ANATOMY OF EXTRAHEPATIC PORTOSYSTEMIC SHUNTS IN DOGS AS DETERMINED BY COMPUTED TOMOGRAPHY ANGIOGRAPHY

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Congenital extrahepatic portosystemic shunts are anomalous vessels joining portal and systemic venous circulation. These shunts are often diagnosed sonographically, but computed tomography (CT) angiography produces high-resolution images that give a more comprehensive overview of the abnormal portal anatomy. CT angiography was performed on 25 dogs subsequently proven to have an extrahepatic portosystemic shunt. The anatomy of each shunt and portal tributary vessels was assessed. Three-dimensional images of each shunt type were created to aid understanding of shunt morphology. Maximal diameter of the extrahepatic portosystemic shunt and portal vein cranial and caudal to shunt origin was measured. Six general shunt types were identified: splenocaval, splenoazygos, splenophrenic, right gastric-caval, right gastric-caval with a caudal shunt loop, and right gastric-azygos with a caudal shunt loop. Slight variations of tributary vessels were seen within some shunt classes, but were likely clinically insignificant. Two shunt types had large anastomosing loops whose identification would be important if surgical correction were attempted. A portal vein could not be identified cranial to the shunt origin in two dogs. In conclusion, CT angiography provides an excellent overview of extrahepatic portosystemic shunt anatomy, including small tributary vessels and loops. With minor variations, most canine extrahepatic portosystemic shunts will likely be one of six general morphologies. © 2011 *Veterinary Radiology & Ultrasound, Vol. 52, No. 5, 2011, pp 498–506.*

Key words: computed tomography, dog, extrahepatic, portosystemic shunt.

Introduction

EXTRAHEPATIC PORTOSYSTEMIC SHUNTS are congenital, anomalous vessels that join the portal and systemic venous circulation, resulting in hepatic encephalopathy, stunted growth, cystic calculi, vomiting, and diarrhea.[1] Extrahepatic portosystemic shunts are most commonly identified in young, purebred, small breed dogs such as Maltese, Yorkshire terrier, and pug, though they can also be found in older or large breed dogs.[2] While an extrahepatic portosystemic shunt may be suspected based on signalment, clinical signs, and biochemical testing, imaging is required for definitive diagnosis and characterization of shunting vessel morphology

As interventional radiography is used increasingly in the treatment of intrahepatic shunts, accurate pretreatment diagnosis is important. Additionally, precise preoperative imaging of extrahepatic portosystemic shunts may help to guide surgical intervention, reducing morbidity and time associated with surgery and allowing accurate assessment of complex shunts.[3] Extrahepatic portosystemic shunts are often described as porto-azygos or porto-caval, without a detailed description of exact shunt location or morphology. Variation in tributary placement, particularly if close to the point of insertion of the extrahepatic portosystemic shunts, is important because improper placement of an occlusion device may allow continued shunting. Our goal was to characterize different types of extrahepatic portosystemic shunts using computed tomography (CT) angiography and to provide high-resolution three-dimensional models to assist diagnostic and surgical assessment of these anomalies.

Materials and Methods

Twenty-five dogs with an extrahepatic portosystemic shunt that was subsequently confirmed surgically were imaged with a 16 slice multidetector CT scanner.* Breeds (and numbers of each dog) were Yorkshire terrier (seven), Shih Tzu (three), miniature schnauzer (three), pug (two), Welsh corgi (two), Jack Russel terrier (two), and one each of Papillon, Maltese, Pomeranian, Entlebucher Mountain Dog, Havanese, and mixed. Dogs ranged from 70 days to 7.5 years of age. Mean age for each shunt type are listed in Table 1. Dogs were imaged in sternal recumbency. Dynamic CT angiography was performed using a previously published protocol.[4] Before the contrast medium administration, a survey CT scan was obtained from the cranial aspect of the diaphragm through the pelvic inlet. A low dose (185 mg I/kg body weight) of iodinated contrast

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*GE Brightspeed, General Electric Healthcare, Princeton, NJ.

TABLE 1. Mean Portal Vein (PV):Aorta Ratio, Maximal Shunt:Aorta Ratio, and Age at Diagnosis for Different Portosystemic Shunt Morphologies

Shunt morphology	Number of Dogs	Caudal PV:Aorta Diameter	Cranial PV:Aorta Diameter	Maximal Shunt:Aorta Diameter	Age (Years)
Splenocaval	6	1.06	0.40*	1.34	0.9
Splenophrenic	4	0.80	0.64	1.28	2.4
Splenoazygos	8	0.89	0.76	1.02	2.1
Double right gastric-azygos	1	1.03	0.74	1.33	0.4
Right gastric-caval	3	1.06	0.57*	1.19	1.6
Double right gastric-caval	3	0.87	0.61	0.92	3.5

*A portal vein was not seen cranial to the shunt insertion in one dog with a splenocaval shunt and one with a right gastric-caval shunt, preventing their measurement.

medium† was then administered at 3 ml/s into a cephalic vein catheter by angiographic injector at the same time a dynamic CT scan was initiated. A CT image was acquired at the level of the porta hepatis every 2 s, for a total of 20 images. The time to maximal aortic and portal venous enhancement was determined. A dual-phase angiogram was then performed by administering a larger dose of contrast medium (814 mg I/kg body weight) followed by two CT scans of the abdomen, with the start of each scan occurring at the time of maximal aortic and portal enhancement, respectively. Positive pressure ventilation was employed during image acquisition to prevent artifact from respiratory motion. Images for the aortic phase were acquired from the cranial aspect of the liver, caudally to the mid-abdomen, and images for the portal phase were acquired from the pelvic inlet, cranially to the diaphragm. Images were acquired using a 0.63 mm slice collimation (except in one dog where 2.5 mm thick slices were acquired), 120 or 140 kVp, and variable mAs and reconstructed using a low pass algorithm. The display field of view was just large enough to include the entire circumference of the abdomen.

