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Canine intrahepatic portosystemic shunt insertion into the systemic circulation is commonly through primary hepatic veins as assessed with CT angiography

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Abstract

Congenital intrahepatic portosystemic shunts (IHPSS) in dogs are traditionally classified as right, left, or central divisional. There are few descriptive studies regarding the variation of IHPSS within these categories. This multicenter, analytical, cross-sectional study aimed to describe a large series of dogs with CT angiography (CTA) of IHPSS, hypothesizing that there would be variation to the existing classification. Ninety CTA studies were assessed for IHPSS type, insertion, and the relationship of the insertion to the primary hepatic veins. Ninety-two percent of IHPSS inserted into a primary hepatic vein (HV) or phrenic vein, 8% inserted directly into the ventral aspect of the intrahepatic caudal vena cava. The most common IHPSS type was a single right divisional (44%), including those inserting via the right lateral HV or the caudate HV. Left divisional IHPSS (33%) inserted into the left HV or left phrenic vein. Central divisional IHPSS (13%) inserted into the quadrate HV, central HV, dorsal right medial HV, or directly into the ventral aspect of the intrahepatic caudal vena cava. Multiple sites of insertion were seen in 9% of dogs. Within left, central, and right divisional types, further subclassifications can therefore commonly be defined based on the hepatic veins with which the shunting vessel communicates. Relating IHPSS morphology to the receiving primary HV could make IHPSS categorization more consistent and may influence the type and method of IHPSS attenuation recommended.

KEYWORDS
CTA, dog, liver, PSS, vascular

1 | INTRODUCTION

Congenital portosystemic shunting vessels in dogs are classified as either intrahepatic or extrahepatic,[1] with intrahepatic portosystemic shunts (IHPSS) being more common in medium and large breed dogs.[2] Intrahepatic portosystemic shunts are traditionally classified as left,

Abbreviations: CTA, CT angiography; CVC, caudal vena cava; HV, hepatic vein; IHPSS, intrahepatic portosystemic shunt.

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central, or right divisional, based on the liver lobe through which the IHPSS passes.[3] Intrahepatic portosystemic shunts morphology has been described in detail using ultrasonography and intraoperative mesenteric portovenography.[1,3,4] Left divisional IHPSS are described as typically forming a short communication between the left portal branch and the left hepatic vein (HV) and most likely represent a patent ductus venosus.[1,5,6] Central divisional IHPSS are described involving the right medial or quadrate liver lobes. On the basis of surgical examination and ultrasonography, the portosystemic communication normally takes the form of a focal dilation of the portal vein forming a foramen with the caudal vena cava (CVC).[3] Right divisional IHPSS are described extending to the right of midline, involving the right lateral and caudate lobes, often forming a long loop before inserting into the CVC.[3]

The availability of CT angiography (CTA), and more recently multidetector CTA, in veterinary care centers has led to an increased use of CTA in the diagnostic work-up and surgical planning for dogs with a suspected portosystemic shunt.[7–11] While there has been considerable work in recent years to characterize and classify extrahepatic portosystemic shunts using CTA,[10,12] there have been no systematic descriptions of the CTA features of IHPSS. A few studies have included a small number of dogs with IHPSS that had CTA performed, but the IHPSS morphology was not described in detail.[7,8,13,14] A single case report describes CTA of a complex IHPSS that did not conform to the traditional classification system.[15] Two studies report multiple IHPSS that were more apparent after surgical ligation.[14,16] Eleven single IHPSS (2 central divisional, 3 right divisional, 6 left divisional) were described using magnetic resonance angiography[17] and a single central divisional IHPSS was described[18] using the same modality.

The authors have observed that in some instances, IHPSS insert into the intrahepatic CVC in the expected position of normal hepatic veins. The aims of this study were to analyze the CTA imaging features of IHPSS identified in a large series of dogs from a multicenter population, further characterize the IHPSS morphology, and identify any relationship between the shunting vessel and the primary hepatic veins. We hypothesized that CTA would identify that IHPSS insert into the intrahepatic CVC via the primary hepatic veins, leading to a further subclassification of IHPSS.

2 | METHODS

In this multicenter, analytical, cross-sectional study, medical records from four veterinary referral centers (Queen Mother Hospital for Animals at the Royal Veterinary College, University of Tennessee Veterinary Medical Center, University of Georgia Veterinary Teaching Hospital, and the University of California, Davis Veterinary Medical Teaching Hospital) were searched for dogs with a final diagnosis of IHPSS, between January 2011 and May 2018. Ethical approval was granted by the Royal Veterinary College Social Science Ethical Review Board (Reference: SR2018-1636). Inclusion criteria included a precontrast and postcontrast CTA examination and confirmed the presence of an IHPSS, as reported in the original radiology report. Excluded were CTA studies that omitted part of the liver and patients with situs inversus. Decisions for subject inclusion were made by a ACVR and ECVDI certified veterinary diagnostic imaging diplomate (R.D.) and a diagnostic imaging resident (M.P.) by consensus agreement. The non-imaging data gathered from the records included gender, neuter status, breed, age, and weight at the time of CTA, in order to assess for possible associations between these data and IHPSS type.

All CTA images were reviewed by the same observers as those described above, using image analysis freeware (OsiriX, v.6.5.2. 64bit; Pixmeo SARL, CH1233 Bernex, Switzerland), with findings recorded based on consensus agreement. Observers used transverse plane images, multiplanar reformatted images, and maximum intensity projections for interpretations. Window width and level were altered as needed to optimize image contrast. At the time of data recording, observers had access to patient signalment and the IHPSS type originally reported. The IHPSS classification (right divisional, left divisional, central divisional, or multiple) was determined by the origin from the portal vein (right or left portal branch), the insertion point into the systemic circulation, and the liver lobe(s) through which the IHPSS coursed. The insertion of the IHPSS was determined as being either directly into the CVC (left, right, or ventral aspect), or via insertion into a primary HV (caudate, right lateral, dorsal right medial, ventral right medial, quadrate, central HV, papillary, or left HV) or a phrenic vein (left or right). Intrahepatic portosystemic shunts involving the right portal branch, the right lateral hepatic lobe, caudate, or papillary processes of the caudate lobe, and their associated hepatic veins were classified as right divisional. Intrahepatic portosystemic shunts involving the left portal branch, the left lateral or left medial hepatic lobes, with insertion via the left HV or left phrenic vein were classified as left divisional. Intrahepatic portosystemic shunts involving the left portal branch, the right medial or quadrate hepatic lobes, and their associated hepatic veins were classified as central divisional. For IHPSS that inserted into the right lateral or left HV, the point of insertion was described as being proximal (closer to the CVC) or distal (more distant to the CVC), based upon a subjective assessment of the relationship of the insertion to the midpoint along the length of the HV.[19] The ability of the observers to identify the other primary hepatic veins was assessed. Extrahepatic portal anatomy was determined as normal or abnormal.[20] The presence of peritoneal effusion, urolithiasis, and any other congenital abnormalities, were also recorded.[21–23]

Statistical analyses were selected and performed by a diagnostic imaging resident (M.P.) using a commercial statistical software program (SPSS 24, IBM, Armonk, NY, USA). Independent associations between IHPSS type and other categorical data were assessed with a Chi-squared test, and associations between IHPSS type and continuous data were assessed with a Kruskal-Wallis test. $P \leq .05$ was considered statistically significant. Significant associations were then assessed with multinomial logistic regression, using the most frequent shunt type as the reference category.

