Magnetic resonance imaging features of canine haemangiosarcoma affecting the central nervous system

Claudia Mallol[1], Rodrigo Gutierrez-Quintana[2]*, Gawain Hammond[2], Daniela Schweizer-Gorgas[3], Steven De Decker[4], Rosa Novellas[1,5], Yvonne Espada[1,5], Anna Oevermann[6], Maria Ortega[7], Andrew Parry[8], Ana Maria Coelho[9], Rita Gonçalves[10], Catherine Stalin[2], Josep Brocal[11]

[1]Diagnostic Imaging Service of the Fundació Hospital Clínic Veterinari, Universitat Autònoma de Barcelona, Cerdanyola del Vallés, Spain

[2]*College of Medical, Veterinary and Life Sciences, University of Glasgow, Bearsden Road, Glasgow, UK. Email: Rodrigo.GutierrezQuintana@glasgow.ac.uk

[3]Division of Clinical Radiology, Department of Clinical Veterinary Medicine, Vetsuisse-Faculty, University of Bern, Bern, Switzerland

[4]Department of Veterinary Clinical Science and Services, The Royal Veterinary College, University of London, Hawkshead Lane, North Mymms, Hertfordshire, UK

[5]Department of Animal Medicine and Surgery, Universitat Autònoma de Barcelona, Cerdanyola del Vallés, Spain

[6]Division of Neurological Sciences, Department of Clinical Research and Veterinary Public Health, Vetsuisse-Faculty, University of Bern, Bern, Switzerland

[7]Centro Clínico Veterinario Indautxu, San Mames Zumarkalea 38, Bilbao, Bizkaia, Spain

[8]Willows Referral Service, Highlands Road, Shirley, Solihull, West Midlands, B90 4NH, UK

[9]WEAR REFERRALS Veterinary Hospital, Bradbury, Stockton-on-Tees, UK

[10]Department of Small Animal Clinical Science, Small Animal Teaching Hospital, University of Liverpool, Leahurst, Chester High Road, Neston, UK

[11]Anderson Moores Veterinary Specialists, Bunstead Barns, Poles Lane, Hursley, Winchester, Hampshire SO21 2LL, UK.

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Abbreviations: CNS, central nervous system; CSF, cerebrospinal fluid

ABSTRACT

Haemangiosarcoma is the most common metastatic tumour involving the brain in dogs but a detailed description of its MRI features is lacking. The objective of this multicentre, retrospective study was to describe MRI characteristics of canine haemangiosarcoma affecting the central nervous system (CNS). Medical records of seven referral institutions were retrospectively reviewed. Dogs were included if they had an histopathologically confirmed diagnosis of haemangiosarcoma affecting the CNS and undergone an MRI of the brain and/or vertebral column. Lesions were independently evaluated by two observers. Twenty dogs met the inclusion criteria and one dog had both intracranial and intramedullary haemangiosarcoma. Consistent MRI features included heterogeneous (17/21) lesions in all sequences with mainly mixed signal intensity (12/21), presence of susceptibility artefact on T2*w (15/16), associated moderate to severe perilesional oedema (21/21) and moderate to strong (20/21) heterogeneous (14/21) or ring-like (6/21) contrast enhancement. Intracranial haemangiosarcoma was frequently multiple and intra-axial, affecting consistently the telencephalon and no differences in MRI features were found between primary and metastatic haemangiosarcoma. This is the first MRI description of primary intracranial haemangiosarcoma and primary intracranial epithelioid haemangiosarcoma. Vertebral haemangiosarcomas were segmental poorly marginated polyostotic and highly aggressive lesions invading the thoracic vertebral canal and paraspinal tissues. Epidural haemangiosarcomas were single and well-marginated lesions in the thoracolumbar and/or lumbar region. Intramedullary haemangiosarcomas were cervical, metastatic in origin, and frequently (3/4) accompanied by intracranial lesions. These described MRI features will aid early identification of haemangiosarcoma guiding subsequent diagnostics and therapeutics.

INTRODUCTION

Haemangiosarcoma is a highly malignant tumour derived from the endothelial cells.[1] It is common in dogs and comprises up to 5-7% of non-cutaneous primary malignant neoplasms and 12-21% of all mesenchymal neoplasms.[2,3] Typical primary sites in dogs include the spleen, liver and right atrium, but it can arise from any vascularised tissue.[4,5] Visceral haemangiosarcoma is characterized by its aggressive behaviour with rapid and widespread metastasis to the lungs, liver, peritoneum, and central nervous system (CNS) through the haematogenous route.[4]

At the time of presentation and based on a post-mortem study, 80% of dogs have metastases to distant organs and, in 14.2% of the cases, metastasis affects the brain.[4,6] In fact, hemangiosarcoma is the most common metastatic tumour involving the brain in dogs.[6,1,7–11] Primary haemangiosarcoma of the CNS is rare in dogs[4,12] and only approximately 30 cases have been reported in people.[13] No imaging description of primary intracranial haemangiosarcoma has been reported in dogs and a detailed magnetic resonance imaging (MRI) description of the metastatic form is only available for one dog.[10]

Spinal haemangiosarcoma has been reported mainly as extradural, arising from vertebrae[14–19] but also as primary epidural,[20–22] multicompartmental (extradural invading the leptomeninges),[19] metastatic intramedullary,[23–26] and intradural extramedullary.[27] It is estimated to comprise 2-3% of all primary bone tumours.[17] Descriptions of the MRI characteristics of the tumour affecting the vertebrae,[15,19] epidural space[20,22] and spinal cord[24,25,28] are sparse, with two, two and four cases respectively.

The aim of this study was to describe the MRI features of histopathologically confirmed canine haemangiosarcoma affecting the CNS.

MATERIAL AND METHODS

Selection and description of subjects

This was a multicentre, retrospective, descriptive study approved by the Research Ethics Committee of the School of Veterinary Medicine of the University of Glasgow (ref. EA46/20). Medical records of seven referral institutions were retrospectively reviewed to identify MRI studies of dogs with a diagnosis of haemangiosarcoma affecting the CNS confirmed by ECVP-certified veterinary pathologists. Dogs with confirmed haemangiosarcoma in distant organs, but without histopathological confirmation of the tumour affecting the CNS were excluded. Dogs were included if the MRI study included at least T2-weighted (T2w), fluid-attenuated inversion recovery (FLAIR), T1-weighted (T1w), T2*-weighted gradient recall eco (T2*w), and T1w post contrast images of the brain and/or at least T1w, T2w and T1w post contrast images of the vertebral column in any plane.