Images of the portal phase were imported into a commercially available CT image analysis program‡ that allowed automatic selection of vessels based on Hounsfield unit differences between enhanced vessels and adjacent fat and soft tissue. Selected structures are then placed in a mask, which is superimposed on each slice of the CT series and can be reconstructed into a three-dimensional model of the selected tissue. Arteries were removed manually from the mask based on anatomy and comparison to arterial phase images. A three-dimensional sculpting tool was used on the three-dimensional model to remove most arterial structures from the mask. Small arteries and arteries that contacted portal or systemic venous structures were removed manually, slice by slice, from the mask using a two dimensional editing tool. Dorsal and sagittal plane reformatting was performed automatically for each dog. Three-dimensional digital models of the caudal vena cava, portal vein, and tributary vessels were created. These models could be rotated, magnified, and specific points on each model could be co-located on the transverse, sagittal, and dorsal plane CT images using a localizer tool.

Identification of the splenic vein, cranial and caudal mesenteric veins, and gastroduodenal vein on the three-dimensional model was performed through correlation with transverse images and multiplanar reformatted images. Attempts were made to identify all small tributary vessels including the right gastric vein, left gastric vein, left and right gastroepiploic veins, cranial pancreaticoduodenal vein, and pancreatic branches. To simplify the three-dimensional models, long peripheral vessels were shortened manually, with a small portion remaining at the point of insertion on each larger vessel.

To further describe each shunt type, the diameter of the portal vein, shunt vessel, and aorta were measured. Cranially, the portal vein diameter was measured on transverse images halfway between the entrance of the gastroduodenal vein and the right portal branch to the liver. Portal vein diameter was also measured immediately caudal to the origin of the shunting vessel. Aortic diameter was measured on transverse images just cranial to the origin of the celiac artery. The diameter of the shunting vessel was measured at its widest point; if the vessel course was tortuous, measurements were made in the plane (sagittal or dorsal) in which the largest diameter was present. The portal vein diameter and shunt vessel diameter were divided by the aortic diameter to account for differences in dog size. Mean values for each parameter were calculated.

Results

Six general conformations of a portosystemic shunt were identified by CT angiography, although variations in exact shunt location, size, and smaller tributaries were present. The first shunt type, termed a splenocaval shunt, was seen in six of the twenty-five dogs. This shunt arose from the splenic vein and terminated in the caudal vena cava at the level of the cranial pole of the right kidney, caudal to the liver in all dogs. The diameter of the splenic vein at its

†Omnipaque 300, General Electric Healthcare, Princeton, NJ.
‡Mimics 14.0, Materialise, Leuven, Belgium.

insertion on the portal vein was the same or greater than the diameter of the portal vein caudal to this site. Cranial to the insertion of the splenic vein, the portal vein narrowed abruptly and could be followed to the liver in five dogs. The shunting vessel extended cranially and dorsally from the dilated splenic vein. Peripheral to the origin of the shunting vessel, the splenic vein was decreased in diameter. The insertion of the splenic vein on the portal vein varied between animals, and was in a region extending from just caudal to the cranial mesenteric artery origin to just cranial to the celiac artery origin. Five of the six dogs with this shunt type had a long shunting vessel, which extended cranially and dorsally to insert on the caudal vena cava from the left side (Fig. 1). One dog of the six had a slightly different shunt conformation, with a short, wide shunting vessel that inserted on the caudal vena cava at the same level as the other five dogs (Fig. 2). In this dog, a portal vein was not seen cranial to the origin of the shunting vessel.

The second shunt type, termed a splenophrenic shunt, arose from the splenic vein and terminated in the caudal vena cava cranial to the liver (Fig. 3). This shunt type was identified in four dogs. The origin of this shunt was the same as that seen in the dogs with a splenocaval shunt, except that the large shunting vessel extended further cranially, passing cranial to the liver along the diaphragm and inserting on the caudal vena cava from the left side. Large hepatic veins entered this shunt from its ventral aspect, near where the shunt inserted on the caudal vena cava. A thin tributary vessel representing a phrenic vein extended from the left side of the diaphragm into the shunting vessel before its entrance into the caudal vena cava in three dogs (Fig. 4).