TABLE 1 Distribution of intrahepatic portosystemic shunt types and their insertion

Shunt Type	Insertion	Number (Percentage)	
Right divisional	Right lateral hepatic vein	34 (38%)	40 (44%)
	Caudate hepatic vein	6 (7%)	
Left divisional	Left hepatic vein	19 (21%)	30 (33%)
	Left phrenic vein	11 (12%)	
Central divisional	Quadrate hepatic vein	4 (4%)	12 (13%)
	Central hepatic vein	1 (1%)	
	Dorsal right medial hepatic vein	1 (1%)	
	Ventral aspect of caudal vena cava	6 (7%)	
Multiple	Variable	8 (9%)	8 (9%)

3 | RESULTS

Ninety dogs with IHPSS were included in the study. Forty-nine of the 90 (54%) dogs were female (22 neutered), 41 of 90 (46%) were male (16 neutered). Median age was 7 months (range 3-160 months). Patient weight was available in 64 of 90 (71%) dogs; the mean weight was 16.4 kg (SD 9.0 kg). The different breeds included in the study are summarized in Supporting Information 1. Computed tomographic angiography acquisition parameters and patient distribution between institutions are summarized in Supporting Information 2.

3.1 | Shunt types

Distribution of IHPSS types observed is summarized in Table 1. In 83 of 90 (92%) dogs, the insertion of the IHPSS into the systemic venous circulation corresponded with the expected position of a primary HV or phrenic vein. Figure 1 shows the most common normal anatomical arrangement of the canine intrahepatic portal vein and primary hepatic veins for reference.[24–26]

3.1.1 | Right divisional

Forty of 90 (44%) dogs had a single right divisional IHPSS. In 34 of 90 (38%) dogs, a single IHPSS inserted into the CVC via the right lateral HV (Figure 2A,B). The exact position of the communication between the right portal branch and the right lateral HV varied and gave rise to either a short C-shaped IHPSS, or a more tortuous vessel, however the origin from the portal vein and insertion into the CVC remained consistent. The normal caudate HV inserted separately into the CVC, caudal to the dilated right lateral HV. The normal dorsal right medial HV inserted separately into the CVC, cranially to the right lateral HV, in 30 of 34 (88%) dogs. In four of 34 (12%) dogs, a non-dilated dorsal right medial HV inserted immediately adjacent to the dilated right lateral HV at its insertion into the CVC. In five of 34 (15%) dogs, the abnormally dilated right portal branch and right lateral HV formed a network of anastomoses, communicating only with each other, retaining a single site of insertion into the CVC (Figure 3).

Six of 90 (7%) dogs had a single right divisional IHPSS that originated at the right portal branch but inserted via the caudate HV (Figure 2C,D). The non-dilated right lateral HV and dorsal right medial HV inserted into the CVC cranial to the dilated caudate HV.

3.1.2 | Left divisional

In 30 of 90 (33%) dogs, a single left divisional IHPSS was present. This included 19 of 90 (21%) single IHPSS that communicated with the ventromedial aspect of a dilated left HV. The position along the left HV at which the anomalous communication occurred varied. Some left divisional IHPSS inserted distally causing dilation of the majority of the left HV (Figure 4A,B). Others inserted proximally, adjacent to the insertion of the central HV into the left HV, resulting in more focal dilatation of the left HV (Figure 4C,D). One left divisional IHPSS had two distinct insertion sites at the left HV, which was considered a type of anastomosis rather than being classified as an IHPSS with multiple insertions.

In 11 of 90 (12%) dogs, the IHPSS originated at the left portal branch but inserted into the left phrenic vein (Figure 4E,F). A short communication existed between the left portal branch and the ventral aspect of the left phrenic vein, approximately on midline. The anomalous communication was identified immediately caudal to the left HV, with no communication between the two structures, and immediately cranial to the papillary process of the caudate lobe. In all dogs, the left HV was subjectively smaller than normal.

One dog with a left HV insertion and two dogs with left phrenic vein insertions had multiple tortuous small vessels (<2 mm diameter) branching from the shunting vessel into the hepatic parenchyma, possibly inserting into distal HV branches separate to the main IHPSS. However, the small caliber of these tortuous vessels meant that they were difficult to follow and the exact anatomic communications to the hepatic veins remain undetermined.