Data recording and analysis

A third-year ECVDI resident (C.M.) and an ECVN-certified veterinary neurologist (J.B.) reviewed medical records, and retrieved the following information: signalment (age, breed, sex), presenting complaint, general physical and neurological examination findings at presentation, neurolocalisation, laboratory findings, results of other imaging investigations (ultrasound, radiography, CT), histopathology results, and outcome. Median and range were used for descriptive statistics as most variables showed skewed distributions.

MRI characteristics

Magnetic resonance images were reviewed by an ECVDI-certified veterinary radiologist (GH) and an ECVN-certified veterinary neurologist (RG). Images were displayed using an open-source Workstation DICOM viewer (Osirix Imaging Sofware, version 3.9.2, Pixmeo, Geneva,

Switzerland). The evaluation of MRI studies included the CNS and all surrounding structures of the imaged area. Imaging characteristics of the lesion(s) were recorded based on a consensus opinion. Observers were asked to record the localisation of the lesion along the neuroaxis as precisely as possible and to record the axial origin as extra-axial or intra-axial (for intracranial lesions) and extradural, intradural-extramedullary, or intramedullary (for lesions affecting the vertebral column and/or spinal cord). The term intramedullary was only used to describe spinal cord lesions. Observers were also asked to specify if the lesions affected mainly grey matter, white matter or the transition zone between them. For extradural lesions, observers were specifically asked to record if the lesion was confined to the epidural space or if it involved the vertebrae and/or paraspinal soft tissues. They were also asked to record if the lesion was segmental (single abnormality even if spanning multiple vertebrae) or multifocal (separate abnormalities) and if it was monostotic (involving one vertebra) or polyostotic (involving multiple vertebrae). The number of lesions was recorded as single or multiple. In dogs with multiple lesions, observers were asked to describe the predominant pattern. The size of the biggest lesion was assessed measuring the maximum dimension in any direction on T2w images. This was done considering findings on other sequences, especially FLAIR, to avoid measuring perilesional oedema. For extradural lesions, size was measured as the length of the vertebral bodies along which the lesion extended. The signal intensity was recorded as hyperintense, hypointense, isointense, or mixed intensity compared to grey matter or to the adjacent tissue for extradural lesions on T2w, FLAIR and T1w images, and signal homogeneity of the lesion was categorized as homogeneous or heterogeneous. All mixed intensity lesions were considered heterogeneous. The presence of susceptibility artefact on T2*w images was recorded. None, partial, or complete presence of hypointense peripheral rim on T2w and presence of non-haemorrhagic areas (lacking a susceptibility artefact) within the lesion were also recorded. The lesion was categorized as well or poorly marginated. Presence of

perilesional oedema was evaluated subjectively and classified as absent, mild, moderate, or severe. Mass effect was recorded in intracranial cases as absent or present and, when present, the type of mass effect (ventricular distortion, midline shift, foramen magnum and transtentorial herniation) was recorded. Presence or absence and subjective degree of spinal cord compression (none, mild, moderate, severe) was recorded in spinal cases. Contrast enhancement was classified as none, mild, moderate, or strong and the pattern of enhancement as homogeneous, heterogeneous, or ring-like.

RESULTS

Subjects

Twenty dogs met the inclusion criteria. Clinical signs, signalment, neurolocalisation, and MRI equipment details are summarized in Appendix 1.

The median duration of clinical signs before referral in dogs with intracranial haemangiosarcoma was 13 days (range, 2-120 days). The median duration of clinical signs before referral in dogs with spinal haemangiosarcoma was 7 days (range, 1-90 days).

MRI characteristics

Eight dogs underwent MRI of the brain only, one of the brain and vertebral column, and eleven of the vertebral column only.

Intracranial lesions

MRI characteristics of intracranial lesions are summarized in Table 1.

All intracranial lesions were intra-axial. Most lesions were multiple (8/9) and all dogs had lesions affecting the telencephalon. The majority of lesions were heterogeneous in all

sequences (8/9), having a mixed signal intensity on T2w, FLAIR and T1w images, being either predominantly hypointense or hyperintense on T2w and FLAIR and predominantly isointense or hypointense on T1w (Figures 1, 2). Most lesions (8/9) showed a susceptibility artefact on T2*w images, matching the location of a lesion observed on T2w images. Small susceptibility artefacts (microhaemorrhages) only visible on T2*w images were present in five dogs (5/9). Multiple stages of the haemorrhage were recognized within most of the lesions (8/9). Most lesions were well-marginated (8/9) and were surrounded by severe perilesional oedema in all dogs (Figures 1B, 2A). Mass effect was present in most dogs (7/9). In two dogs, invasion of the adjacent lateral ventricle was suspected, where loss of suppression of the cerebrospinal fluid (CSF) signal was noted on FLAIR (Figure 1F). Contrast enhancement was present in all dogs (and most lesions) and was predominantly moderate and heterogeneous (6/9) (Figure 1E, 2E). Four dogs (4/9) had at least one lesion with ring-like contrast enhancement (Figure 3). Meningeal enhancement was present in four dogs (4/9) (Figure 3). Multifocal lesions in the masticatory muscles were present in three dogs (3/9).

Spinal lesions

MRI characteristics of spinal lesions are summarized in Table 2.

Spinal lesions were extradural in seven dogs (7/12) and intramedullary in five (5/12). All extradural lesions were single, four (4/7) arising from thoracic vertebrae, and three (3/7) confined to the thoracolumbar (2/7) or lumbar (1/7) epidural space. All vertebral lesions were segmental (4/4) and most were polyostotic (3/4). Invasion of the adjacent paraspinal soft tissues and vertebral canal was noted in all of them (Figure 4). Most intramedullary lesions (4/5) were single, and all were located in the cervical spinal cord.