The third shunt type, termed a splenoazygos shunt, arose from the splenic vein and terminated in the azygos vein (Fig. 5). This type of shunt was seen in eight dogs. The origin of this shunt was identical to the two shunt types

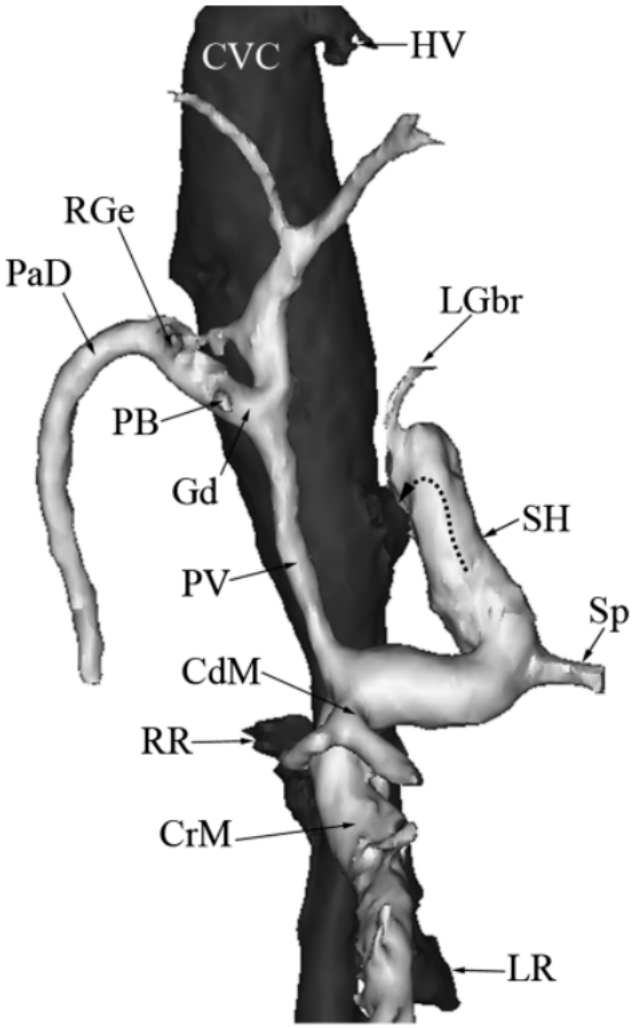

FIG. 1. Splenocaval shunt as viewed from the ventral aspect. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; PB, pancreatic branch; LGbr, branch to the lesser curvature of the stomach; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein

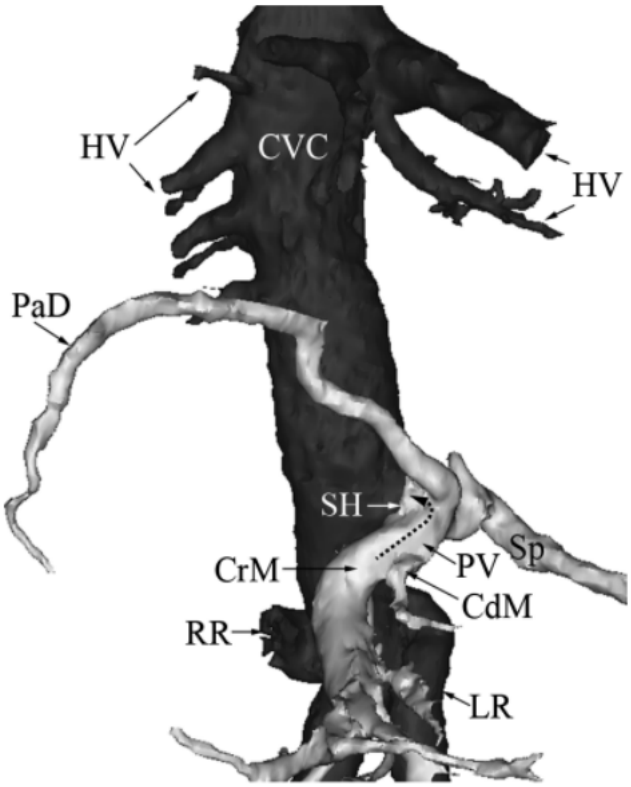

FIG. 2. Atypical splenocaval shunt as viewed from the ventral aspect. Note that a portal vein is not visible extending cranially from the shunt insertion on the caudal vena cava. The dotted arrow within the portal vein and shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein.

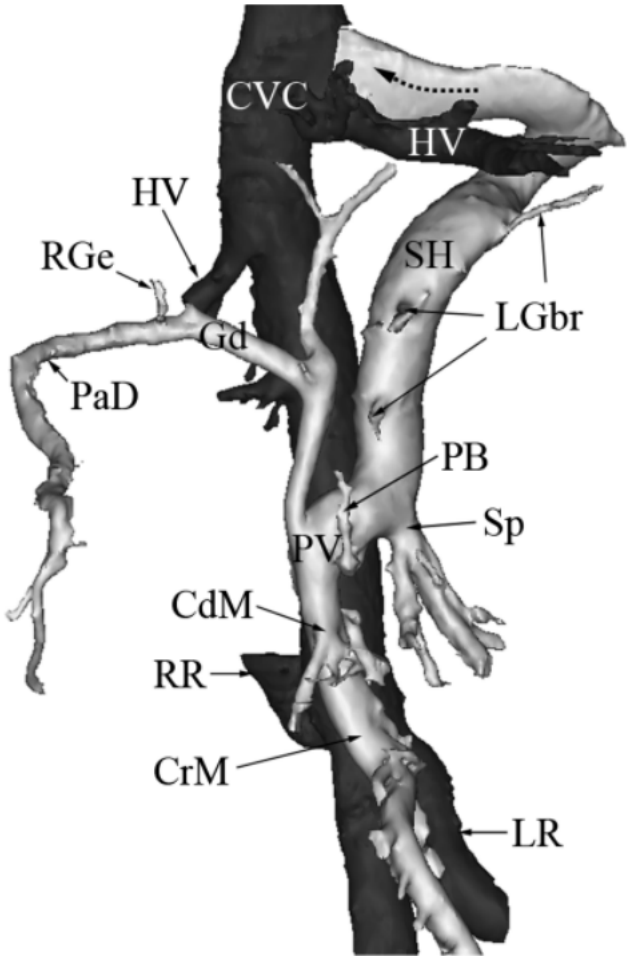

FIG. 3. Splenophrenic shunt as viewed from the ventral aspect. The dotted arrow within the shunt indicates the direction of blood flow. Note the cranial insertion of this shunt compared with a splenocaval shunt. The cranially located hepatic veins entered the shunt from its ventral aspect, near the shunt insertion on the caudal vena cava. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; PB, pancreatic branch; HV, hepatic vein; RR, right renal vein; LR, left renal vein; LGbr, branches to the lesser curvature of the stomach.

