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Magnetic Resonance Imaging of Focal Splenic and Hepatic Lesions in the Dog

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Focal hepatic and splenic lesions in the dog are common, and approximately half of such lesions are malignant. Both incidentally discovered lesions and lesions in patients with known malignancies represent diagnostic dilemmas. Ultrasound often fails to characterize such lesions adequately. This uncertainty may result in unnecessary splenectomies and liver biopsies for benign lesions or noncurative surgery for advanced-stage malignancies. In humans, ultrasound largely has been supplanted by computed tomography and magnetic resonance imaging (MRI) for the characterization of focal hepatic and splenic lesions. The inherently high soft tissue contrast of MRI allows the differentiation of benign from malignant hepatic and splenic lesions in the human patients. In this prospective study, 35 focal lesions of either the spleen (n = 8) or the liver (n = 27) were characterized by MRI in 23 dogs. Lesions were presumptively classified as malignant or benign on the basis of MRI findings. Imaging results then were correlated with histopathologic (29) or cytologic (6) evaluation of the lesions. The overall accuracy in differentiating malignant from benign lesions was 94% (33 of 35 lesions). The overall sensitivity and specificity were 100% (95% CI, 78–100%) and 90% (95% CI, 68–99%), respectively. MRI classified malignant hepatic lesions as hepatocellular carcinoma (HCC) in all confirmed cases and correctly predicted the histologic grade of 5 HCC lesions. These results suggest that MRI is a useful modality for abdominal imaging in veterinary patients, and MRI accurately differentiated benign from malignant focal hepatic and splenic lesions in this sample of patients.

Key words: Abdominal imaging; Hemangiosarcoma; Hepatocellular carcinoma; Nodular hyperplasia.

In the canine liver, focal lesions may represent benign (eg, focal nodular hyperplasia [FNH] or regeneration, extramedullary hematopoiesis, cyst, abscess, hematoma) or malignant (eg, hepatocellular carcinoma [HCC], lymphosarcoma, malignant histiocytosis, hemangiosarcoma, metastatic carcinoma, metastatic sarcoma) processes.[1–4] Similarly, focal lesions in the spleen may be the result of benign (eg, lymphoid hyperplasia, cyst, abscess) or malignant (eg, hemangiosarcoma, metastatic sarcoma/carcinoma, malignant histiocytosis, lymphosarcoma) conditions.[5–8] These lesions traditionally have been identified by radiography or ultrasonography and commonly represent a diagnostic dilemma for the clinician, because each may require substantially different management.[1,2] Ultrasound is commonly used for abdominal imaging in veterinary medicine, but its ability to distinguish benign from malignant lesions in the liver and spleen is poor.[9–12] Consequently, unnecessary surgeries or biopsies may be performed on patients with benign lesions.

In humans, the limitations of ultrasound are well recognized, and its role in specific patients is limited. Magnetic resonance imaging (MRI) provides soft tissue contrast that is far superior to that provided by either ultrasound or computed tomography (CT).[13–21] MRI currently is the modality of choice for characterizing hepatic lesions in human patients based on an interpretation of the lesion's signal intensity and morphology on precontrast T1-weighted (T1W), precontrast T2-weighted (T2W), and postcontrast T1W images.[13–21] The use of paramagnetic gadolinium chelate contrast agents provides additional information about a lesion's vascularity, the presence or absence of internal necrosis, and the presence or absence of a nonnecrotic tumor.[22–26] Based on image analysis by standard MRI protocols, lesions can be accurately categorized as benign or malignant, with an overall accuracy approaching 95% and a sensitivity and specificity greater than 90%.[13–16,19]

Numerous studies in human medical literature document the MRI characteristics of the most common focal hepatic lesions, some of which are sufficiently pathognomonic to render histologic confirmation unnecessary.[13,17–19] MRI is highly sensitive in the detection, diagnosis, and staging of HCC, the most common primary hepatic malignancy in people.[13,16,18,20,23] In addition, MRI allows superior lesion detection, quantification, and localization in patients with metastatic disease when compared with more traditional imaging modalities.[13–16,18,19]

MRI of the human spleen is not yet widely used in clinical practice for 2 reasons: the relatively low incidence of splenic lesions and the technical characteristics associated with small differences in the relaxation time of splenic tissues.[27–30] Although the use of paramagnetic contrast media enhances the ability of MRI to detect tumors, splenic MRI historically has been used for evaluation of posttraumatic lesions.[28,29] Focal disease processes such as lymphomatous deposits and metastases do occur and often can be differentiated on the basis of contrast media characterization.[28,29]

In veterinary medicine, MRI has commonly been used in the evaluation of the central nervous system, but other applications are currently under investigation.[31–39] To the author's knowledge, only 1 study has characterized the appearance of several abdominal tumors in dogs; 1 hepatic and 1 splenic hemangiosarcoma were included.[40]

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Table 1. MRI protocol used for examination of focal hepatic and splenic lesions (1.5 T).