All lesions were heterogeneous on T2w images, with a mixed signal intensity in eight (8/12), and hyperintense in four dogs (4/12). Most lesions (10/12) were heterogeneous on T1w images,

isointense in seven (7/12), mixed signal intensity in four (4/12) and hyperintense in one dog (1/12) (Figure 2, 4 and 5). A susceptibility artefact was present in all dogs where T2*w images were available (Figure 5E). Five (5/7) dogs had non-haemorrhagic areas within the lesions.

All vertebral lesions (4/4) were poorly-marginated and all epidural lesions (3/3) were well-marginated. All extradural lesions showed moderate perilesional oedema and caused moderate to severe spinal cord compression. Moderate to severe perilesional oedema was noted in all intramedullary lesions (Figure 2D).

Contrast enhancement was present in all lesions, being in most dogs (11/12) moderate to strong and heterogeneous (10/12). Two (2/5) intramedullary lesions showed ring-like contrast enhancement (Figure 2E).

Additional imaging findings

Fourteen dogs had other imaging investigations. All dogs had thoracic radiographs or CT, with no evidence of lung metastasis in 11 dogs and with multiple pulmonary soft tissue nodules compatible with metastasis in three. In one dog, CT revealed numerous soft tissue nodules in the left brachial plexus and left semimembranosus and gracillis muscles, histopathologically confirmed as metastatic haemangiosarcoma. Eleven dogs had abdominal imaging. Seven dogs had abdominal ultrasound, which was unremarkable or revealed minor unrelated changes in six dogs, and a large splenic mass histopathologically confirmed as haemangiosarcoma in one. Two dogs had abdominal CT, which revealed a splenic mass in one, and multiple peritoneal nodules in the other, both histopathologically confirmed as haemangiosarcomas. Two dogs had unremarkable abdominal radiographs. One dog had an unremarkable echocardiogram.

Outcome and post-mortem examination

Eleven dogs were euthanized during anaesthesia and eight dogs were euthanized within two weeks of diagnosis due to marked deterioration. One dog was lost from follow-up.

A full body post-mortem examination was performed in nine dogs (9/20), five intracranial haemangiosarcomas and four intramedullary spinal haemangiosarcomas. In the remaining 11 dogs, the post-mortem was limited to the CNS in eight, and the diagnosis was confirmed by biopsy in three dogs. On post-mortem examination, haemangiosarcoma was found in other organs in six (6/9) dogs. Affected organs were the lungs (5/9), heart (4/9), spleen (4/9), liver (3/9), kidneys (3/9), pituitary gland (1/9), adrenal glands (2/9), muscles (1/9), pancreas (1/9), gastrointestinal tract (1/9), omentum (1/9), and urinary bladder (1/9). In the remaining three dogs with full body post-mortem examination, no evidence of haemangiosarcoma was found outside the CNS (three intracranial and one vertebral haemangiosarcoma). Immunohistochemistry was performed in three cases (including two primary intracranial, one of which was the epithelioid form, and one epidural) using CD3 or Factor 8 markers, confirming the endothelial cell origin of the neoplasia.

DISCUSSION

This study describes the MRI characteristics of dogs with primary and metastatic haemangiosarcoma affecting the CNS. Metastatic intracranial haemangiosarcoma has been scarcely described as multiple (rarely single) and mixed intensity masses in T2w and T1w, with associated mass effect, marked perilesional oedema and variable and often peripheral contrast enhancement,[10] resembling our results.

The telencephalon is the most common site for brain metastasis in dogs, including haemangiosarcoma,[6,9] and was affected in all dogs with intracranial haemangiosarcoma in our study. Only one case in this study had a single intracranial lesion, and although uncommon,

238 both primary[4] and metastatic[6,9,29] intracranial haemangiosarcomas can occur as a solitary
239 lesion. Similarly to a previous MRI study, all dogs had at least one lesion that was bigger than
240 4 mm.[30]

241 Intracranial haemorrhage associated with haemangiosarcoma can be expected due to the
242 endothelial origin of the tumour and its friable consistency.[6,7] Different magnetic properties of
243 haemoglobin products/metabolites may be used to determine the age of the haemorrhage.[31]
244 Multiple haemorrhagic stages were recognized within most of the lesions in this study, and this
245 was evident as a mixed signal intensity of the lesions in all sequences. The presence of a
246 hypointense peripheral rim reflecting the conversion of the intracellular oxyhaemoglobin to
247 deoxyhaemoglobin in the acute phase of the haemorrhage was also common. In people,
248 multiple haemorrhagic stages within lesions has been used as a criteria to differentiate between
249 neoplastic or spontaneous haemorrhages.[32]

250 Most lesions in this study had susceptibility artefact on T2*w images, corresponding to the
251 presence of haemorrhage. The only dog to have lesions with no susceptibility artefact had been
252 examined with the lowest field MRI (0.2T) used in this study. Susceptibility artefact distortion
253 is proportional to magnetic field strength[30], so this can potentially explain the absence of
254 susceptibility artefact in this case despite the presence of a haemorrhagic lesion. T2*w is a
255 sequence sensitive to haemorrhage given that haemoglobin derivates are paramagnetic and
256 produce local magnetic field inhomogeneities[31,33,34] Similarly to a previous study in five dogs,
257 the susceptibility artefact present on T2*w images allowed visualization of small haemorrhagic
258 lesions not seen in either T2w nor FLAIR images.[34] Reports of metastatic haemangiosarcoma
259 and intracerebral haemorrhage described a susceptibility artefact on T2*w images comprising
260 the entire mass;[34] however, we found non-haemorrhagic areas (areas lacking susceptibility
261 artefact) within lesions in four dogs. The presence of solid areas within haemorrhagic lesions

is a criteria in people to differentiate neoplastic from non-neoplastic intracerebral haemorrhage.[32]

Haemorrhages are often associated with perilesional vasogenic oedema in the acute phase, although perilesional oedema may persist even in the chronic phases or along multiple haemorrhagic stages, when an underlying neoplastic origin is present.[32] Oedema is also commonly associated with brain metastasis [33] and this is in agreement with our cases, where perilesional oedema was a consistent finding.