described above. A large vessel extended from the splenic vein cranially and dorsally along a curved, tortuous route to the right of the gastric fundus to the azygos vein, which extended cranially into the thorax. A venous branch from the lesser curvature of the stomach entered the shunt from its ventral aspect at the level of the diaphragm as the shunt extended dorsally in all dogs. In six of the eight dogs, the shunting vessel was moderately to severely narrowed as it extended along the right ventrolateral surface of the aorta (Fig. 6).

The fourth shunt type, termed a right gastric-caval shunt, was noted in three dogs. The shunting vessel extended ventrally, leftward, and caudally along the lesser curvature of the stomach, to insert on the caudal vena cava from the left side (Fig. 7). These shunts inserted on the caudal vena cava at a similar level as the splenocaval shunts described above. In two of three dogs, the splenic vein inserted on the portal vein in a normal location. In one dog, the splenic vein inserted on the shunting vessel (Fig. 8). Variation in shunt origin existed. In one of the three dogs, the shunt arose from the gastroduodenal vein near its portal vein insertion. In two of the three dogs, two short shunting branches arose from the portal system (from the gastroduodenal vein alone or from both the gastroduodenal vein and portal vein) and anastomosed to form one large shunting vessel.

The fifth shunt type, termed a right gastric-azygos shunt with a caudal loop, arose from the gastroduodenal vein and terminated in the azygos vein (Fig. 9). This shunt type was identified in one dog. This shunting vessel extended leftward and dorsally, following a course similar to a splenoazygos shunt. A smaller, secondary shunting branch arose from the splenic vein and extended cranially and dorsally to unite with the larger branch from the gastroduodenal vein, along the lesser curvature of the stomach.

The final shunt type, termed a right gastric-caval shunt with a caudal loop, had a double shunting conformation with two anastomosing shunting loops (Fig. 10). This shunt conformation was seen in three dogs. A large vessel extended leftward from the gastroduodenal vein where it was joined by another large shunting vessel arising from the splenic vein. The right-sided vessel had an origin similar to the right gastric-caval shunts and the left sided vessel had an origin similar to the splenocaval shunts. These vessels fused to form a short common large stalk, which entered the caudal vena cava caudal to the liver. In two of the three dogs, the left and right sides of this loop were similar in diameter, but in one dog the left-sided (splenic) shunting loop was much smaller.

The portal vein cranial to the origin of the shunting vessels was consistently smaller than its diameter immediately caudal to the origin of the shunt. In all dogs, the shunting vessel had a maximal diameter that was the same or greater than the maximal diameter of the portal vein at any level. Splenocaval and splenophrenic shunts tended to have a maximal shunt diameter that was greater than the diameter of the portal vein, compared with other shunt types that had a diameter similar to the portal vein. Mean maximal portal vein:aorta, cranial portal vein:aorta, and maximal shunt diameter:aorta ratios are displayed in Table 1. In two dogs, one with a splenocaval shunt and one with a right gastric shunt, a portal vein could not be identified cranial to the origin of the shunting vessel.

Smaller tributary vessels were identified. The right and left gastroepiploic veins could be seen inserting on the gastroduodenal and splenic veins, respectively. Their course was tortuous and their anastomosis could be seen by tracing their course along the greater curvature of the

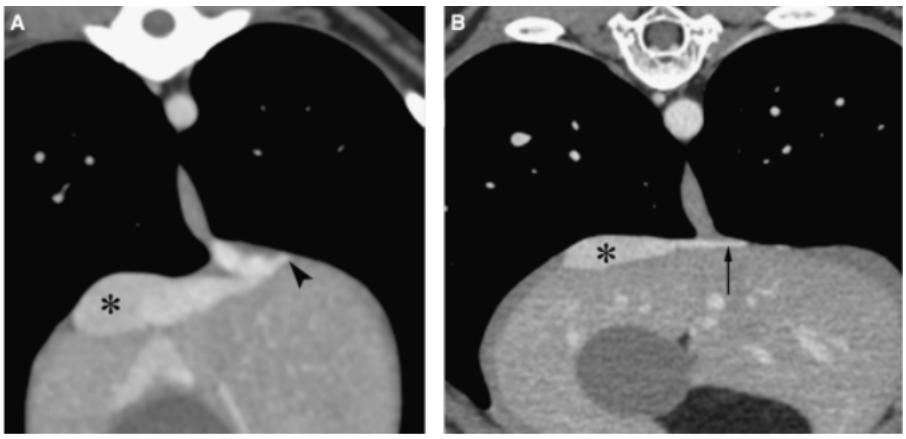

FIG. 4. Transverse images of a dog with a splenophrenic shunt (A) and a dog with a splenocaval shunt (B; shunt not seen in this image). The caudal vena cava is indicated by *. The arrowhead indicates the point of insertion of a phrenic vein on the splenophrenic shunt and the arrow indicates the insertion of the phrenic vein in a normal area of the caudal vena cava.

stomach. Small vessels from the fundus of the stomach could be seen extending to the shunting vessel in many dogs. Small left pancreatic lobe branches could variably be seen extending to the portal vein, shunting vessel, or gastroduodenal vein.