	Sequence	Plane	TR	TE	Flip	FOV (cm)	Thickness (mm)	Skip (mm)
Localizers	T2	Sagittal and coronal	20,000	80		35–48	8	2
Chemical shift shift	T1-GRE	Axial	100–300 milliseconds	4.6 milliseconds	90°	20–28	5	1
	T1-GRE	Axial	100–300 milliseconds	2.3 milliseconds	90°	20–28	5	1
Respiratory-triggered fat-saturated T2	T2-FSE	Axial	6,000–9,000 milliseconds	80–110 eff		20–28	5	1
Pre-Gd and dynamic post-Gd (breath hold)	T1-GRE	Axial	Minutes	Minutes	10	28	5	1
Delayed post post–Gd (breath hold)	T1-GRE	Axial	68–280 milliseconds	4.2 milliseconds	90°	20–28	5	1

TR, repetition time; TE, echo time; FOV, field of view; T2, T2-weighted image; T1-GRE, T1-weighted gradient echo; T2-FSE, fast spin echo; Gd, gadolinium; MRI, magnetic resonance imaging.

The goal of this prospective study was to use MRI to characterize a variety of focal splenic and hepatic lesions and to correlate these findings with histopathologic or cytologic diagnoses in order to determine both the feasibility and diagnostic accuracy of this imaging modality in veterinary patients.

Materials and Methods

Patient Population

Twenty-three animals were prospectively enrolled for MRI at the Matthew J. Ryan Veterinary Hospital of the University of Pennsylvania (VHUP). Criteria for case recruitment included abdominal ultrasonography, owner consent for MRI, and either a lesion biopsy or a fine-needle aspiration. Case selection also was based on the availability of MRI and the patient's health status. Specifically, critical patients requiring immediate surgery were not selected because of the timing constraints of MRI accessibility.

MRI Analysis

Dogs were anesthetized by means of standard VHUP anesthesia protocols. Twenty patients were imaged with a General Electric 1.5-T LX system at the Hospital of the University of Pennsylvania (HUP). An additional 3 patients were imaged at Veterinary Imaging Centers, Ambler, PA (n = 2), or at Iams Imaging Center, Vienna, VA (n = 1), which also used 1.5-T systems. A human torso coil array was the type of radio-frequency coil used in all animals, and for each study, patients were placed in lateral recumbency. Respiratory gating by the placement of bellows across the thorax of each patient was used to minimize respiratory artifact. The pulse sequences used were the same as those used for abdominal imaging in human patients at HUP (see Table 1). Approximate scan times included T1W gradient recall echo: 30 seconds for in phase, 30 seconds for out of phase, and 4–6 minutes for T2W (subject to respiratory rate). For imaging, the axial plane was chosen because it is the most commonly used plane for imaging of the liver in human patients. Gadolinium chelates were used for contrast analysis. Gadolinium chelates are Food and Drug Administration approved for MRI of both human adult and pediatric patients. MAGNEVIST[a] at a recommended dosage of 0.2 mL/kg (0.1 mmol/kg) was used in all patients. Postinjection imaging was performed at 30 seconds and 1 minute later. These sequences required breath holding of 40–60 seconds to minimize respiratory artifact. This study was performed in accordance with the University of Pennsylvania's ''Use of Client-Owned Animals'' Protocol.

MRI clinicians (ESP, ESS) were provided with a clinical history and ultrasound findings. Clinicians were blinded to the results of histopathology or cytology when it was performed before imaging. Lesions were classified either as malignant or benign on the basis of lesion signal characteristics. This classification was made on the basis of accepted findings and experience with the use of MRI in human patients.[23,41–60]

For each patient, the characterization of the lesion by MRI was correlated with the histopathology or cytology results. For animals in which a biopsy or an aspiration of a lesion was performed before MRI (n = 26), the location of the specific lesion was recorded for comparison with the location of the lesion on MRI. If several lesions were noted on MRI, only the lesion on which a biopsy had been performed was correlated. For patients in which MRI was performed before surgery, the location of the lesions, based on MRI, was used as a guide for the surgeon to perform a biopsy on the same lesion. Multiple lesions with identical MRI characteristics were counted as 1 lesion.

MRI was used for lesion grading in animals with HCC in which lesion homogeneity and degree of signal similarity to descriptions of normal liver were interpreted as signs of lower tumor grade. A low-grade HCC resembles a normal liver on all pulse sequences but has an abnormal architecture, which marks it as a neoplasm. Higher-grade neoplasms have areas of internal hemorrhage, necrosis, or extensive heterogeneous enhancement. Resectability of lesions was determined by the presence or absence of lymphadenopathy or by evidence of distant metastatic disease. Surgical planning was undertaken depending on which hepatic segments were shown by MRI to be involved by the tumor.