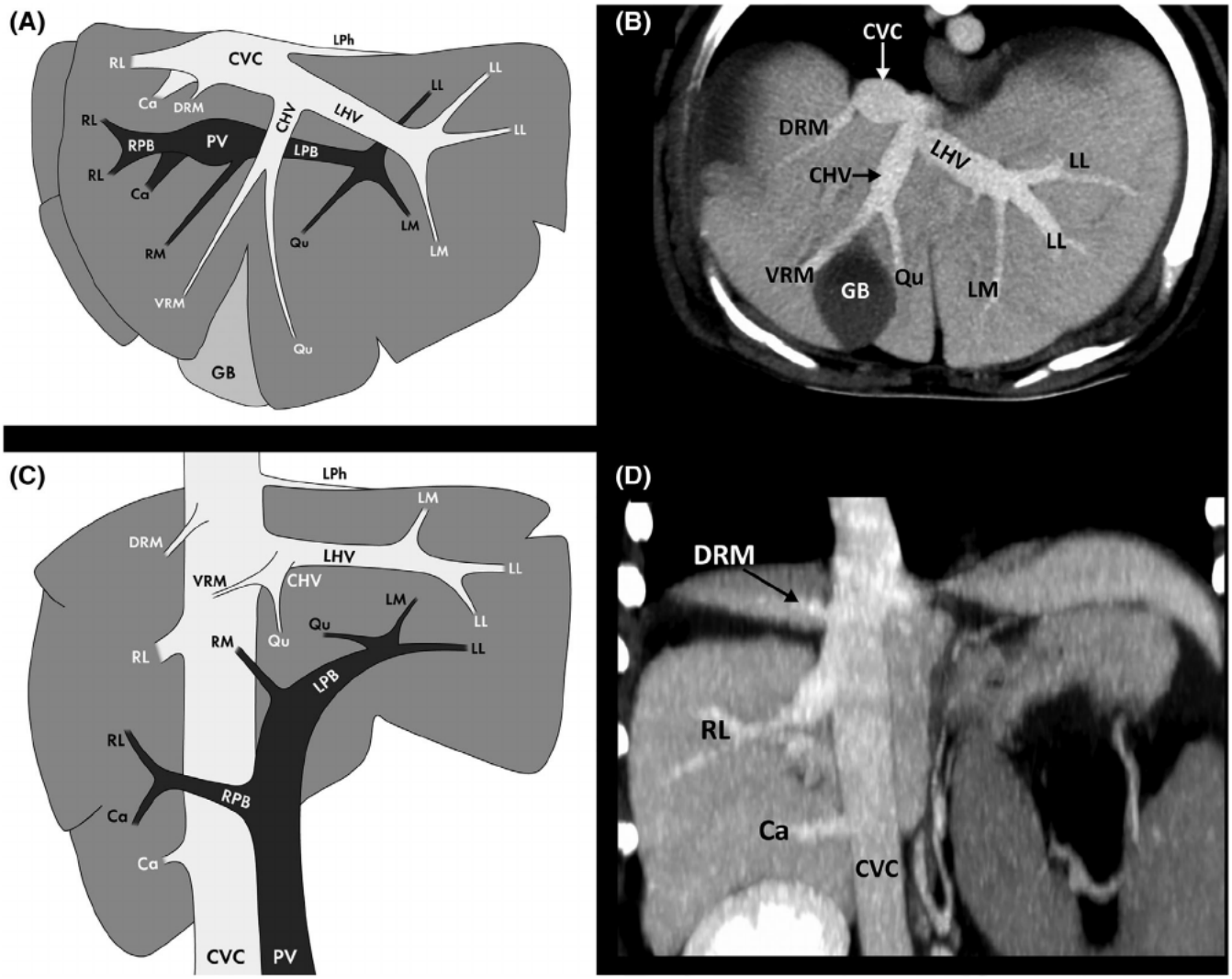

FIGURE 1 Schematic transverse (A) and dorsal plane (C) diagrams showing the most common normal anatomical arrangement of the canine intrahepatic portal vein (dark gray) and primary hepatic veins (light gray). Equivalent 5 mm transverse (B) and 8 mm dorsal plane (D) maximum intensity projection Computed tomographic angiography (CTA) images of a dog with hepatic venous congestion and ascites, highlighting the normal hepatic veins. The papillary process and its vessels are not shown. Computed tomographic angiography images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, Window width 200 HU, window level 100 HU.
Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; LPh, left phrenic vein; DRM, dorsal right medial hepatic vein; VRM, ventral right medial hepatic vein; RL, right lateral lobar vein; Ca, caudate lobar vein; Qu, quadrate lobar vein; LM, left medial lobar vein; LL, left lateral lobar vein; GB, gallbladder

3.1.3 | Central divisional

A single central divisional IHPSS was present in 12 of 90 (13%) dogs. In four of 90 (4%) dogs, there was a single anomalous communication between the ventral aspect of the left portal branch and the left side of a dilated quadrate HV (Figure 5A,B). This dilated quadrate HV continued dorsally as a dilated central HV that inserted into the proximal left HV in a normal position. A non-dilated ventral right medial HV joined the dilated quadrate HV, to form the central HV in the usual manner.

One dog (1%) had a central divisional IHPSS that inserted via the central HV, without dilation of the quadrate HV (Figure 5C,D). A single tortuous vessel originated from the left portal branch and formed two separate communications with the right side of the dilated central HV. The dilated central HV inserted into the ventral aspect of the left HV in the normal position.

One dog (1%) had a single central divisional IHPSS inserting with the dorsal right medial HV (Figure 6). The anomalous vessel originated from the left portal branch, ran ventrally along the right side of the gallbladder then dorsally along the diaphragmatic surface to insert into the right side of the CVC in the expected position of the dorsal right medial HV. The other hepatic veins were non-dilated and inserted normally into the CVC.