Contrast enhancement is often present in metastatic lesions[33] and was present in all dogs in this study. Breakdown of the blood-brain barrier and peripheral neovascularization are possible explanations for the enhancement,[8] the last explaining the ring-like enhancement in almost half of the dogs. Meningeal enhancement was present in four dogs. Histologically, neoplastic cells were found in the meninges of one dog, and another one showed multifocal accumulation of perivascular haemosiderophages and a small number of lymphocytes and plasma cells.

Haemangiosarcoma is the most common metastatic tumour involving the brain in dogs, compromising 29% of all secondary intracranial tumours.[9] Primary intracranial haemangiosarcoma is extremely rare in dogs, with only few cases reported, and no MRI descriptions.[4,12] Primary haemangiosarcoma was confirmed in two dogs, in which no evidence of haemangiosarcoma was found outside the CNS based on thoracic and abdominal imaging and their complete post-mortem examinations. One case was a haemangiosarcoma affecting the rostral cerebrum and invading the lateral ventricle, with haemorrhages identified in the diencephalon and meninges on histopathology. Invasion of a lateral ventricle also occurred in a dog with suspected (based on thoracic and abdominal imaging) primary haemangiosarcoma. Both cases had lack of suppression of CSF signal on FLAIR images inside the affected lateral ventricle due to the presence of histopathologically confirmed intraventricular haemorrhage.

The other confirmed primary case was an epithelioid haemangiosarcoma, in which neoplastic cells were found in the telencephalon, diencephalon, and mesencephalon. Epithelioid haemangiosarcoma is an uncommon histological variant of haemangiosarcoma that resemble tumours of epithelial origin. This variant has been poorly described in veterinary species and affects mostly the integument.[35] Case reports suggest a similar biological behaviour to the non-epithelioid visceral form,[35,36] but given its rarity in dogs and therefore the lack of studies, its biological behaviour is still to be determined. This is the first description of a primary intracranial epithelioid haemangiosarcoma, and the first description of the MRI features of primary intracranial haemangiosarcoma. In people, the MRI features of primary intracranial haemangiosarcoma are described as a single enhancing lesion with heterogeneous signal intensity on T1w and T2w images.[37] Interestingly, both confirmed primary haemangiosarcomas in this study had multiple intracranial lesions and their MRI features did not differ from metastatic haemangiosarcoma.

Skeletal muscle metastases occur in 24.6% of haemangiosarcomas, and always associated with involvement of other organs.[38] In people, muscle metastases are considered a late event in clinical progression and herald a poor prognosis.[39] Histopathology of the masticatory muscle lesions identified in this study was not available, although a metastatic origin was suspected. As opposed to previous studies,[38] these dogs had no evidence of other metastatic lesions on thoracic or abdominal imaging.

Extradural tumours represent approximately 50% of all spinal tumours[26] and were the most common type in this study (7/12). They can be conceptually classified as primary or secondary (metastatic), but in aggressive tumours such as haemangiosarcoma, it may be difficult to determine its origin because metastases are frequently encountered at the time of diagnosis.[40] Most primary vertebral tumours in dogs involve thoracic vertebrae; while most metastatic

vertebral tumours involve lumbar vertebrae.[16] All vertebral haemangiosarcomas in this study affected thoracic vertebrae and were suspected to be primary, based on thoracic and abdominal imaging (4/4) and a full body post-mortem examination (1/4). Osseous lesions are detected in 21% of dogs with haemangiosarcoma, and in 9% of cases metastasis involve vertebrae.[17] Descriptions of haemangiosarcoma arising from the bone are in agreement with our study, and are predominantly lytic and highly aggressive lesions, often invading the paraspinal soft tissues and extending into the vertebral canal.[15,18,41] We found segmental, poorly marginated polyostotic highly aggressive large mass-like lesions. There is only one case report describing the MRI characteristics of canine primary vertebral haemangiosarcoma.[15]

Three cases of epidural haemangiosarcoma in dogs have been reported,[21,20,22] affecting the lumbar region in one dog and all suspected to be primary. In all cases herein the definitive diagnosis was reached by biopsy, and none underwent full body imaging or complete post-mortem examination, so we were unable to classify them as primary or metastatic.

The MRI features of epidural haemangiosarcoma are described[20,22] with similar findings to the ones we encountered. MRI findings of extradural hematoma in dogs are similar to epidural haemangiosarcomas. However, most reported canine extradural/epidural hematomas did not show contrast enhancement, although diffuse[42] and strong[43] contrast enhancement are reported.

Primary intramedullary tumours are more common than metastatic intramedullary tumours, and tend to be located in the cervical spinal cord.[25] Metastatic intramedullary haemangiosarcoma is reported to frequently affect the thoracolumbar spinal cord[23,25] often accompanied by brain metastasis.[23] Interestingly, all intramedullary lesions we identified on MRI were located in the cervical spinal cord, had disseminated disease involving multiple thoracic and abdominal organs and, in almost all dogs (4/5), the cerebrum was affected on histopathology.

The MRI findings of intramedullary haemangiosarcoma have been briefly described in dogs.[24,25,28] Our cases showed similarities in the signal intensity and contrast enhancement, but in contrast to previous reports, the presence of perilesional oedema was a consistent finding. The use of corticosteroids prior to imaging studies may be the reason behind the disparity, although this information was not available in previous reports. Interestingly, all dogs but one described hereby had a single intramedullary lesion identified on MRI despite being metastatic in origin.

MRI findings of an intradural extramedullary haemangiosarcoma (suspected metastatic) in a dog have recently been described as similar to those of intramedullary haemangiosarcoma, but with the presence of a "golf tee sign".[27] No intradural extramedullary haemangiosarcomas were found in this study.

Non-neoplastic spontaneous haemorrhage (including coagulopathies, parasitic migration, and congenital or acquired vascular malformations, among others) and haemorrhagic tumours like haemangiosarcoma and haemangioma or often high-grade gliomas, may share similar characteristics on MRI and should be considered in the differential diagnosis of haemorrhagic lesions affecting the CNS.[13,29,44] This was a descriptive study, and further studies comparing haemangiosarcoma and other neoplastic or non-neoplastic haemorrhages are necessary to identify reliable MRI features that could aid in their antemortem differentiation.