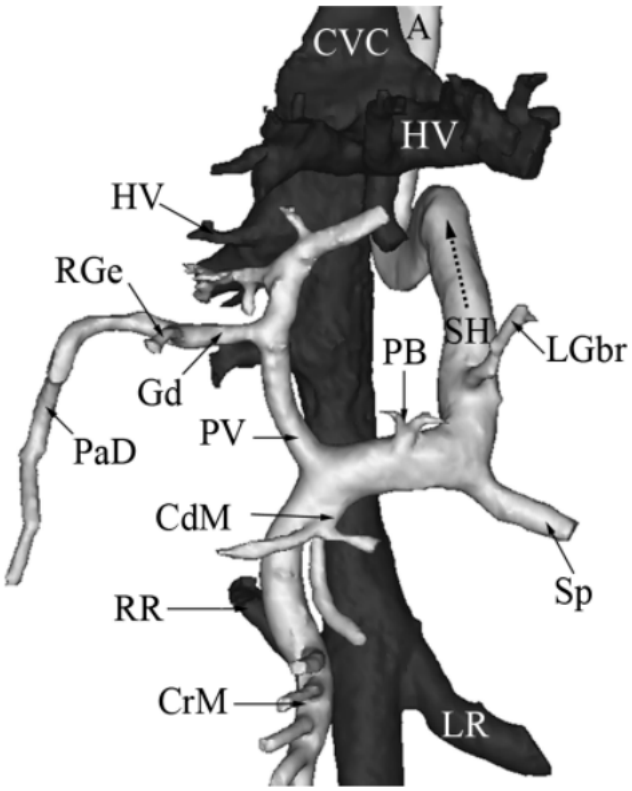

FIG. 5. Splenoazygos shunt as viewed from the ventral aspect. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; PB, pancreatic branch; LGbr, branch to the lesser curvature of the stomach; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein; A, azygos vein.

Exploratory laparatomy confirmed the presence of aberrant shunting portal vasculature in all dogs. Computed tomography correctly identified the termination of all shunts as either caval or azygos. General morphology of shunting vessels as spleno-caval, right gastric-caval, right gastric-azygos, and spleno-azygos was confirmed, but caudal shunt loops were not identified surgically in any dog. The insertion of portal tributary vessels were not identified surgically, as the goal of surgery was placement of an occlusion device and not conformation of fine shunt morphology.

Discussion

The six general types of extrahepatic portosystemic shunts identified in this study likely represent the most common extrahepatic portosystemic shunt conformations. Producing the vascular models was time consuming, requiring careful separation of the caval and portal branches and removal of arterial branches. This time requirement will limit the utility of three-dimensional models in clinical practice. However, our descriptions can provide sufficient detail of shunt variation so that that identification of different shunt types from transverse images can be performed more easily.

Three-dimensional models were helpful but not necessary to identify smaller portal tributary vessels, such as the gastroepiploic veins and pancreatic branches. With an understanding of overall shunt anatomy, small tributary vessels were recognized easily on transverse angiographic images. Acquisition of thin slice CT images was of great importance in characterizing the course and insertion of smaller vessels. Thicker CT slices (2.5 mm thick) were acquired in one dog in this study. Overall shunt morphology in this dog was evident, but identification of smaller tributary vessels was difficult. While the study was diagnostic for general shunt conformation, facilities with CT units