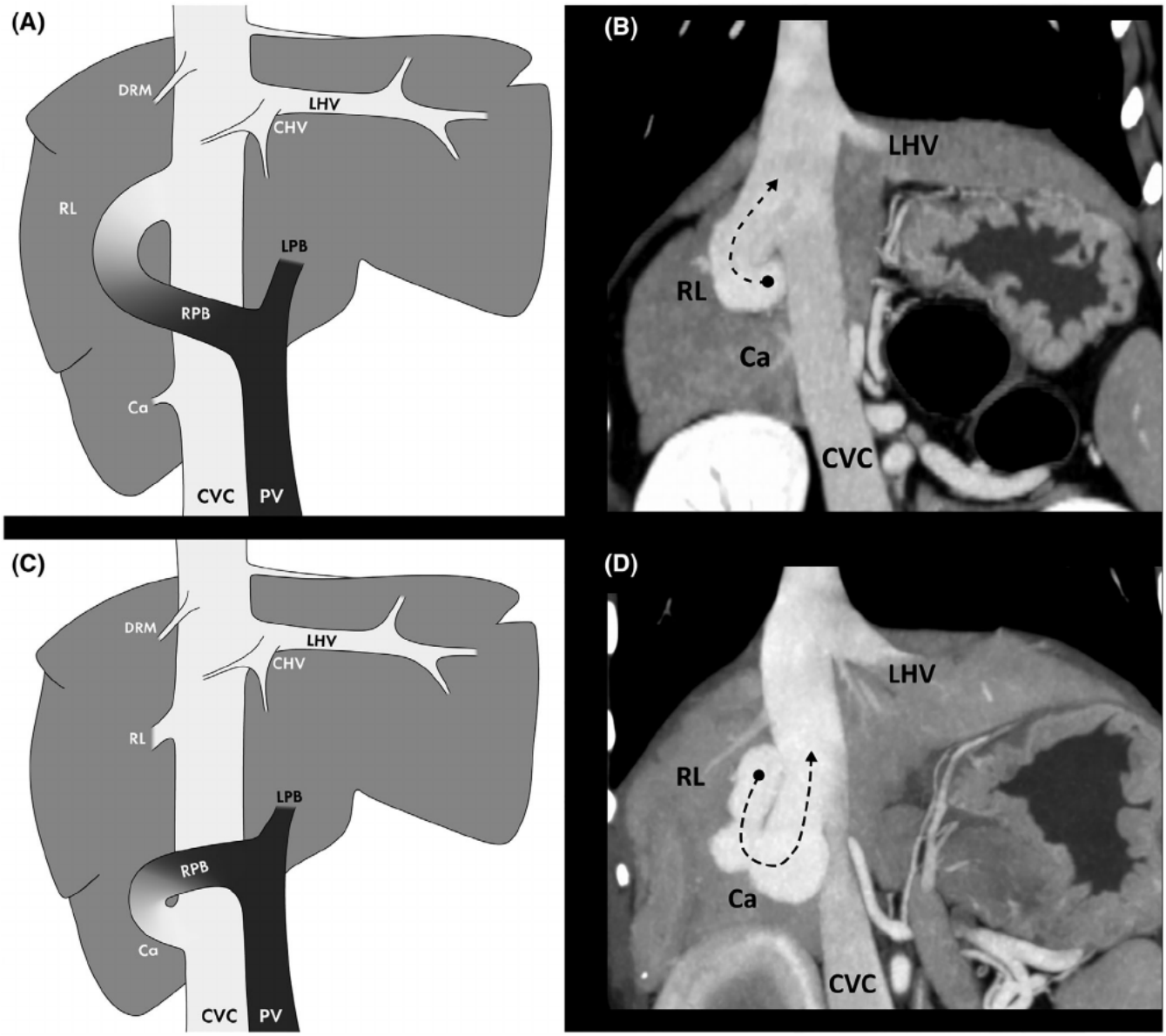

FIGURE 2 A and B, Dorsal plane schematic diagram (A) and 3 mm maximum intensity projection CTA image (B) of a single right divisional intrahepatic portosystemic shunt inserting via the right lateral hepatic vein. Note the normal separate insertion of the caudate hepatic vein caudal to the shunting vessel. C and D, Dorsal plane schematic diagram (C) and 5 mm maximum intensity projection CTA image (D) of a single right divisional intrahepatic portosystemic shunt that inserts via the caudate hepatic vein. Note the normal separate insertion of the right lateral hepatic vein cranial to the shunting vessel. Dashed arrows show the assumed direction of blood flow from the portal system to the systemic circulation. Computed tomographic angiography images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, Window width 400 HU, window level 100 HU.
Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; DRM, dorsal right medial hepatic vein; RL, right lateral lobar vein; Ca, caudate lobar vein

In six of 90 (7%) dogs, a single IHPSS originated from the left portal branch and inserted into the ventral aspect of the CVC, without dilation of any recognizable HV (Figure 7). Therefore, the insertion was deemed to be independent of the hepatic venous system. The aberrant communication formed a short vessel or foramen between the dorsal aspect of left portal branch and the ventral aspect of the CVC to the right of the central HV.

3.1.4 | Multiple insertions

In eight of 90 (9%) dogs, multiple insertions into the systemic circulation were identified, with varying morphologies. This included four IHPSS with insertions into the left HV and one or more thinner, tortuous vessels inserting into the quadrate or central hepatic veins. One IHPSS involved a large diameter IHPSS inserting via the

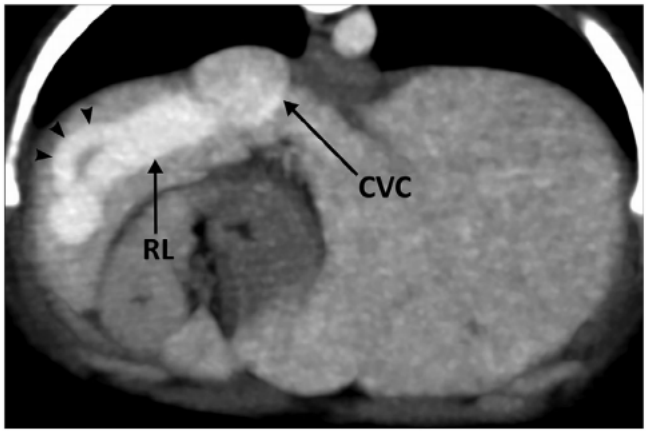

FIGURE 3 Transverse plane 4 mm maximum intensity projection CTA image of a right divisional intrahepatic portosystemic shunt inserting via the right lateral hepatic vein with a simple anastomosis. A short looping vessel branches from, then rejoins, the dilated right lateral hepatic vein (arrowheads); one of several anastomotic loops seen in this dog. Computed tomographic angiography image was reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, Window width 200 HU, window level 100 HU.
Abbreviations: RL, right lateral lobar vein; CVC, caudal vena cava

right lateral HV with an additional thinner vessel inserting via the central HV. One IHPSS involved two separate insertions into the ventral aspect of the CVC: one typical short vessel between the left portal branch and the ventral aspect of the CVC, and a smaller caliber tortuous vessel that coursed through the right medial lobe before inserting into the ventral aspect of the CVC. Two IHPSS inserted into the left HV; however, proximally the left HV did not insert normally into the CVC. Instead, distal to the communication with the portal vein, a looping vessel ran from the ventral aspect of the left HV ventrally and to the right, to insert into the ventral aspect of the CVC in one dog and to insert with the dorsal right medial HV in the other.

3.2 | Additional vascular anomalies

Extrahepatic portal anatomy was normal in 89 of 90 (99%) dogs. One dog that had a single IHPSS inserting into the left phrenic vein, had evidence of multiple acquired extrahepatic portosystemic shunts adjacent to the caudal pole of the right kidney. This dog also had a subjectively large volume of peritoneal fluid and marked gastric wall thickening consistent with edema.

Evidence of arterioportal malformation was present in one dog within the right lateral and right medial lobes of the liver. This dog was not excluded from the study because it had an additional single IHPSS inserting into the left HV that had no communication with the arterioportal malformation.

3.3 | Related findings

Peritoneal effusion was evident in 20 of 90 (22%) dogs. Nephroliths were evident in 21 of 90 (23%) dogs, and cystoliths were present in 23 of 84 (27%) dogs in which the urinary bladder was included in the CTA field of view. Three dogs (3%) had unilateral renal agenesis.

3.4 | Association of shunt type with categorical data

For initial independent assessments of association between IHPSS type and other data, significance was only achieved for breed (Labrador vs other breed). Multinomial logistic regression using right divisional shunts as the reference category showed that left divisional shunts were more common in Labradors compared to other breeds (odds ratio 3.3, 95% confidence interval 1.05-10.3). There was no significant association between referral center and IHPSS type, nor for country of origin (UK vs USA) and IHPSS type ($P = .35$). There was no significant association between IHPSS type and gender ($P = .21$), age ($P = .46$), or weight ($P = .83$).