Limitations of this study include its multi-institutional and retrospective nature leading to variability in the clinical, imaging and pathologic information available. Full body post-mortem examinations were only available for nine dogs and there was variability in the post-mortem report detail. Most patients with intracranial haemangiosarcoma had multiple lesions, of which the presence or absence of neoplastic cells in every lesion was only specified in some post-mortem reports. In a previous post-mortem study, 25% of dogs with haemangiosarcoma

and a grossly identifiable brain lesion were diagnosed with ischemic or haemorrhagic infarcts, all located in the cerebrum.[6] Therefore, some of the lesions described in this study could represent cerebrovascular accidents. MRI studies were performed with different machines and different field strengths, of which seven were a low field. Low field MRI machines provide less anatomical detail compared to high field MR imaging machines. Another limitation of this study is the small sample size. Despite involving seven referral institutions, only 20 patients were recruited.

Our study population probably had a strong bias towards cases with obvious neurological signs in which systemic signs might had been missed or not been present. Patients are more likely to have MRI if no evidence of neoplastic or metastatic disease is suspected or found elsewhere.

In conclusion, this study describes the MRI features of canine primary and metastatic haemangiosarcoma affecting the CNS. Consistent imaging features that can be employed for diagnosis include heterogenous and frequently mixed signal intensity lesions with the presence of susceptibility artefact on T2*w, associated moderate to severe perilesional oedema and moderate to strong heterogeneous or ring-like contrast enhancement. Intracranial haemangiosarcomas were frequently multiple and intra-axial, affecting consistently the telencephalon. Vertebral haemangiosarcomas were segmental, poorly marginated, polyostotic, and highly aggressive lesions invading the thoracic vertebral canal and paraspinal tissues. Epidural haemangiosarcomas were single and well-marginated lesions in the thoracolumbar and/or lumbar region, and intramedullary haemangiosarcomas were metastatic in origin and always located in the cervical spinal cord.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Mallol, Brocal

(b) Acquisition of Data: Mallol, Gutierrez-Quintana, Hammond, Schweizer-Gorgas, De Decker, Novellas, Espada, Ortega, Parry, Oevermann, Coelho, Stalin, Gonçalves, Brocal

(c) Analysis and Interpretation of Data: Mallol, Gutierrez-Quintana, Hammond, Brocal

Category 2

(a) Drafting the Article: Mallol, Brocal

(b) Revising Article for Intellectual Content: Mallol, Gutierrez-Quintana, Hammond, Schweizer-Gorgas, De Decker, Novellas, Espada, Ortega, Parry, Oevermann, Coelho, Stalin, Gonçalves, Brocal

Category 3

(a) Final Approval of the Completed Article: Mallol, Gutierrez-Quintana, Hammond, Schweizer-Gorgas, De Decker, Novellas, Espada, Ortega, Parry, Oevermann, Coelho, Stalin, Gonçalves, Brocal

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Tables

Table 1. MRI characteristics of intracranial haemangiosarcoma

Axial origin		**Haemorrhage**	
Intra-axial	9 (100%)	**Signal void**	
Extra-axial	0	Present	8 (89%)

Topographical location	
Telencephalon	9 (100%)
Thalamus	3 (33%)
Cerebellum	3 (33%)
Mesencephalon	2 (22%)
Pons	1 (11%)
Medulla oblongata	2 (22%)
Specific location	
White matter	1 (11%)
Grey matter	2 (22%)
Transition zone	2 (22%)
All or undetermined	4 (44%)
Number of lesions	
Single	1 (11%)
Multiple	8 (89%)
Median number	4
Size	
Median	1.7 cm
Range	0.4-9.6 cm
Signal intensity	
T2w, FLAIR	
Hyperintense	1 (11%)
Mixed	8 (89%)
T1w	
Isointense	1 (11%)
Mixed	8 (89%)
Hyperintense areas	5 (56%)
Lack CSF signal suppression within ventricles on FLAIR	2 (22%)
Signal homogeneity	
Homogeneous	1 (11%)
Heterogeneous	8 (89%)
Margin distinction	
Well-marginated	8 (89%)
Poorly-marginated	1 (11%)
Microhaemorrhages	5/8 (62%)
Absent	1 (11%)
Non-haemorrhagic areas	
Present	4 (44%)
Absent	5 (56%)
Hypointense rim T2w	
None	2 (22%)
Partial	6 (67%)
Complete	1 (11%)
Haemorrhagic stages	
Single	1 (11%)
Multiple	8 (89%)
Perilesional oedema	
Absent	0
Present	9 (100%)
Mild, moderate	0
Severe	9 (100%)
Mass effect	
Absent	2 (22%)
Present	7 (78%)
Type	
Ventricular distortion	7 (78%)
Herniation	
Foramen magnum	0
Transtentorial	2 (22%)
Midline shift	5 (56%)
Contrast enhancement	
Mild	0
Moderate	6 (67%)
Strong	3 (33%)
Meningeal enhancement	4 (44%)
Pattern of enhancement	
Homogeneous	1 (11%)
Heterogeneous	4 (44%)
Ring-like	4 (44%)