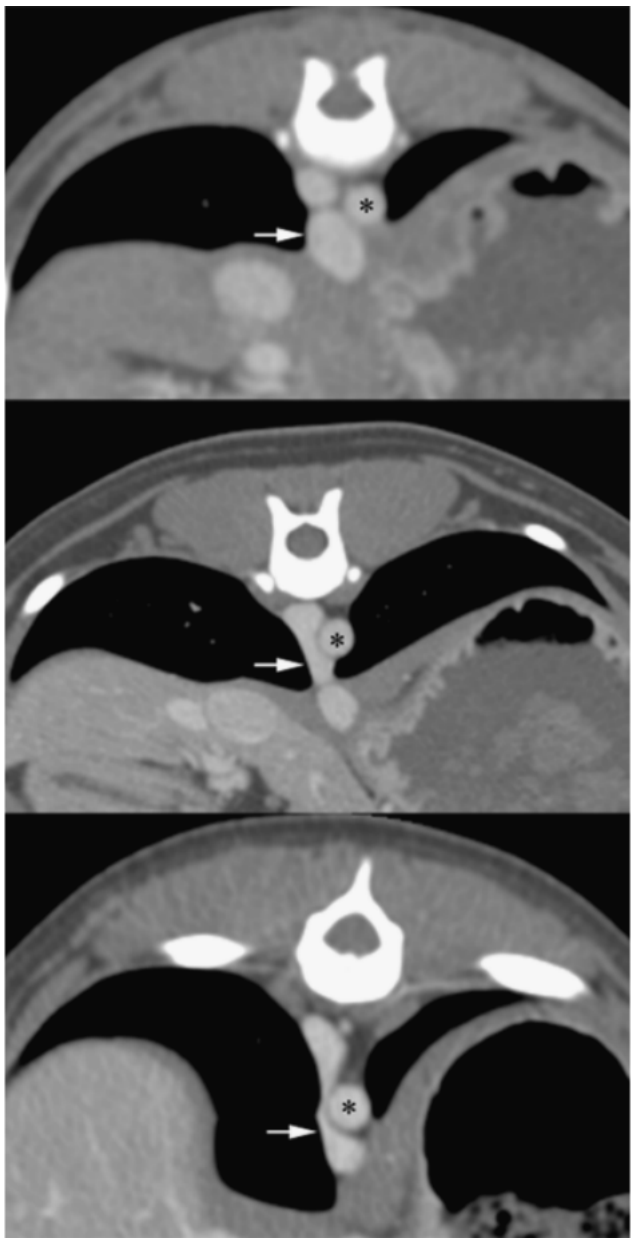

FIG. 6. Transverse images of three dogs with a splenoazygos shunt. Note the differences in shunt diameter at the level of the aorta. The shunting vessel is indicated by an arrow, and the aorta is indicated by *.

unable to produce thin slice images should be aware of this limitation.

Naming conventions of extrahepatic portosystemic shunts have not always been clear or specific.[5] Shunts are frequently described as portocaval or portoazygos without exact information regarding shunt origin, course, or morphology. Shunt origins have been described as arising from the main trunk of the portal vein itself or the left gastric vein, splenic veins, gastroduodenal, or mesenteric veins.[6] Some dogs have been described as having multiple congenital extrahepatic portosystemic shunts, but the number or anatomy is not always indicated specifically.[7]

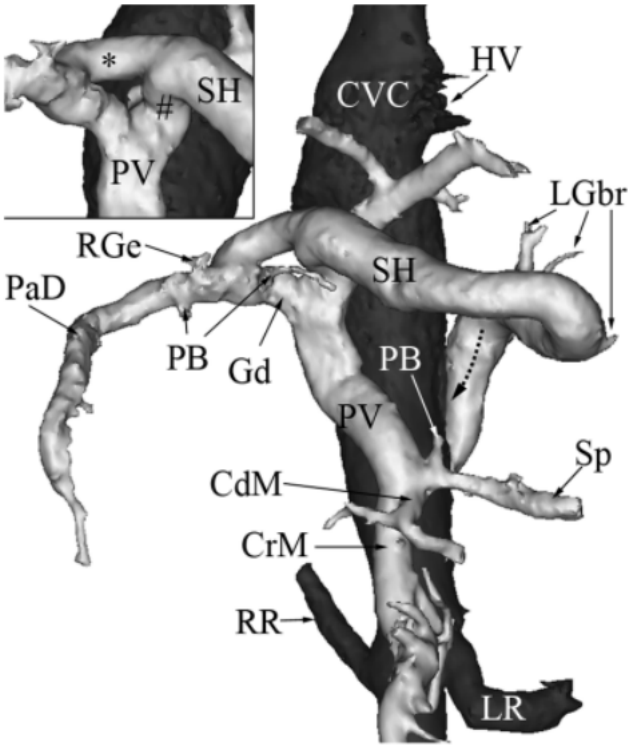

FIG. 7. Right gastric-caval shunt as viewed from the ventral aspect. Hepatic veins did not opacify well in this patient and only the origin of left sided hepatic veins are included. The inset is an oblique projection with some tributaries removed illustrating the double origin of the shunt in this patient. One branch (indicated with *) is from the gastroduodenal vein and the other (indicated with #) from the portal vein. These vessels anastomose near their origin to form one shunt vessel. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein, Sp, splenic vein; PB, pancreatic branch; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein.

The terminology we used was based on anatomic definition of the veins associated with the shunt origin and insertion and is consistent with recent publications.[5,8] Most congenital extrahepatic portosystemic shunts arise from the portal vein, but in reality involve a splenic vein or right gastric vein and may be named for the involved tributary.[5,8,9] CT images confirmed the involvement of the splenic vein with multiple shunt conformations. The involvement of the right gastric vein was more difficult to confirm, but its involvement was inferred based on several observations. First, the course of the right gastric shunt was along the lesser curvature of the stomach, an expected location for the right gastric vein. Second, variation in origin of this shunt type provides additional support for the involvement of the right gastric vein. In this study, the right gastric shunts arose from the gastroduodenal vein or simultaneously from the gastroduodenal vein and portal vein via an anastomosing loop. While not observed here, right gastric shunts have been described to arise as a single vessel from the portal vein.[5] In normal dogs, the right

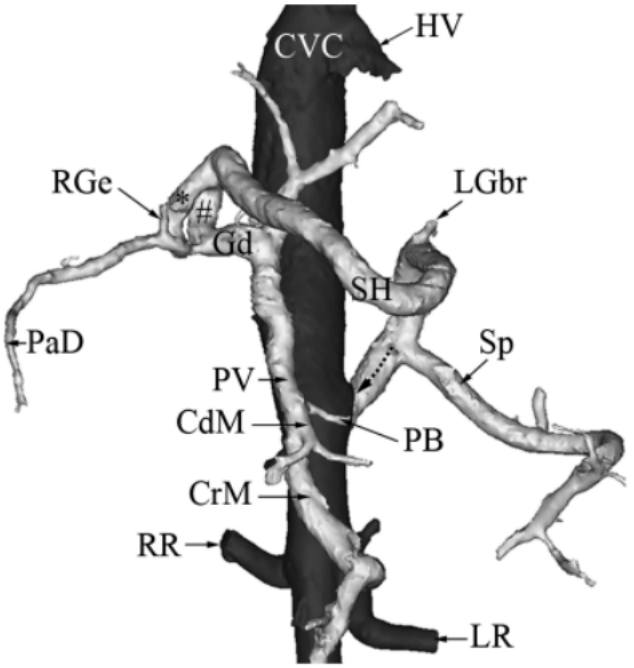

FIG. 8. Right gastric-caval shunt as viewed from the ventral aspect, with alternate location of the splenic vein. Two shunting branches (marked with a * and #) arise from the gastroduodenal vein and anastomose to form one shunt vessel. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; PB, pancreatic branch; LGbr, branch to the lesser curvature of the stomach; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein.

