis with MRI[8]) or the differences in MRI scanners and protocols (including the use of a BALTGRAD sequence) in this study. Regarding the SM position in relation to SAD, it has been suggested that SM would be more often cranial to a thoracolumbar SAD in dogs.[16] However, dogs in this study had the position of the syrinx defined by the SAD conformation, being opposed to the direction of the SAD "tail." This agrees with human studies, where the location of the dome-capped aspect of the cyst would define whether the SM was above or below the spinal arachnoid cyst.[6] No relationship between syrinx location and clinical presentation or size of the spinal arachnoid cyst could be established in these studies.[6,17] Furthermore, it has been hypothesized that the variations in the syrinx position would be related to the direction of resistance to CSF flow.[17]

In the C-SAD group, Rottweilers and Pugs were the most common breeds (5/12 dogs), which is in accordance with previous reports.[12,18,19] All dogs with a cervical SAD had a cranial tethered conformation. A different etiology for C-SAD compared with TL-SAD is possible, and further investigations are warranted.

A different conformation for the TL-SAD was noticed, with half of the dogs having a caudal tethered and the other half a cranial tethered SAD. Variations in SAD conformation were related to SM localization. However, the presence of a vertebral malformation or intervertebral disc disease at the site of SAD was not different between groups. In this study, a large proportion of cases (64%) were identified with a vertebral condition in close relationship with TL-SAD. This is not surprising considering that 33 (66%) of the 50 dogs with TL-SAD were either Pugs or French Bulldogs. Equally, in previous studies, the presence of neurologic disease diagnosed at the same or an adjacent site of the SAD has been noticed, particularly amongst Pugs (33.3% and 59%)[3,20] and French Bulldogs (61.5% and 64%).[3,21] Additionally, a possible relationship between the presence of CAP dysplasia leading to chronic instability or meningeal irritation and the formation of SAD in Pugs has been proposed.[22,23] In this study, the neurological diseases identified in close proximity to SAD between caudal and cranial tethered dogs were heterogeneous. This made it difficult to conclude a clear relationship between the presence of a specific vertebral condition and the conformation of SAD. Recently, it has been shown that MRI has a fair sensitivity for the identification of CAP dysplasia, particularly if using three-dimensionally reconstructable volumetric interpolated breath-hold examination (VIBE) sequences compared with traditional T2-W.[24] Although CAP dysplasia was identified in some dogs in this study, given that CT is the gold standard for diagnosis of this condition and the VIBE sequence was not performed, this could have been missed.

Furthermore, no differences in clinical presentation and choice of recommended therapy were found with a different SAD conformation. However, caudal tethered TL-SAD dogs had more extensive SM, and this group also showed improved short-term outcomes. This latter finding was independent of the SM length in a multivariable analysis. Although this result could suggest that SAD conformation has clinically relevant implications, these results need to be interpreted with caution as a short-term outcome for 14 of 50 dogs with TL-SAD was unknown. Moreover, the same link between SAD conformation and long-term outcome was not found, although only information about 13 dogs was available. The largest canine SAD study to date indicates that surgical therapy might be associated with clinical improvement compared with medical treatment.[25] Although information regarding short-term and long-term outcomes was collected, a distinction between these two outcome time periods was not made in that study.[25] Interestingly, when these time periods were separated, a poor long-term outcome (12 months or longer) for SAD in the Pug breed was established, with 86% of dogs showing deterioration and half of those undergoing repeat MRI showing a recurrent SAD or new SAD.[20] Therefore, the role of SAD conformation for the long-term outcome and possible implications depending on different treatments remains difficult to characterize. Further research would be necessary to investigate the association between long-term outcomes and variations in SAD conformation.

This study has several limitations. First, the restraints related to the nature of a retrospective single-center study. Although a limited number of cases were included, this can potentially be explained by the strict inclusion criteria for all cases that need to include a BALT GRAD sequence. Nowadays, this sequence is routinely performed in the authors' institution for dogs with SAD, which therefore reduces the risk of a selection bias. There were a substantial number of cases with TL-SAD for which short-term (14/50) and long-term outcome information (37/50) was not available. This is an important limitation but linked again to the retrospective nature of the study and the difficulty in obtaining reliable and comparable follow-up information on cases with chronic myelopathic clinical signs.

This is the first study to describe in detail the different SAD conformations in dogs. While dogs with C-SAD all showed a cranial tethered SAD conformation, dogs with TL-SAD could show a caudal or cranial tethered SAD conformation. A high prevalence of SM associated with SAD was found, with 82% cases in the TL-SAD group and 58% cases in the C-SAD group. Furthermore, the SM position was related to SAD conformation, being opposite to the tail of the SAD. Caudal tethered TL-SAD dogs had significantly longer SM than the cranial tethered TL-SAD. A possible link between an improved short-term outcome and caudal tethered TL-SAD conformation was found, but the same was not found for the long-term outcome. Further research is warranted to clarify this association further.

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LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and design: De Frias, Llabres-Diaz
(b) Acquisition of data: De Frias
(c) Analysis and interpretation of data: De Frias, De Decker, De Stefani, Llabres-Diaz

Category 2

(a) Drafting the article: De Frias, De Decker, De Stefani, Llabres-Diaz
(b) Revising article for intellectual content: De Frias, De Decker, De Stefani, Llabres-Diaz

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(a) Final approval of the completed article: De Frias, De Decker, De Stefani, Llabres-Diaz

Category 4

(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: De Frias, De Decker, De Stefani, Llabres-Diaz

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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REPORTING CHECKLIST DISCLOSURE

The authors declare no reporting checklist use.

DATA ACCESSIBILITY STATEMENT

The data used in this study are available from the corresponding author upon reasonable request.

ORCID

Joao Miguel De Frias https://orcid.org/0000-0001-5508-7666
Steven De Decker https://orcid.org/0000-0002-2505-2152
Francisco Llabres-Diaz https://orcid.org/0000-0003-3966-1642

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