Abbreviations: CSF, cerebrospinal fluid

Table 2. MRI characteristics of spinal haemangiosarcoma

	Extradural		**Intramedullary**
	Vertebral	**Epidural**	
Topographical location			

Cervical Thoracic Thoracolumbar Lumbar	0 4/4 (100%) 0 0	0 0 2/3 (67%) 1/3 (33%)	5/5 (100%) 0 0 0
Number of lesions			
Single (or segmental for vertebral) Multiple Monostotic Polyostotic	4/4 (100%) 0 1/4 (25%) 3/4 (75%)	3/3 (100%) 0 N/A N/A	4/5 (80%) 1/5 (20%) N/A N/A
Median size			
Length vertebral bodies and/or lesion length (cm)	2 vertebral bodies	2 vertebral bodies	2.1cm
Signal intensity **T2w**			
Hyperintense Mixed	2/4 (50%) 2/4 (50%)	0 3/3 (100%)	2/5 (40%) 3/5 (60%)
T1w			
Hyperintense Isointense Mixed	0 2/4 (50%) 2/4 (40%)	1/3 (33%) 1/3 (33%) 1/3 (33%)	0 4/5 (80%) 1/5 (20%)
Signal homogeneity			
Homogeneous	0	1/3 (33%) T1w 0 T2w	1/5 (20%) T1w 0 T2w
Heterogeneous	4/4 (100%)	2/3 (67%) T1w 3/3 (100%) T2w	4/5 (80%) T1w 5/5 (100%) T2w
Haemorrhage			
T2*w available Presence signal void	1/4 1/1 (100%)	2/3 2/2 (100%)	4/5 4/4 (100%)
Non-haemorrhagic areas			
Present Absent	1/1 (100%) 0	1/2 (50%) 1/2 (50%)	3/4 (75%) 1/4 (25%)
Margin distinction			
Well-marginated Poorly marginated	0 4/4 (100%)	3/3 (100%) 0	2/5 (40%) 3/5 (60%)
Perilesional oedema			
Moderate Severe	4/4 (100%) 0	3/3 (100%) 0	2/5 (40%) 3/5 (60%)
Spinal cord compression			
Moderate Severe	1/4 (25%) 3/4 (75%)	1/3 (33%) 2/3 (67%)	N/A N/A
Contrast enhancement			
Mild Moderate Strong	0 2/4 (50%) 2/4 (50%)	0 2/3 (67%) 1/3 (33%)	1/5 (20%) 2/5 (40%) 2/5 (40%)
Pattern enhancement			
Heterogeneous Ring-like	4/4 (100%) 0	3/3 (100%) 0	3/5 (60%) 2/5 (40%)

501

Figure legends:

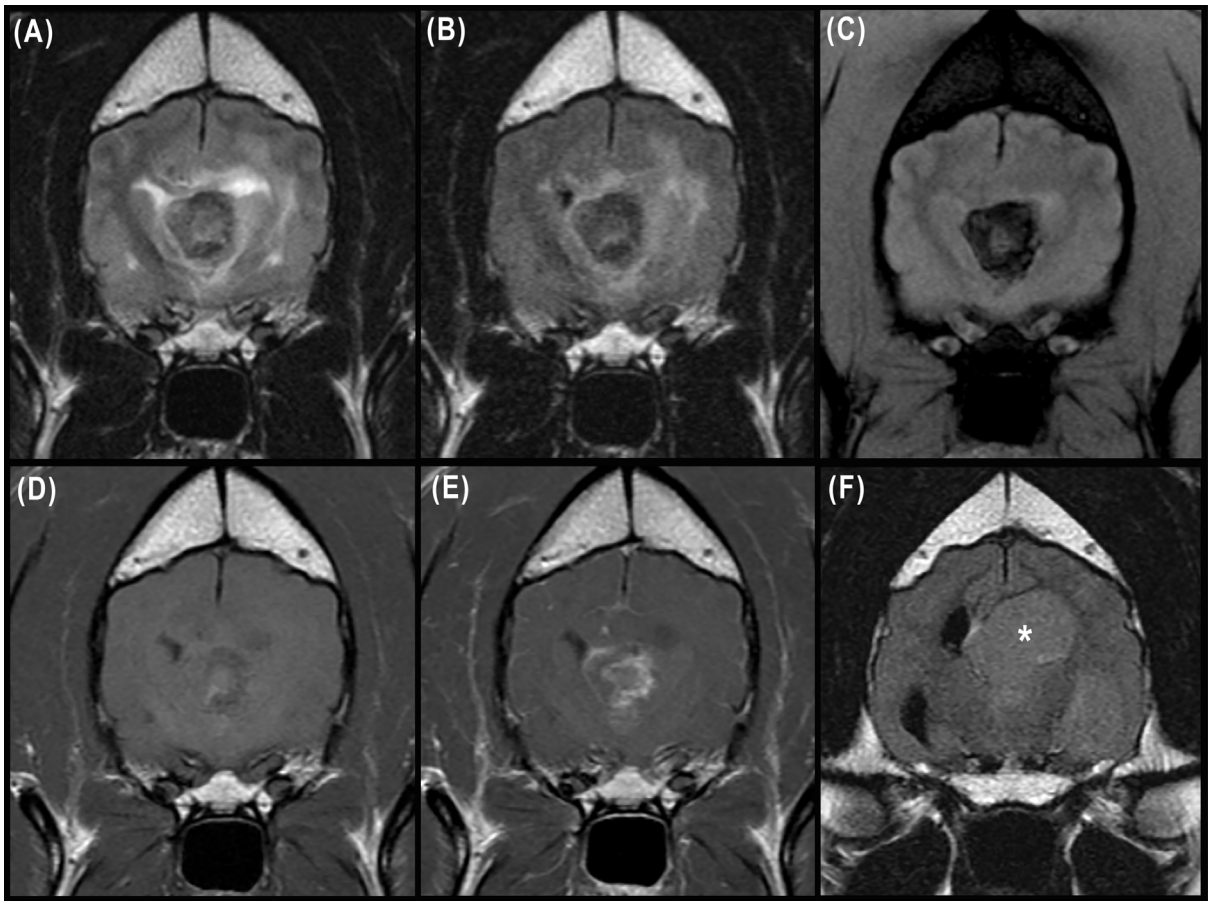

Figure 1 Primary intracranial haemangiosarcoma in an 11-year-old male neutered Golden Retriever at the level of the optic chiasm (A-E) and thalamus (F). A, Transverse T2w; B and F, FLAIR; C, T2*w; D, T1w; and E, T1w post contrast images. Note the intra-axial, well-marginated mass lesion in the telencephalon, heterogeneous with a mixed signal intensity (predominantly hypointense) on T2w, FLAIR and T1w images, with a susceptibility artefact on T2*w, and with associated severe perilesional oedema and moderate heterogeneous contrast enhancement. Note the lack of suppression of CSF signal within the left lateral ventricle (asterisk, F) confirmed to be haemorrhage secondary to ventricular invasion.