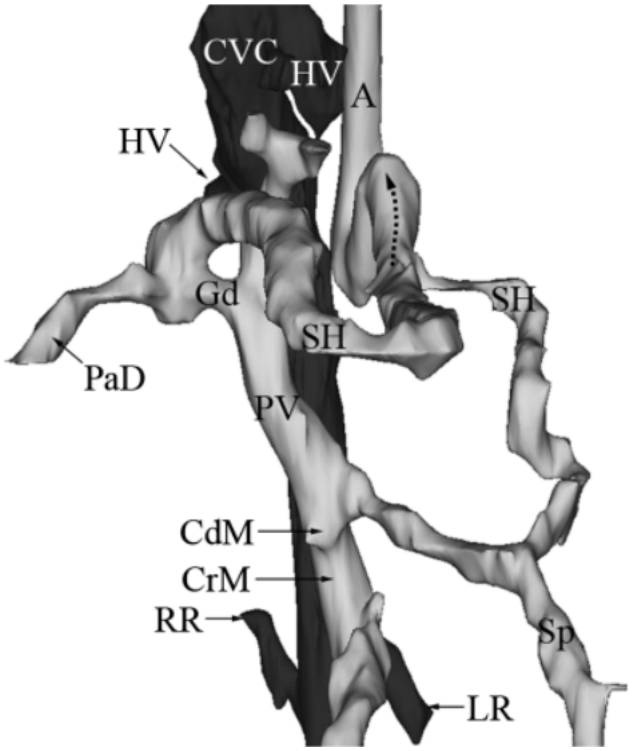

FIG. 9. Right gastric-azygos shunt with a caudal loop as viewed from the ventral aspect. Images of this patient were acquired at 2.5 mm slice thickness resulting in a coarse appearance to three-dimensional image. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein; A, azygos vein.

gastric vein usually flows into the gastroduodenal vein, but may flow directly into the portal vein.[8,10] Because variation in right gastric shunt origin is similar to variation in normal right gastric vein insertion i.e. the shunts may arise from either the portal vein or gastroduodneal vein, it is assumed that the right gastric vein is involved. Finally, use of the term gastroduodenal-caval to describe these shunts would be incorrect in some dogs as the gastroduodenal was not involved.

The term splenophrenic shunt has been mentioned sporadically, but has not been described fully.[11] This name was chosen based on the observation of a thin vein not associated with the shunting vessel that in some dogs extended to the left of the caudal vena cava along the craniodorsal liver margin by the diaphragm. Based on its location, this was thought to represent a normal phrenic vein.[12] In dogs with a splenophrenic shunt, the shunting vessel extended cranially from the splenic vein and followed the same course to the caudal vena cava as the phrenic vein in other dogs. While shunting blood ultimately enters the caudal vena cava, the term portophrenic distinguishes this morphology from the more caudally inserting splenocaval shunts.

Small tributaries from the lesser curvature of the stomach were seen to enter the shunt in many dogs. In a normal animal, the left gastric vein extends along the lesser curvature of the stomach and inserts on the splenic vein near its insertion on the portal vein.[12] In dogs with a shunt in the region of the splenic vein, it is likely that the shunting vessel incorporates an aberrant left gastric vein. This has likely contributed to confusion in naming of portosystemic shunt morphologies, with some previously referred to as left gastric-azygos and left gastric-caval. This terminology was not used here to stay consistent with previously published standards and to recognize the consistent involvement of the splenic vein with splenocaval and splenoazygos shunt types.

Shunts with a double looping morphology combined characteristics of different shunt types. Most commonly, the double loop morphology had components of right gastric-caval and splenocaval shunts, but one dog had a combination of right gastric azygos and splenoazygos shunts. The right gastric-caval double loop type has been described previously and referred to as a right gastric shunt with a caudal loop.[8] This naming convention reflects the fact that the right gastric vein may be the dominant contributor to shunting blood, even though the caudal loop appears similar to a splenocaval shunt. The right gastric-