Statistical Analysis

Sensitivity and specificity were determined for MRI as the diagnostic test in the detection of malignant lesions. Using the gold standard for this diagnosis, malignant lesions were determined by cytologic or histopathologic examination of samples obtained from the imaged lesions. Contingency table analysis was used to determine the sensitivity and specificity of MRI as a diagnostic test for malignancy. The sensitivity of MRI was expressed as the percentage of lesions that were diagnosed as malignant on the basis of cytologic or histopathologic examination that were also diagnosed as malignant by MRI. Similarly, the specificity of MRI as a diagnostic test for malignancy was expressed as the percentage of those animals that did not have malignancy on the basis of cytologic or histopathologic examination that were also diagnosed as negative for malignant disease by MRI. The overall accuracy for MRI as a diagnostic tool for malignant lesions was determined as the percentage of all lesions correctly diagnosed by MRI. Ninety-five percent confidence intervals were determined for overall accuracy, sensitivity, and specificity by the binomial exact method. All statistical calculations were performed by a statistical software program.[b]

Results

Twenty-three animals were evaluated in this study, allowing MRI characterization of 35 separate lesions. Ultrasound was performed on all patients, and focal lesions were identified in all animals. An MRI was performed in all animals within 10 days of ultrasound (median, 5 days; range, 1–10 days). Histopathologic or cytologic evaluation of each lesion was performed within 1 month of MRI (median, 3 days; range, 1–28 days). MRI was performed before surgery in 5 animals and before postmortem examination in 4 animals. Twenty-seven lesions were of hepatic origin, and 8 lesions were of splenic origin. Overall, there were 15 malignant lesions of the liver (n = 14) and spleen (n = 1) and 20 benign lesions of the liver (n = 13) and spleen (n = 7).

Microscopic diagnosis of hepatic lesions was based on cytology (n = 2) or histopathology (n = 25). Cytologic examination by means of ultrasound-guided fine-needle aspiration confirmed 1 malignant lesion (HCC) and 1 benign lesion (normal liver). Histopathologic diagnosis was based on the results of a surgical biopsy (n = 17), an ultrasound-guided Tru-cut biopsy (n = 5), or a postmortem examination (n = 3). Malignant hepatic lesions confirmed by histopathology (n = 13) included HCC (n = 6), hemangiosarcoma (n = 3), leiomyosarcoma (n = 1), malignant plasma cell tumor (n = 1), myoerythrolipoma (n = 1), and carcinoid tumor (n = 1). Benign lesions confirmed by histopathology included nodular regeneration or hyperplasia (n = 10), focal hepatic congestion (n = 1), and hepatopathy (n = 1). In the liver, MRI accurately differentiated benign from malignant lesions in 25 of 27 cases with a sensitivity of 100% and a specificity of 86%.

Microscopic diagnosis of splenic lesions (n = 8) was based on cytology (n = 4) or histopathology (n = 4). Cytologic diagnosis by ultrasound-guided fine-needle aspiration identified 4 benign lesions (extramedullary hematopoiesis [EMH] [n = 3] and lymphoid hyperplasia [n = 1]). Histopathologic diagnosis of splenic lesions was based on the results of a surgical biopsy (n = 2), an ultrasound-guided Tru-cut biopsy (n = 1), or a postmortem examination (n = 1). Splenic lesions confirmed by histopathology included malignant plasma cell tumor (n = 1) and lymphoid hyperplasia (n = 3). In the spleen, MRI accurately differentiated benign from malignant lesions in all instances (8 of 8), with a sensitivity and specificity of 100%.

Overall, MRI accurately differentiated benign from malignant disease processes for 33 of 35 lesions, yielding an overall accuracy of 94%. The overall sensitivity and specificity were 100% (95% CI, 78–100%) and 90% (95% CI, 68–99%), respectively. The 2 cases in which MRI yielded an incorrect diagnosis were both large hepatic lesions diagnosed as nodular hyperplasia (nodular regeneration) on histopathology (Tru-cut biopsy [n = 1] or surgical biopsy [n = 1]). In the 1st case, MRI identified and characterized several other lesions in the liver as malignant, and these lesions were not noted on ultrasound. In addition, on a T2W localizer sequence, a pulmonary lesion was noted that was not identified by thoracic radiography. A subsequent reevaluation of this patient by ultrasound has since identified numerous target lesions in the liver. A repeat biopsy was declined by the owner. In the 2nd case, a large lesion was identified in the liver and characterized as a malignancy (HCC), but histopathologic examination of a surgical biopsy specimen identified nodular regeneration.