4 | DISCUSSION

This study demonstrates that most IHPSS communicate with the systemic circulation via the hepatic venous system, rather than directly with the CVC. Therefore, while the traditional classification of left, right, and central divisional IHPSS remains relevant, subclassification is possible for refinement of the descriptions of these vascular anomalies. In this study, 92% of IHPSS were observed inserting into the CVC via a primary HV or phrenic vein. Identifying which hepatic venous structure an IHPSS involves can promote consistent and accurate classification of the IHPSS as right, left, or central divisional. Classification of the IHPSS based on the venous structure it inserts through is likely to be more reliable than attempting to classify the IHPSS based on the portal vasculature, since the intrahepatic portal branches are often small or not visible on CTA in dogs with IHPSS. Similarly, because the exact borders of each hepatic lobe are not clearly delineated with CTA, attempting to classify the IHPSS solely based on the lobe through which the aberrant vessel passes is often unrewarding. With IHPSS, the hepatic parenchyma may be asymmetrically hypoplastic, resulting in lateral shift of normal anatomical structures, such as the gallbladder and the portal vein itself, to one side, making the traditional characterization further unreliable. The position of insertion of the hepatic veins into the CVC will remain constant despite these potential shifts, allowing easy distinction with CTA, providing a consistent method of IHPSS classification.

Subclassification of left, central, and right divisional IHPSS allows additional description of the morphological variation within these categories. For example, among right divisional IHPSS, the insertion into

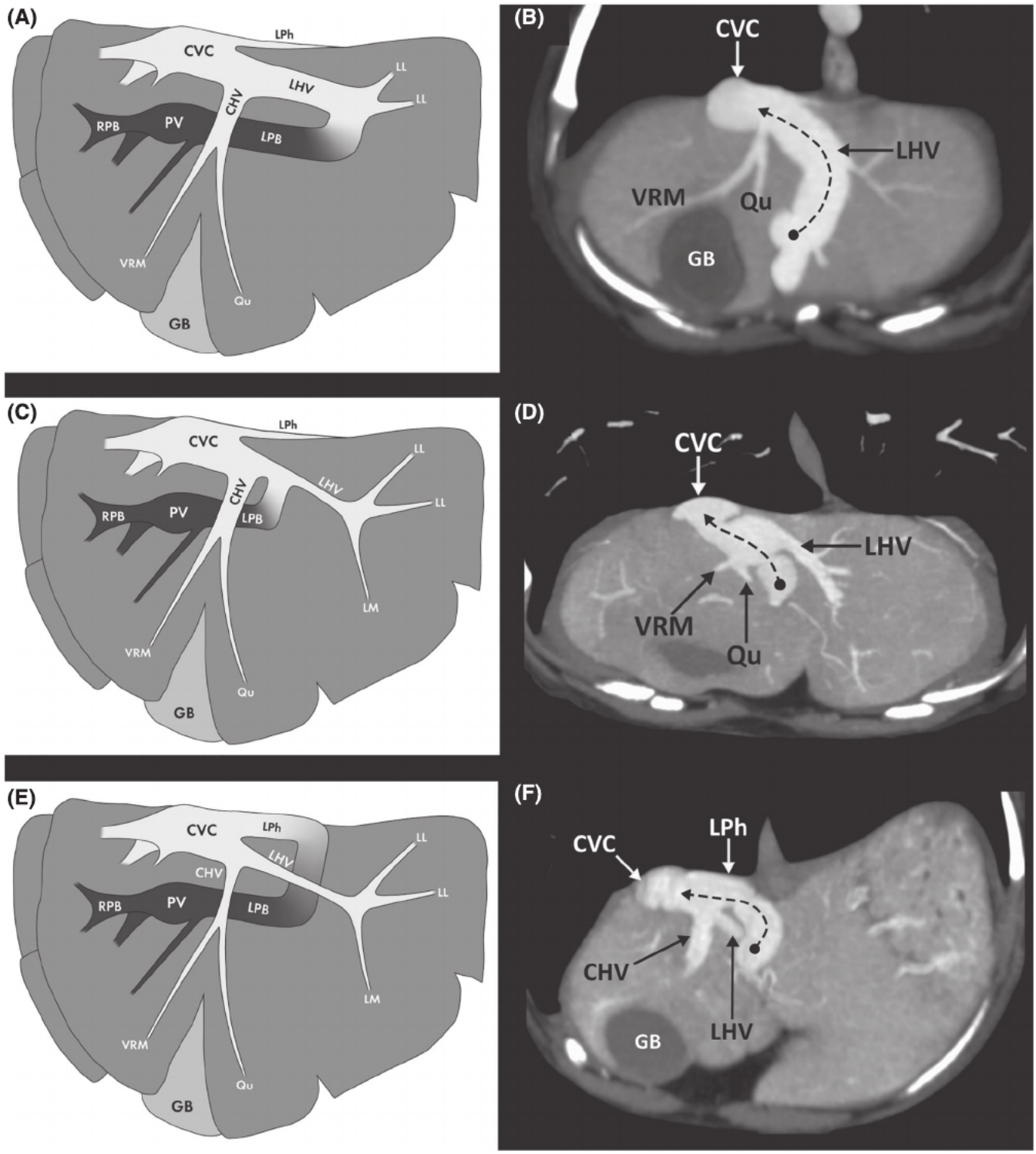

FIGURE 4 A and B, Transverse plane schematic diagram (A) and 5 mm maximum intensity projection computed tomographic angiography (CTA) image (B) of a single left divisional intrahepatic portosystemic shunt inserting via the distal portion of the left lateral hepatic vein. C and D, Transverse plane schematic diagram (C) and 8 mm maximum intensity projection CTA image (D) of a single left divisional intrahepatic portosystemic shunt inserting via the proximal portion of the left lateral hepatic vein. E and F, Transverse plane schematic diagram (E) and 2 mm maximum intensity projection CTA image (F) of a single left divisional intrahepatic portosystemic shunt inserting via the left phrenic vein. Note the normal insertion of the non-dilated left lateral and central hepatic veins. Dashed arrows show the assumed direction of blood flow from the portal system to the systemic circulation. Computed tomographic angiography images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, window width 400 HU, window level 100 HU.

Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; LPh, left phrenic vein; LM, left medial lobar vein; LL, left lateral lobar vein; VRM, ventral right medial hepatic vein; Qu, quadrate lobar vein; GB, gallbladder

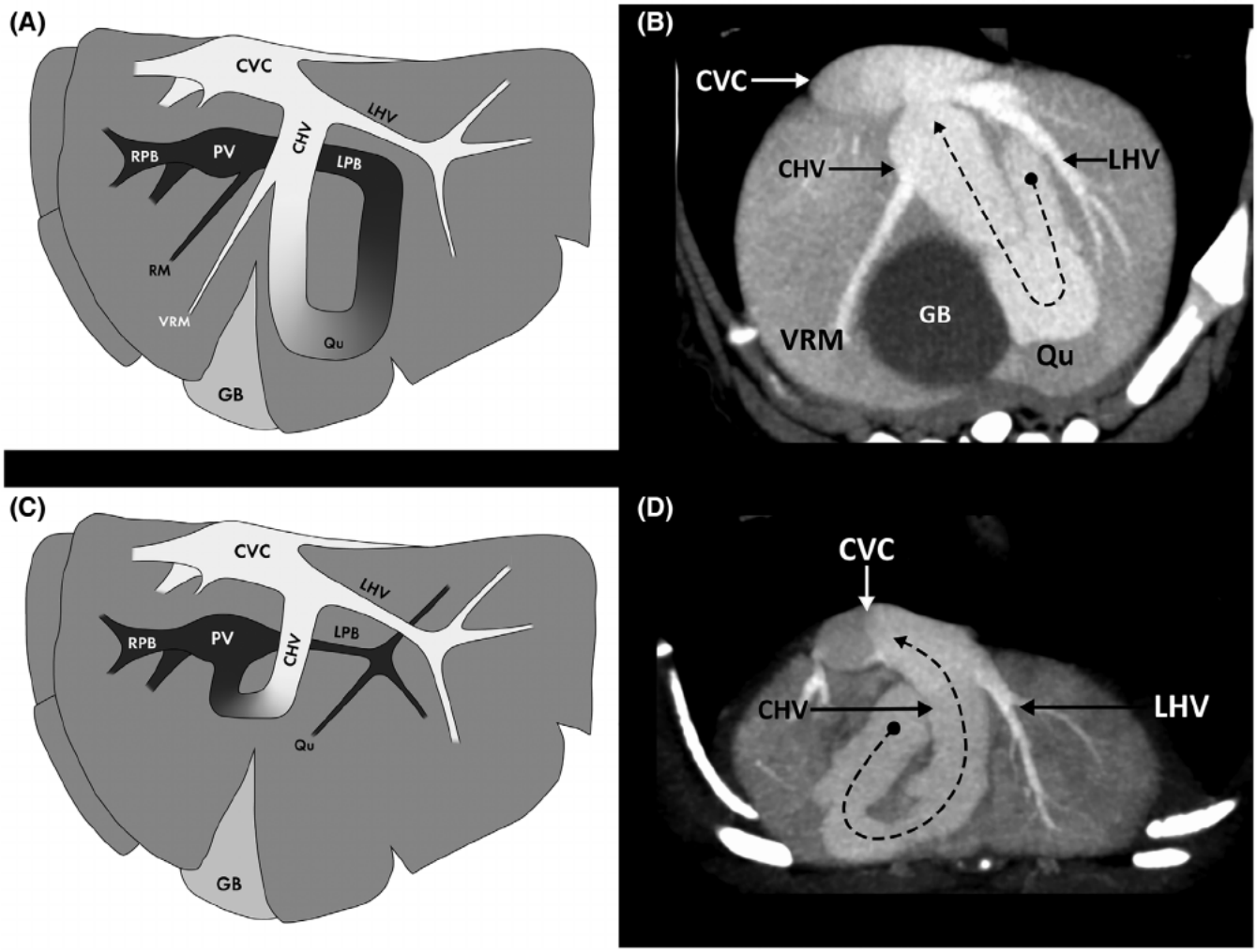

FIGURE 5 A and B, Transverse plane schematic diagram (A) and 5 mm maximum intensity projection CTA image (B) of a single central divisional intrahepatic portosystemic shunt inserting via the quadrate hepatic vein. C and D, Transverse plane schematic diagram (C) and 5 mm maximum intensity projection CTA image (D) of a single central divisional intrahepatic portosystemic shunt inserting via the central hepatic vein. Note the communication of the shunting vessel with the right side of the central hepatic vein. An additional communication between the shunting vessel and the central hepatic vein immediately caudal to this is not shown. Dashed arrows show the assumed direction of blood flow from the portal system to the systemic circulation. Computed tomographic angiography images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, Window width 300 HU, window level 100 HU.
Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; VRM, ventral right medial hepatic vein; Qu, quadrate lobar vein; GB, gallbladder

the CVC may be via the right lateral HV or via the more caudally located caudate HV. If surgical ligation of the IHPSS is considered, distinguishing which HV is involved may have implications for the surgical approach required and the remaining venous drainage post-occlusion. Similarly, for left divisional IHPSS, insertion may be via the left HV or left phrenic vein, which may require differing surgical approaches.

The concept of IHPSS insertion via hepatic veins may also have an impact on the method of IHPSS attenuation selected. Intrahepatic portosystemic shunts attenuation can be achieved through surgical ligation, delayed occlusive devices or transvenous embolization.[14,27–29] Surgical IHPSS attenuation is commonly performed as close to the CVC as possible and the current technique of coil embolization requires attenuation at the junction of the shunting vessel (or dilated HV) with the CVC. However, the anomalous communication between the portal and systemic circulations is often located in the more distal portion of the affected HV. Therefore, attenuation of the IHPSS close to the CVC will inevitably occlude the normal hepatic venous drainage of the involved lobe. Since the left hepatic and central hepatic veins merge adjacent to their insertion into the CVC, surgical occlusion at this site for IHPSS involving either of these vessels may interrupt the venous drainage from multiple hepatic lobes, and not only the lobe in which the IHPSS occurs. The exact impact of such a compromise on normal primary hepatic venous drainage has not been directly assessed. It is conceivable that attenuation of IHPSS types that do not involve other venous tributaries, such as those inserting via the left phrenic vein, would have less impact on normal hepatic venous drainage.