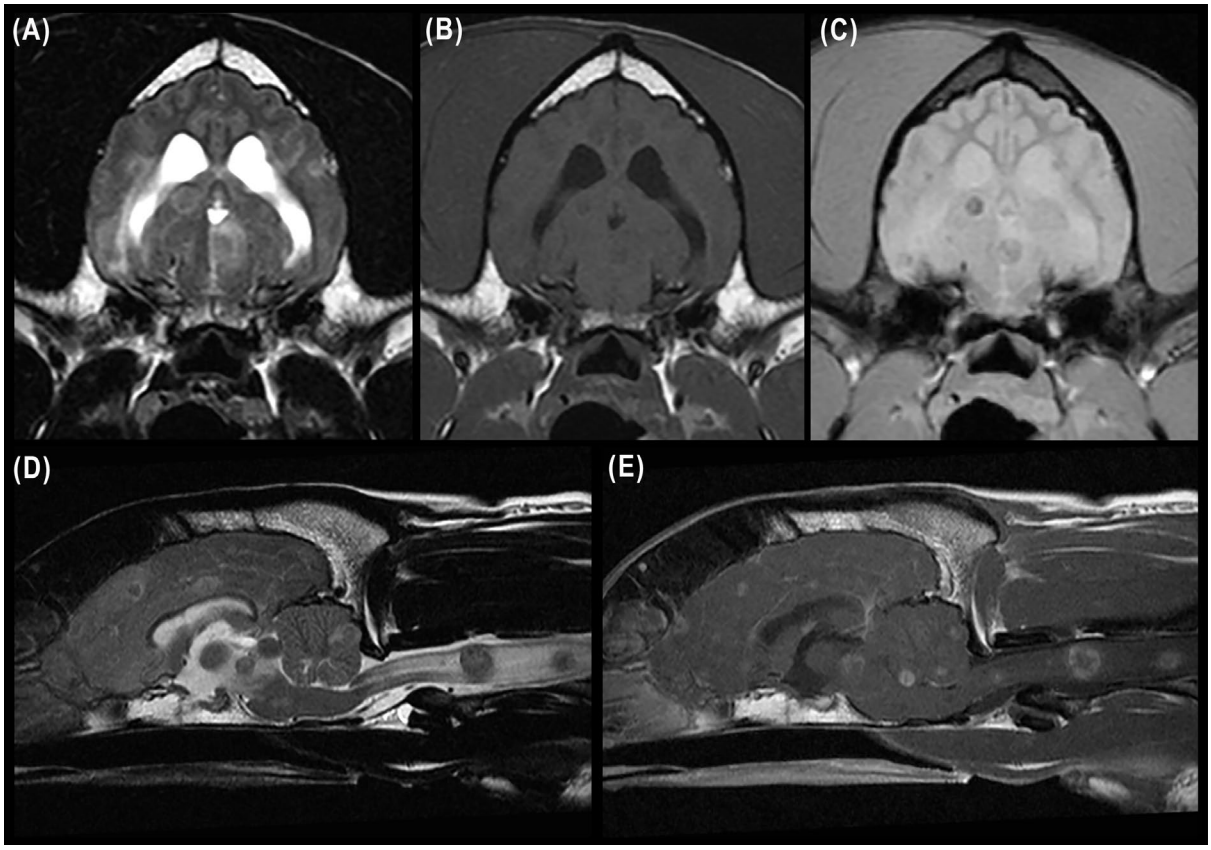

Figure 2 Metastatic intracranial haemangiosarcoma in a 7-year-old male neutered Border Collie at the level of the rostral mesencephalon (A-C) and mid-sagittal plane (D-E). A, Transverse T2w; B, transverse T1w; C, transverse T2*w; D, sagittal T2w; and E, sagittal T1w post contrast images. Note the multiple, intra-axial, well-marginated lesions in the cerebrum, cerebellum and brainstem. Lesions were slightly heterogeneous an predominantly hypointense in all images, showing susceptibility artefact on T2*w, severe perilesional oedema and moderate to ring-like contrast enhancement. Note the intramedullary lesions in the cervical spinal cord (D and E) showing similar characteristics.

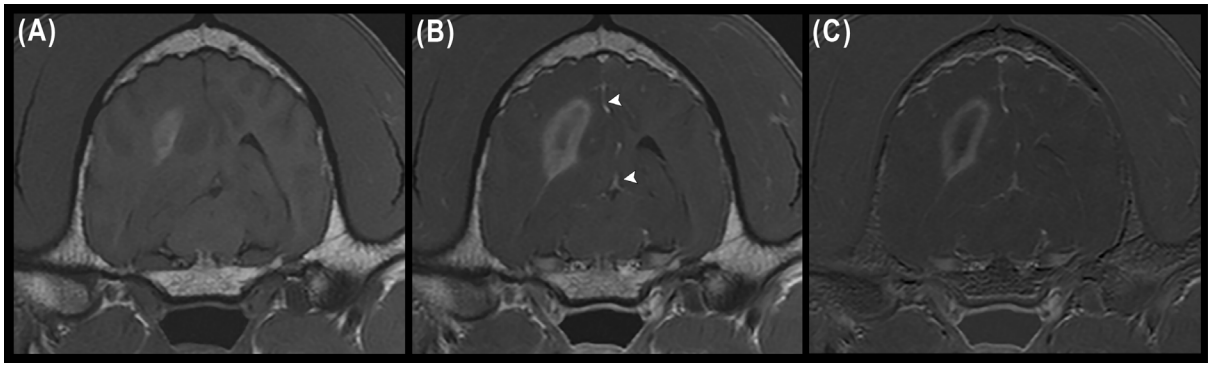

Figure 3 Haemangiosarcoma in the right parieto-temporal lobes in an 11-year old male neutered mixed-breed dog. A, Transverse T1w; B, T1w post contrast; C, corresponding Dynamic subtraction image. Note the meningeal (arrowheads, B) and ring-like contrast enhancement of the mass. Meningeal metastases were found on histopathology.