For the 7 confirmed HCC cases, MRI radiologists classified the lesion as low grade (n = 2), high grade (n = 3), or unspecified (n = 2). Grading of HCC is not typically performed in veterinary medicine, but the histologic descriptions of these lesions were consistent with MRI findings in all 5 cases. One case was diagnosed by cytology, which precludes grading, and in another case, arterial phase imaging was not optimal, precluding further characterization. In one case, a hypointense rim surrounding the tumor, consistent with a capsule or pseudocapsule, was observed and confirmed as a pseudocapsule on histopathology. Preoperative MRI (n = 5) accurately determined which lesions were resectable (n = 3) or nonresectable (n = 2). Of the 2 nonresectable lesions, MRI identified a secondary lesion in another lobe of the liver with identical signal intensity characteristics, consistent with intrahepatic metastasis. No biopsy was performed on this secondary lesion.

MRI characterization of selected lesions is presented in Table 2, and images from selected lesions are presented in Figures 1–3. Of the 10 histopathologically confirmed hepatic nodules or hyperplastic lesions, 4 were identified with MRI. The remaining 6 patients had normal scans. Of the 4 lesions noted on MRI, 2 were characterized as HCC (including the case that likely represented a biopsy sampling error), and 2 were characterized as hepatic regenerative nodules. In the other cases, MRI was unremarkable.

Discussion

The identification of a focal splenic or hepatic lesion by ultrasound often leads to a diagnostic quandary for the clinician and may lead to the surgical removal of a potentially benign lesion. This study was designed to examine the feasibility of MRI to differentiate benign from malignant splenic and hepatic lesions. Abdominal ultrasound is widely used in veterinary medicine because of its noninvasiveness, accessibility, and cost. However, ultrasound often is unable to differentiate between benign and malignant processes reliably.[9–12] A recent study found the presence of target lesions a positive predictor of malignancy.[9] However, the authors also reported the presence of target lesions in several dogs with benign disease.[9] MRI and CT have surpassed ultrasound as the tool of choice for the evaluation of human patients with focal hepatic or splenic lesions.[13] The lack of ionizing radiation, the overall safety of gadolinium as a contrast agent, and the inherently better soft tissue contrast associated with MRI are 3 important considerations for the preferential use of MRI instead of CT.[13–21,48,59,61,62] Numerous studies have documented the increased accuracy of MRI compared with iodinated contrast-enhanced CT scanning for the detection and characterization of hepatic lesions.[13–21,61,62]

In people, lesions identified by abdominal ultrasound that are not confirmed by MRI generally are presumed to be artifacts of ultrasound scanning techniques. In malignant lesions, the value of MRI lies in the ability to accurately stage the disease by determining the extent and location of

Table 2. MRI characterization of selected hepatic and splenic lesions.

Lesion	n[a]	General Description	T1-Weighted Image	T2-Weighted Image	Postcontrast
Hepatic regenerative nodules	2	Lesions had a similar nodular contour and a texture similar to the liver.	Lesions were isointense to the remainder of the liver.	Lesions were isointense to the remainder of the liver.	Lesions were enhanced the same as the remainder of the liver.
Hepatic metastasis[b]	2		Lesions were hypointense to the remainder of the liver, and multiple lesions were noted.	Lesions were hyperintense to the remainder of the liver but were not as hyperintense as fluid.[c]	Mean lesions had characteristic continuous peripheral rim enhancement.
Hepatocellular carcinoma	7	In one case, a thin ''capsule'' was seen on most images.[d]	Lesions were similar but were not identical to the remainder of the liver.	Lesions were similar but not identical to the remainder of the liver and were more heterogeneous than the remainder of the liver.	Lesions were hypervascular in the early phase, with washout noted in the late phase, and lesions were more heterogeneous than the remainder of the liver. Higher-grade lesions have greater internal heterogeneity of signal intensity.[e]
Hemangiosarcoma	3		Lesions were hypointense to the remainder of the liver, and multiple lesions were noted.	Lesions were hyperintense to the remainder of the liver.	Lesions with an internal clot were enhanced with nodular rim enhancement, often ''bulging'' the contour of the liver. Many lesions were enhanced progressively on delayed-phase postcontrast images and became hyperintense to the liver.[f]
Splenic nodules[g]	7		Lesions were hypointense to the remainder of the spleen.	Lesions were hypointense to the remainder of the spleen.	Lesions were enhanced less than the remainder of the spleen.
Splenic metastasis	1		Lesion was hypointense to the remainder of the spleen.	Lesion was hyperintense to the remainder of the spleen.	Lesion was enhanced more than the remainder of the spleen, with peripheral and nodular enhancement.