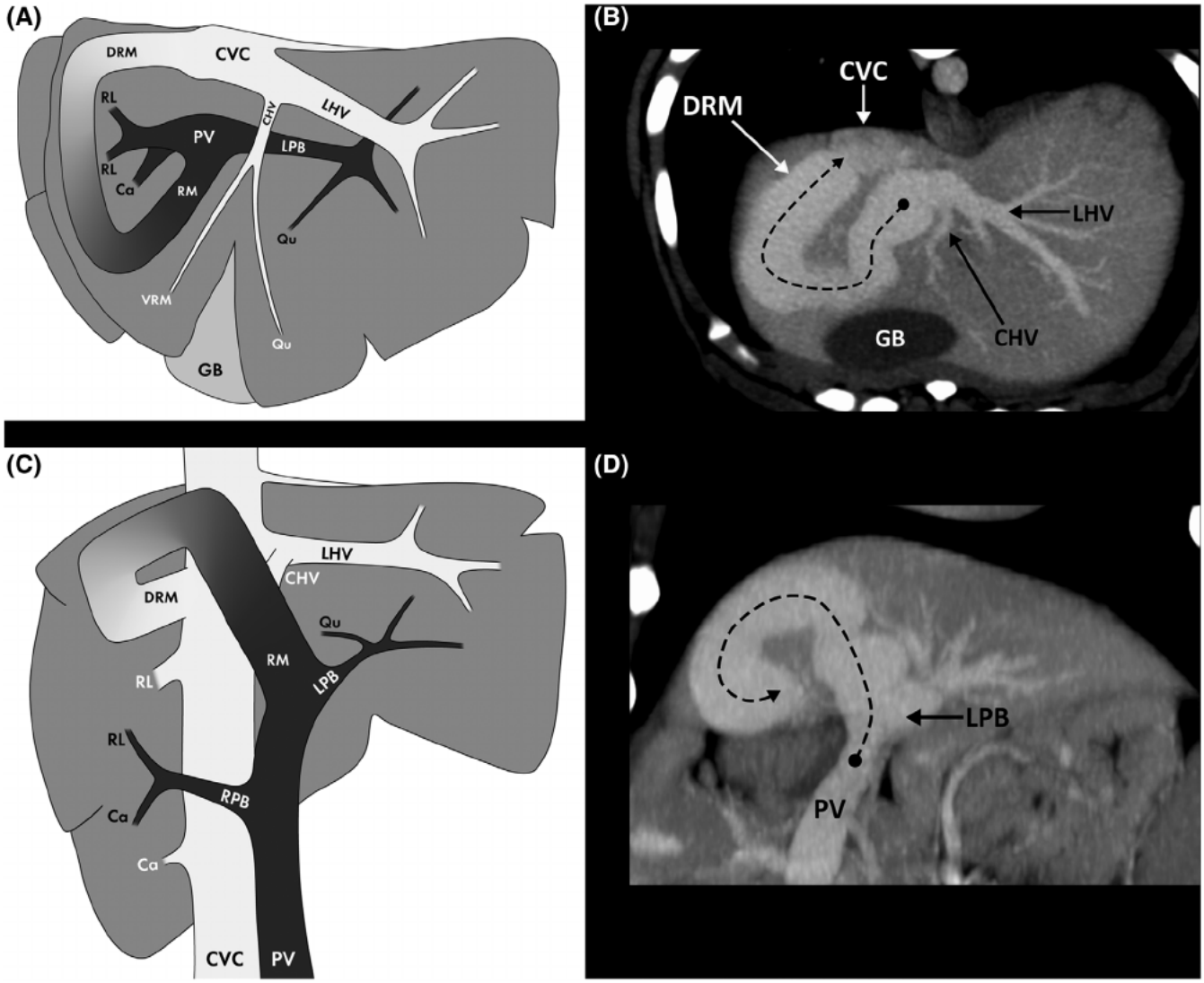

FIGURE 6 Schematic transverse (A) and dorsal plane (C) schematic diagrams and 5 mm transverse (B) and 10 mm dorsal plane (D) maximum intensity projection CTA images of a single central divisional intrahepatic portosystemic shunt inserting via the dorsal right medial hepatic vein. Dashed arrows show the assumed direction of blood flow from the portal system to the systemic circulation. Computed tomographic angiography images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, window width 400 HU, window level 100 HU.

Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; DRM, dorsal right medial hepatic vein; VRM, ventral right medial hepatic vein; RL, right lateral lobar vein; Ca, caudate lobar vein; Qu, quadrate lobar vein; GB, gallbladder

Further studies comparing surgical outcomes of different IHPSS types may indicate whether this consideration is clinically relevant.

There was additional morphological variation within groups of IHPSS that inserted via the same HV, particularly in those dogs with either right lateral or left HV insertion. The anomalous communication could occur proximally or distally along the affected HV. This variation likely reflects the complex embryological development of the intrahepatic portal and hepatic veins from a dense network of vitelline veins in the fetal liver.[30] It is likely that an abnormally enlarged communication between the developing portal veins and hepatic veins could occur anywhere within this dense network. This could result in an IHPSS between any portion of the portal vein and an adjacent HV. This development from a network of vessels may also explain the variant of single right divisional IHPSS, described in the current study, in which there were multiple anastomoses along the course of the IHPSS.

Left divisional IHPSS have been assumed to represent a patent ductus venosus.[3,6] The ductus venosus in dogs is an anatomically consistent embryological vessel between the left branch of the developing portal vein and the proximal portion of the left HV.[5] Previous studies of patent ductus venosus describe this vessel inserting into a venous ampulla at the confluence of the left HV and left phrenic vein as they insert into the CVC.[6,31] In accordance with more recent studies on the morphology of canine hepatic veins,[24–26] the present study describes this insertion site as the proximal left HV. As previously

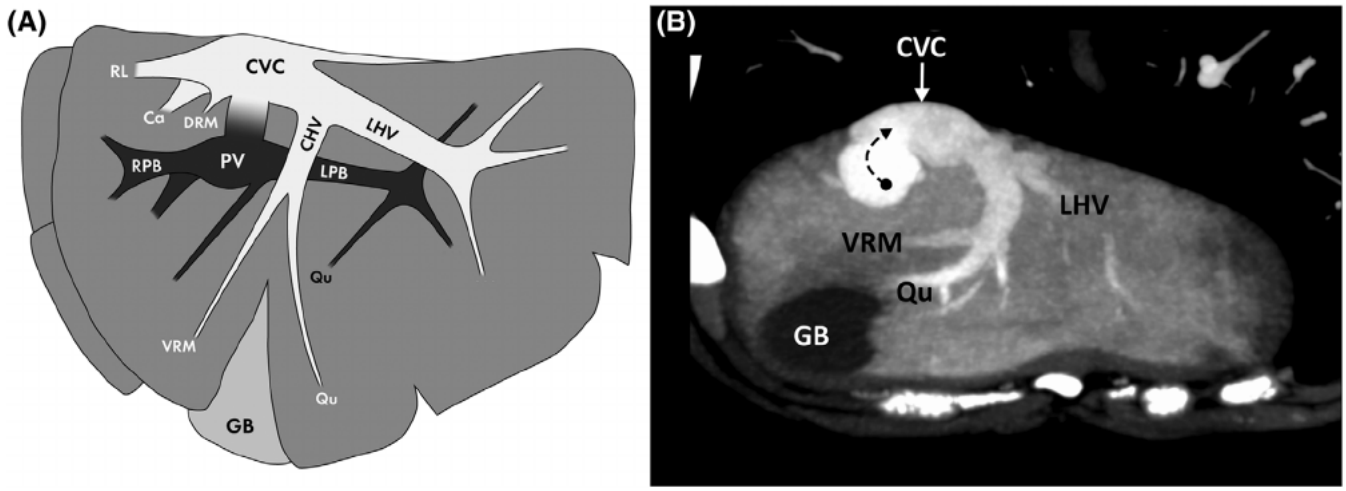

FIGURE 7 Transverse plane schematic diagram (A) and 10 mm maximum intensity projection CTA image (B) of a single central divisional intrahepatic portosystemic shunt inserting via the ventral aspect of the caudal vena cava. Note the normal insertion of the non-dilated left hepatic vein and central hepatic vein. Dashed arrow shows the assumed direction of blood flow from the portal system to the systemic circulation. CTA images were reconstructed with a soft tissue algorithm, field of view adjusted to patient size, matrix 512 × 512, window width 230 HU, window level 130 HU.