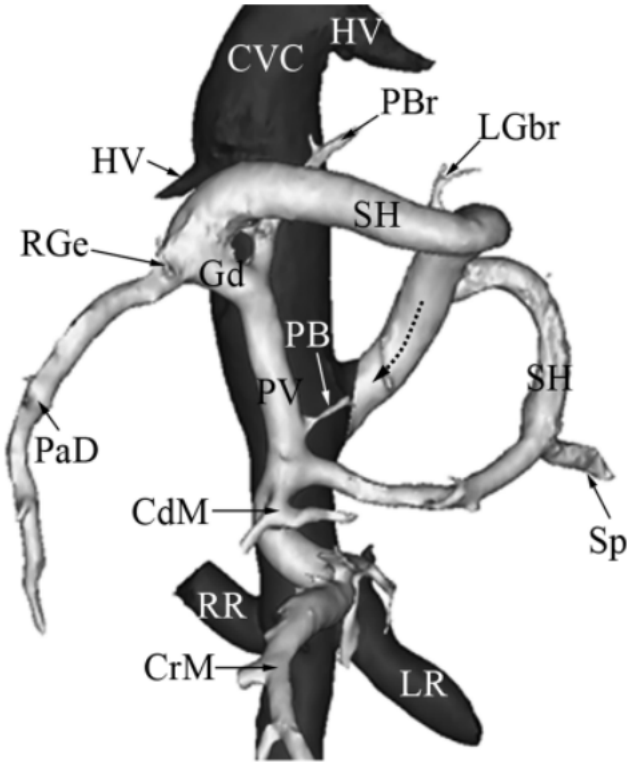

FIG. 10. Right gastric shunt with a caudal loop as viewed from the ventral aspect. The dotted arrow within the shunt indicates the direction of blood flow. SH, shunt; PV, portal vein; PBr, branches of portal vein in liver; Gd, gastroduodenal vein; PaD, pancreaticoduodenal vein; Sp, splenic vein; PB, pancreatic branch of the portal vein; LGbr, branch to the lesser curvature of the stomach; RGe, right gastroepiploic vein; CrM, cranial mesenteric vein; CdM, caudal mesenteric vein; CVC, caudal vena cava; HV, hepatic vein; RR, right renal vein; LR, left renal vein.

azygos shunt with a caudal loop has not been described previously. It is likely that right gastric-azygos shunts occur without this caudal loop, but they were not observed in this study.

It has been recommended that portosystemic shunts be ligated as far from their origin and close to their insertion as possible because portal tributaries may enter the shunting vessel.[13] Our results support this assertion, particularly regarding double-loop shunts. During exploratory laparotomy, the more ventrally located and often larger right gastric loop would likely be more obvious. Placing the occlusion device on that loop alone could result in persistent shunting of blood via the caudal splenic vein loop. For many shunt types, small, late entering gastric branches were often noted. This was particularly evident in the splenoazygos shunts, which featured a large gastric vessel that entered the shunt dorsally near the diaphragm, an area that may be difficult to thoroughly investigate surgically. Occlusion of the shunt between the portal vein and the point of entry of these tributaries could result in persistent blood flow into the systemic circulation from the stomach.[13]

Variation in the exact origin and insertion of shunting loops was greater than previously described. The origin of portocaval shunts has been described as being slightly cranial to the origin of the celiac artery from the aorta.[8] Shunts in this study originated in an area extending from just caudal to the level of the cranial mesenteric artery origin to cranial to the celiac artery origin. The insertion of each portocaval shunt was typically immediately caudal to the liver, at the level of the right kidney, cranial to the phrenicoabdominal vein. Familiarity with these landmarks has been useful in the identification of these shunts ultrasonographically and in surgery at our institution.

Variation between dogs in splenoazygos shunt diameter was seen at the level of the aorta. Dogs with a splenoazygos shunt have less severe clinical signs compared with dogs with other extrahepatic portosystemic shunts shunt conformations and may be diagnosed at an older age.[11,14] This has been theorized to occur because of compression of the shunt by the stomach or diaphragm, resulting in less flow through the shunting vessel.[11] In this study, all shunts were similar in diameter near the stomach, but some abruptly narrowed more dorsally by the aorta. This observation may be attributable to the use of positive-pressure ventilation during image acquisition, leading to an artifactually narrowed vessel diameter as the shunt vessel is forced against the aorta by the lungs. Splenoazygos shunt diameter likely increases during other phases of the respiratory cycle, but this was not assessed.

Portal vein and shunting vessel diameters were measured to fully describe the shunts. Although splenocaval and splenophrenic shunts tended to be relatively large compared with other shunt types, there was variation in the shunt and portal vein diameter between dogs with similar shunt conformations. Statistical comparison of shunt or portal vein diameter was not performed given the low number of dogs with each shunt conformation. Ratios of the portal vein diameter to aortic diameter and shunt diameter to aortic diameter have been reported for ultrasound measurements.[15] The range in shunt to aorta ratio and portal vein to aorta ratio found in this study are similar to those quantified sonographically.[15] Most shunts were the same or slightly greater in diameter than the aorta and the cranial portal vein less than that of the aorta. Assessment of portal vein size cranial to the shunt origin may be important in animals, where surgery is contemplated. In all but two dogs, the portal vein had a decreased diameter cranial to the origin of the shunting vessel. This is consistent with secondary portal vein hypoplasia due to shunting of most or all of the portal venous return to the systemic circulation.[5] In two dogs, the portal vein could not be identified cranial to the origin of the shunt, likely representing portal atresia.[11] Diagnosis of portal vein atresia on CT should be performed with some caution as a small persistent portal vein may be present but not

detectable by CT and may enlarge when blood flow is redirected surgically.

In conclusion, most dogs with a congenital extrahepatic portosystemic shunt will have a conformations similar to one described in this paper. Shunts with two large anastomosing loops were identified and are important to recognize if surgical correction is considered. While other complex shunts have been described, the three-dimensional models here should represent the majority of shunts and serve as a useful guide. Minor variations of each shunt exist, with differences in origin and insertion as well as tributary vessels, but these are not likely to be clinically significant.

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