MRI, magnetic resonance imaging.
[a] Number of cases.
[b] Cases included a malignant plasma cell tumor and a leiomyosarcoma.
[c] See Figure 1.
[d] See Figure 2a.
[e] See Figure 2b.
[f] See Figure 3.
[g] Cases included lymphoid hyperplasia and extramedullary hematopoiesis.

the lesion.[20] MRI therefore can help direct appropriate future therapies for both resectable and nonresectable lesions.[20]

In our pilot study, MRI accurately differentiated between benign and malignant disease in 33 of 35 lesions, with an overall sensitivity and specificity for malignancy of 100 and 90%, respectively. These results are comparable to those obtained in studies of human patients.[13–19] Results of this pilot study demonstrate that MRI is capable of identifying and characterizing common benign and malignant hepatic and splenic lesions in the dog. Malignant lesions have very similar imaging characteristics in both dogs and humans, presumably because both normal hepatic and splenic tissues in dogs have signal characteristics similar to these tissues in people.[3,20]

The lesion FNH, as reported in the veterinary medical literature, is referred to as regenerative nodules in human patients and refers to a benign regenerative condition of the liver. The term FNH, in the human medical literature, refers to a very different and relatively uncommon lesion that is markedly hypervascular compared to the remainder of the liver in the arterial phase.[13,18,22,60,63,64] FNH in humans occurs more commonly in females, usually is solitary, has no malignant potential, and is thought to originate as a hyperplastic response to a congenital vascular malformation.[13,18,22,63,64] FNH is markedly hypervascular to the remainder of the liver but consists of normal hepatocytes. Such a lesion was not identified in the dogs of this study. To avoid confusion, the term regenerative nodules has been used in this study to denote benign regeneration of the liver.

Of the 10 dogs with regenerative nodules, no macroscopic lesions were detected with MRI in 6. In people, hepatic regenerative nodules usually are isointense to the remainder of the liver on both T1W and T2W sequences and have enhancement equal to the remainder of the liver. They are visualized because of their abnormal architecture. In our

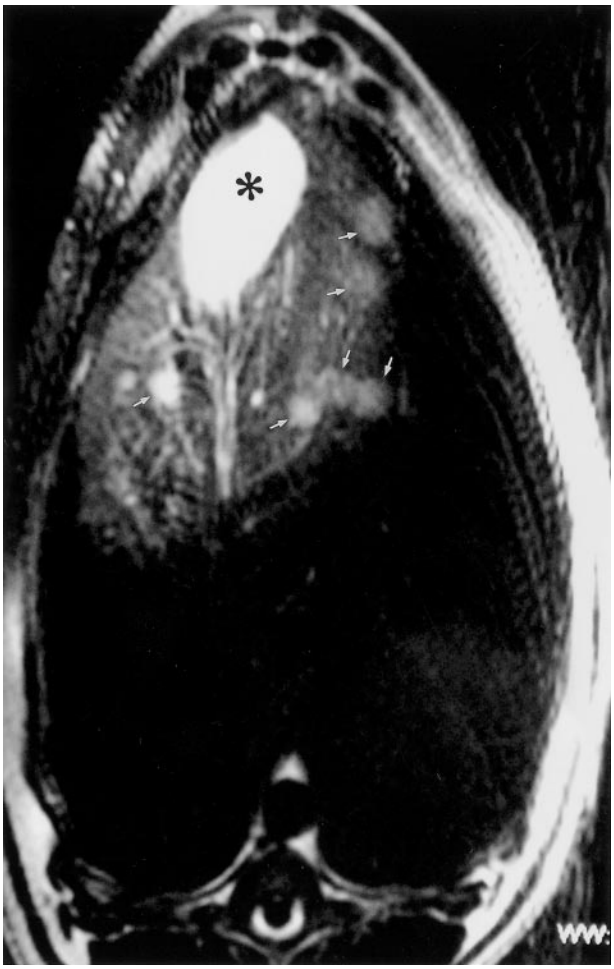

Fig 1. Metastatic hepatic leiomyosarcoma in a 6-year-old female spayed Labrador Retriever. Transverse T2-weighted image (TR, 7,000; TE, 82) near the hepatic dome demonstrates multiple round lesions and intrahepatic lesions (arrows) that are hyperintense to the liver. The gallbladder (asterisk), containing fluid, is markedly hyperintense on this sequence.