Abbreviations: PV, portal vein; RPB, right portal branch; LPB, left portal branch; CVC, caudal vena cava; LHV, left hepatic vein; CHV, central hepatic vein; DRM, dorsal right medial hepatic vein; VRM, ventral right medial hepatic vein; RL, right lateral lobar vein; Ca, caudate lobar vein; Qu, quadrate lobar vein; GB, gallbladder

discussed, there was variation among left divisional IHPSS in the position of insertion along the left HV and it is currently unclear whether those inserting proximally, traditionally classified as a patent ductus venosus, would have the same embryological formation as those inserting more distally along the left HV. It was not possible to distinguish those IHPSS inserting distally from those inserting proximally into the left HV. It is also unclear whether the left divisional IHPSS inserting into the left phrenic vein, rather than the left HV, represent an aberrant patent ductus venosus or a different vascular anomaly.

Intrahepatic portosystemic shunts with multiple insertion sites were uncommon, consistent with a sporadic number of prior reports.[14,15,32] In humans, and in a recent review of canine portal venous anomalies, IHPSS with multiple insertion sites have been recognized as a distinct classification type.[33,34] In the present study, 9% of IHPSS involved more than one communication with the systemic circulation, yet commonly retained a pattern of insertion via the primary hepatic veins. Prior to surgical intervention, multiple insertion sites are particularly important to identify, as occlusion of only one of the anomalous communications may reduce the efficacy of shunt attenuation. Given the variability seen within this subclassification, detailed descriptions of the individual morphology of each IHPSS with multiple insertions were deemed beyond the scope of this manuscript, and the authors suggest further investigations into this particular subsection of IHPSS. In particular, assessment of portosystemic flow through the multiple branches, using intraoperative mesenteric portovenography or dynamic CTA, and corroboration with surgical findings and postoperative outcomes, would help clarify the clinical significance of identifying multiple insertion sites with CTA. Assessment of CTA for concomitant vascular anomalies is also important, as demonstrated by the identification of one dog with arterioportal malformation, and one dog with multiple acquired extrahepatic portosystemic shunts, with each finding separate from the IHPSS.

Three dogs with left divisional IHPSS had multiple associated tortuous branches that may indicate additional routes of portosystemic shunting. These small vessels were only noted with slice thickness of 0.625 mm. Reducing slice thickness may increase the detection of these small vessels by improving spatial resolution in the *z*-axis, reducing volume averaging artifact, and producing isotropic voxels to allow multiplanar reconstruction without loss of image quality.[35] The detection of small vessels such as these may also rely on adequate opacification with contrast, and so will be affected by the contrast protocol used.[36] In this study, the contrast protocol, including injection rate and scan timing, was variable between the different institutions. While the major portal branches and hepatic veins were adequately opacified in all dogs included, it is possible that some smaller additional shunting vessels were not seen due to inadequate contrast protocol optimization and standardization. These tortuous small caliber vessels have been described previously, and have been shown to increase in size and conspicuity following shunt attenuation.[14,16]

The distribution of IHPSS types seen in the present study is different to those previously reported. In the present study, right divisional IHPSS were the most common, followed by left divisional, central divisional, and multiple insertions. Previous reports have shown left divisional and central divisional IHPSS to be most common.[3,27,37] A previous study has shown an association between IHPSS type and breed, country of origin (USA vs Australia), and gender.[37] Labrador Retrievers were the most frequent breed in the present study and were more likely to have a left divisional IHPSS compared to other breeds. Previously identified associations between IHPSS type and

other breeds include Irish Wolfhounds with left divisional IHPSS, and Australian Cattle Dogs with right divisional IHPSS, however only one of each of these breeds were included present study.[37,38] No association between country of origin (USA vs UK) and IHPSS was identified, likely reflecting the similar breed distributions between the two countries. A previously identified association between male dogs and right divisional IHPSS was not demonstrated in this population.[37]

Another reason for the different distribution of IHPSS types in our study when compared to previous reports may be due to the inclusion of only patients with CTA. It is possible that an alternative diagnostic technique such as ultrasonography was employed first, and that CTA may have only been used in dogs when other techniques were deemed inconclusive. This may have produced a selection bias toward more complex and unusual IHPSS types.

Another limitation of our study is the lack of surgical confirmation for every dog. While surgical intervention was performed in many of the dogs, it was considered that making this a specific inclusion criterion would exclude some of the more complex IHPSS types in which surgical intervention may not have been attempted. Additionally, surgical visualization of the exact morphology of the IHPSS in its entirety is limited compared to the more comprehensive assessment of the intrahepatic structures that can be achieved with CTA. Intraoperative mesenteric portovenography was also not assessed in these patients. While this technique provides dynamic information about the flow through the aberrant vessel before and after occlusion and can better assess portal arborisation,[39] CTA has the advantage of a tomographic assessment without superimposition and facilitates three-dimensional assessment of vessel morphology. However, without portovenography only the morphological features of the IHPSS can be assessed and the portal to systemic shunting of blood is assumed.

In conclusion, IHPSS commonly communicate with the CVC via primary hepatic veins, the identification of which may assist in classification and surgical planning. Computed tomographic angiography is a useful method of evaluation of these shunts and allows further subclassification to refine the anatomical descriptions of these vascular anomalies.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Plested, Drees
(b) Acquisition of Data: Plested, Drees, Hecht, Zwingenberger, Secrest
(c) Analysis and Interpretation of Data: Plested, Drees, Brockman, Zwingenberger, Culp

Category 2

(a) Drafting the Article: Plested, Drees
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Category 3

(a) Final Approval of the Completed Article: Plested, Drees, Brockman, Hecht, Zwingenberger, Secrest, Culp

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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