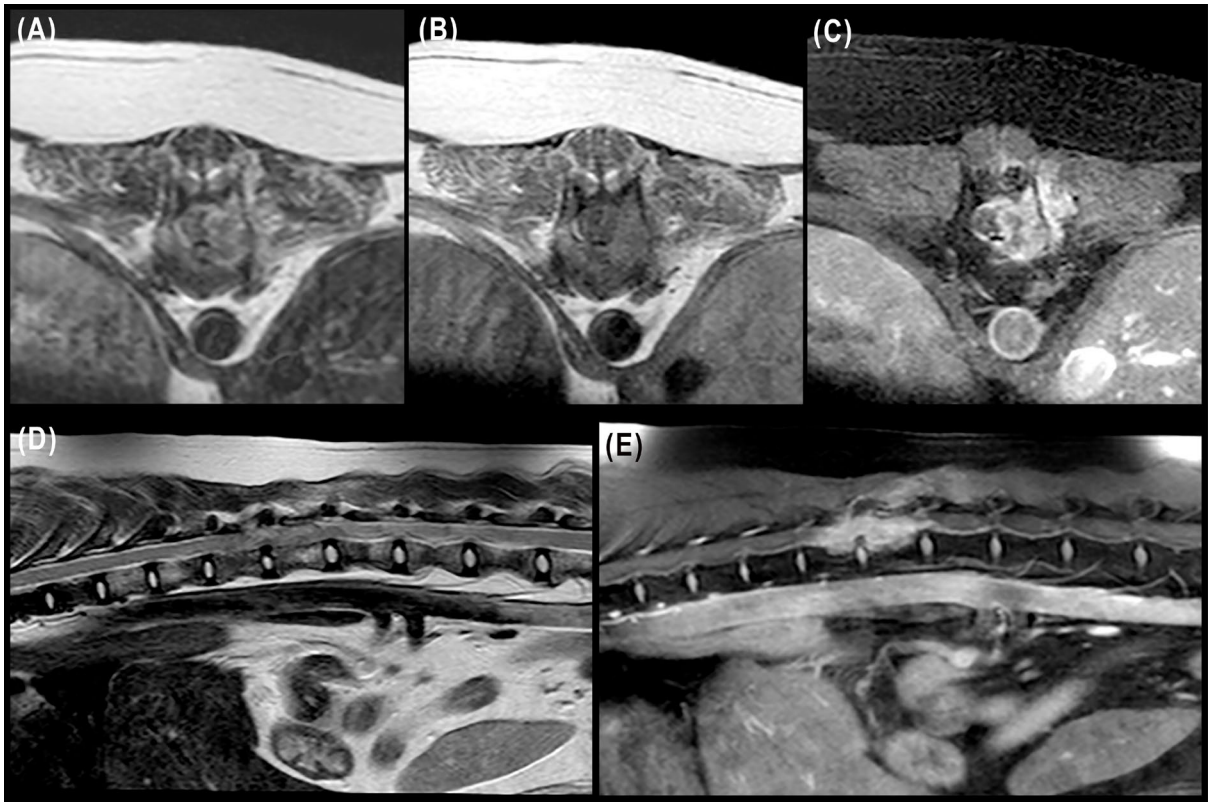

Figure 4 Vertebral haemangiosarcoma in a 10-year old spayed female mixed-breed dog. A, Transverse T2w; B, T1w; C, T1w fat sat post contrast images; D, Sagittal T2w; E, T1-weighted fat sat post contrast images. Note the extradural, segmental, poorly marginated and polyostotic

aggressive lesion extending over the length of two thoracic vertebral bodies. It showed mixed signal intensity on T2w, iso- to hyperintense signal on T1w, and strong heterogeneous contrast enhancement. The mass was invading the adjacent paraspinal soft tissues and vertebral canal, causing severe spinal cord compression.

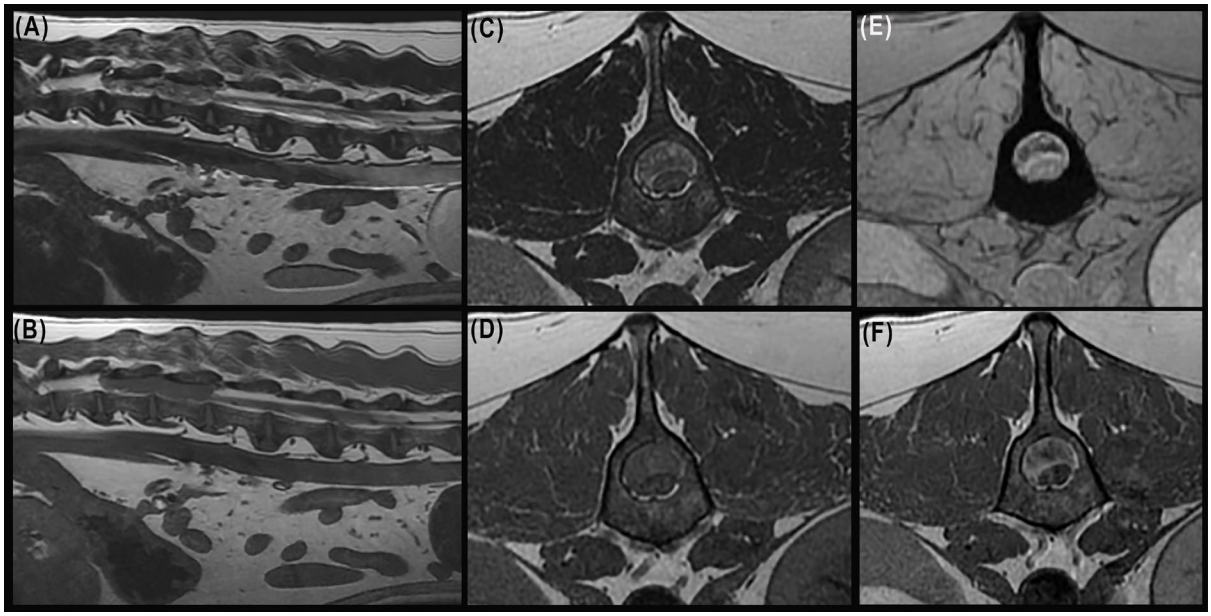

Figure 5 Epidural haemangiosarcoma in a 8-year old male neutered Labradoodle. A, Sagittal T2w; B, T1w images; C, Transverse T2w; D, T1w; E, T2*w; F, T1w post contrast images. Note the single, epidural, well-marginated thoracolumbar mass, extending over the length of two vertebral bodies, with T2w and T1w mixed signal intensity, susceptibility artefact on T2*w and strong heterogeneous contrast enhancement, causing severe spinal cord compression.