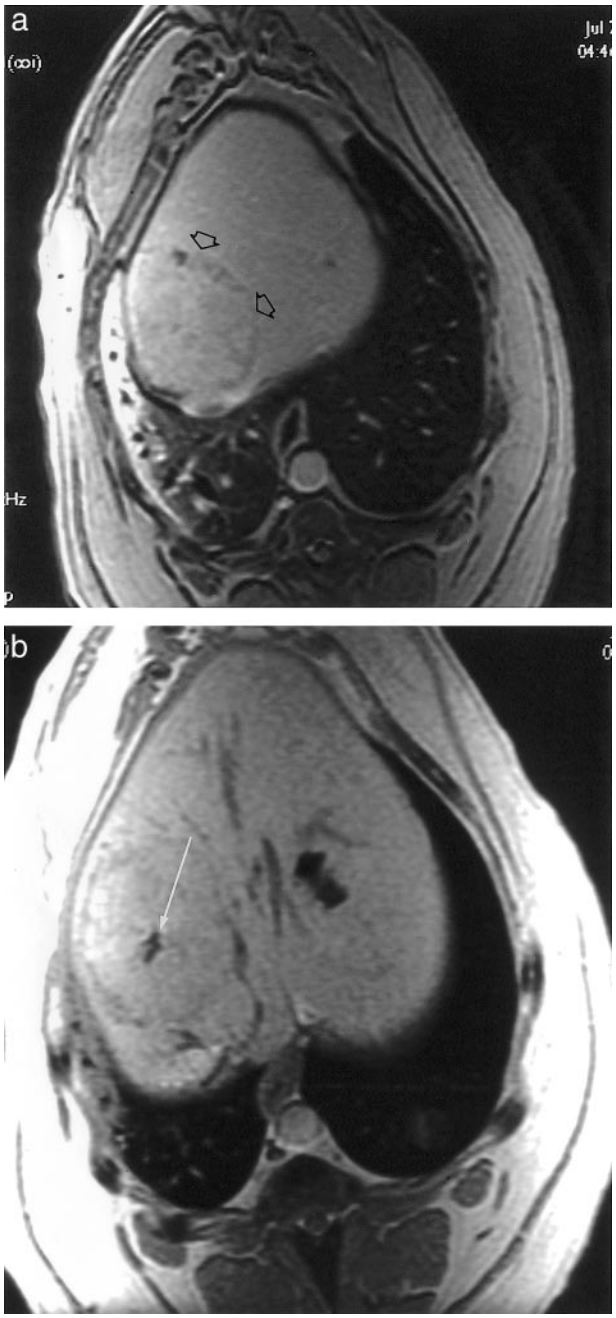

Fig 2. **(a)** Low-grade hepatocellular carcinoma (HCC) in an 8.5-year-old male castrated Golden Retriever. The transverse T1-weighted image (TR, 220; TE, 1.6) demonstrates a lesion in the hepatic dome that is roughly isointense to the remainder of the liver. This marks it as a lesion of hepatocellular origin. A thin, hypointense lesion capsule is seen (arrows). **(b)** After contrast administration (TR, 240; TE, 1.6), the lesion enhances isointense to the liver and is itself homogeneous. These are magnetic resonance (MR) features consistent with a lower tumor grade. There is a central scar (arrow), which has been described in HCC.

study, the liver was characterized as normal, with no abnormalities on any precontrast or postcontrast sequences. This categorization is accurate in the sense that regenerative nodules are composed of normal hepatocytes and have normal hepatic organization and vasculature.[1,2] Therefore, it is logical that MRI would not detect any signal differences between these lesions and normal tissue, because nodular regeneration is a lesion composed of normal hepatocytes. MRI therefore correctly demonstrates normal hepatic signal intensity on all pulse sequences without focal abnormality. In our study, regenerative nodules were identified by MRI in only 2 animals in which macroscopic nodules were present. One animal had cirrhosis of the liver, and in the 2nd animal, the lesion contained a large amount of glycogen that could have altered the signal and enabled detection. In the animal with hepatic cirrhosis, the signal characteristics of the lesions were similar to those seen with regenerative nodules that often occur in human patients with cirrhosis.[64]

The 2 discrepancies noted in our study involved large lesions diagnosed as regenerative nodules on histopathology that were thought to be hepatocellular malignancies on MRI. In one animal, several lesions were noted on MRI, all showing similar signal characteristics and not identified by ultrasound. In that same animal, a pulmonary nodule was noted on MRI that was not apparent on thoracic radi-

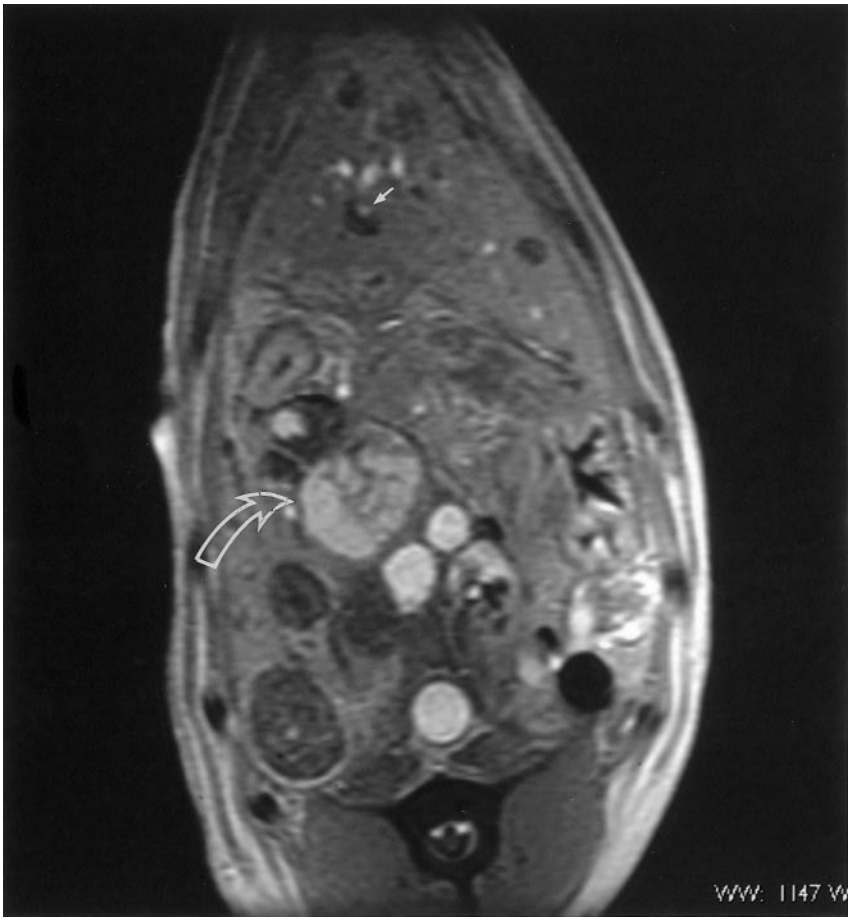

Fig 3. Metastatic hepatic hemangiosarcoma in a 9.5-year-old male castrated Standard Poodle. Transverse T1-weighted images (TR, 240; TE, 1.6) obtained in the delayed phase of contrast enhancement demonstrate that some lesions enhance only on the tumor periphery (small arrow). This corresponds with a lesion composed primarily of internal, nonenhancing clots with a thin rim of viable tumor. Other lesions enhance throughout (curved arrow), which correlates with a viable tumor throughout the lesion. Like the very rare human tumor angiosarcoma, these tumors tend to show more enhancement on delayed-phase images.

ography. This lesion was diagnosed on the basis of a Tru-cut biopsy sample, and subsequent serial ultrasound examinations identified new masses that showed target lesion characteristics. It seems likely that this lesion represents HCC (as classified by MRI), and either the lesion was missed by biopsy, or insufficient tissue was obtained to make an accurate diagnosis. It can be difficult to differentiate regenerative nodules from HCC on Tru-cut biopsy specimens.[1,2] The 2nd lesion was characterized by MRI as HCC; however, on histopathology of a sample obtained at surgery, the lesion was classified as regenerative nodules. Histologically, no abnormalities were present in the tissue that would explain the MRI characteristics of the lesion. The reason for the imaging characteristics associated with this lesion is unknown.

Results of this study demonstrate that MRI of hepatic and splenic lesions in dogs can provide the clinician with valuable information. 1st, MRI was able to accurately determine the location and extent of hepatic lesions in order to assess the feasibility of surgical resection. In 2 animals, the results prevented a noncurative surgery for conditions that represented either an unresectable tumor or a metastatic disease. 2nd, MRI differentiated metastatic hepatic tumors from HCC. As in human patients, HCC lesions had an appearance similar to that of a normal liver on T1W images, whereas metastatic lesions were hypointense to the liver on T1W.[22] MRI also provided useful information regarding tumor grade in 5 of the 7 dogs with HCC on the basis of contrast enhancement characteristics. Additionally, in one animal, a thin hypointense rim was noted around the tumor, which is characteristic of a capsule or pseudocapsule that, in humans, has been confirmed on histopathology.[22,52,65] The ability to estimate tumor grade on the basis of contrast enhancement is commonly reported in human medicine but has not been described previously in veterinary medicine.[22,65]

Dynamic contrast administration provides clinicians with additional useful information about specific lesions and enables lesion examination during 3 phases: arterial (20–30 seconds postinjection), portal (1 minute postinjection), and delayed or equilibrium (3–5 minutes postinjection). In general, during the arterial phase, little hepatic parenchymal enhancement is present. Most primary hepatic tumors and some metastatic tumors (called hypervascular metastatic tumors) overtake arterial supply and enhance avidly.[22] During the portal phase, hepatic parenchyma will enhance as a re-

Table 3. Hepatic lesion characterization relative to normal liver.

	T1	T2	Post-Gd	Other
Malignant:				
HCC	Isointense to liver	Isointense to mildly ↑[a]	↑↑↑	Capsule; abnormal hepatic architecture
Hemangiosarcoma	↓↓[b]	↑↑	↑↑	Multiplicity; continuous rim enhancement, progressive enhancement in delayed phase
Metastatic disease	↓↓	↑	↑	Multiplicity; continous rim enhancement
Benign:				
Regenerative nodules	Isointense	Isointense	Isointense	Nodular contour to liver
Pseudolesion	Isointense	Isointense	Isointense	No lesion present

Gd, gadolinium; HCC, hepatocellular carcinoma.
[a] Up arrows represent hyperintense.
[b] Down arrows represent hypointense.

sult of the 75–85% of blood flow that comes from the portal vein. During this phase, a decrease in lesion contrast exists for some HCCs and hypervascular metastases.[22] This finding likewise was noted in our study of patients with metastatic leiomyosarcoma, hemangiosarcoma, and malignant plasma cell tumor. Other postcontrast imaging characteristics consistent with malignant neoplasia include the presence of continuous peripheral rim enhancement (thought to be a result of neoangiogenesis along the periphery, perhaps inflammatory infiltrate surrounding the tumor or edema as a result of expanding tumor compressing normal tissue parenchyma).[22] These findings were noted with metastatic leiomyosarcoma and hemangiosarcoma. Optimal MRI with contrast agents largely is dependent on the timing of scan acquisition relative to the administration of the contrast agent.[22] Enhancement of a tumor becomes a reflection of the intrinsic characteristics of the tumor (eg, size, vascularity, interstitial space) and scan timing.[22]

Relatively few splenic lesions were observed in this study, with most being benign (eg, lymphoid hyperplasia, EMH). This finding may have resulted from case selection, because most dogs with hemangiosarcoma presented because of tumor rupture and often required emergency surgery that precluded MRI. Of the benign lesions, MRI was unable to differentiate lymphoid hyperplasia from EMH. All nonsplenectomized patients that were examined had lesions that appeared similar to those with confirmed lymphoid hyperplasia and EMH. These lesions were not reported in this study, because many were not noted on ultrasound and consequently did not have a biopsy specimen or an aspiration available for diagnosis. This observation suggests that these lesions are extremely common in older dogs.[6,7]

Table 4. Splenic lesion characterization relative to normal spleen.

	T1	T2	Post-Gd	Other
Malignant:				
Metastatic disease	↓[a]	↑[b]	↑↑	Heterogeneous enhancement
Benign:				
Lympoid hyperplasia	↓	↓↓	↓↓	

Gd, gadolinium.
[a] Down arrows represent hypointense.
[b] Up arrows represent hyperintense.

It is difficult to compare results from MRI with ultrasound findings, because most ultrasound reports typically list likely differential diagnoses rather than a single specific cause. In addition, ultrasound was performed by many ultrasonographers, thereby precluding consistency among examinations. Fewer lesions, however, were identified by ultrasound when compared to MRI. In addition, results of this study suggest the value of negative MRI examinations, especially in animals in which a lesion was noted on ultrasound. Negative MRI implies there is no recognizable lesion on which to perform a biopsy in the liver. In human medicine, when lesions are noted on ultrasound but not on MRI, the lesions are considered pseudolesions and felt to be artifacts of the ultrasound examination. It is well recognized that MRI allows superior lesion detection, quantification, and localization in patients with metastatic disease when compared with more traditional imaging modalities.[13–16,18,19]

One point to consider is whether MRI findings could have been influenced by a recent biopsy because, in several cases, MRI was performed after the biopsy. Although a recent biopsy theoretically could lead to internal hemorrhage in the tissue, no such signal associated with internal hemorrhage was noted in any of the animals of our study.

Limitations of this study include a potential bias in case selection. Animals were chosen on the basis of 2 criteria. The 1st requirement was the owners' willingness to have MRI and lesion biopsy or aspirate performed on their pets. This bias may have excluded many animals. 2nd, all animals had an ultrasound performed in which lesions were identified; the patient population therefore represented a selected group of patients. However, the sample in our study represents the actual cases of interest, specifically those in which the nature of a hepatic or splenic lesion was in question. A 3rd limitation of this study was that not all patients

followed the same diagnostic course. MRI was not always performed immediately before or after a lesion biopsy. This limitation became necessary, because the clinical status of some patients precluded repeated anesthesia. Lastly, MRI clinicians were aware of the ultrasound findings of the patient, which may have led to bias about the presence and location of a particular lesion. However, the most commonly encountered benign etiology in our study was FNH, which, in most cases, was not identified on MRI.

To our knowledge, this is the 1st study to characterize the MRI findings associated with hepatic and splenic lesions in the dog. Although we do not mean to imply that MRI should replace a lesion biopsy for diagnosis, a biopsy is not performed on most liver lesions identified in people because of the accuracy of MRI characterization. This accuracy and comfort level in lesion characterization comes from the results of many studies in human medicine.[23,41–61] We have included pertinent MRI characteristics that were used to differentiate malignant from benign lesions in the patient population in Tables 3, 4.

Footnotes

[a] Gadopentetate dimeglumine, Berlex Laboratories, Wayne and Montville, NJ

[b] Intercooled Stata 7.0 for Windows, College Station, TX

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