Portosystemic shunts in dogs and cats: imaging portosystemic shunts in small animals – ultrasonography, nuclear scintigraphy, computed tomography, magnetic resonance imaging

Portosystemische shunts bij honden en katten: beeldvorming van portosystemische shunts bij kleine huisdieren – echografie, nucleaire scintigrafie, computertomografie, magnetische resonantie

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ABSTRACT

Because of the non-specificity of the clinical signs and laboratory findings, imaging techniques such as portography, ultrasonography (US), nuclear scintigraphy, computed tomography (CT), or magnetic resonance imaging (MRI) are required to provide a definitive diagnosis of portosystemic shunts (PSSs). Nuclear scintigraphy is the gold standard for detecting PSSs, but it is not useful in distinguishing the different types of shunts. Due to its high sensitivity, portography has for a long time been considered the gold standard for differentiation of PSSs, despite its invasive nature. However, the recent development of a standard protocol for US and the routine use of Doppler modalities have resulted in the same sensitivity as portography. Therefore, with the additional benefit of being fast and noninvasive, US is now more commonly performed. It may be considered a "new" gold standard, depending upon the experience of the radiologist. Computed tomography and MRI provide detailed anatomic information. In this fourth article about portosystemic shunts in dogs and cats a comprehensive overview of the literature covering US and nuclear scintigraphy will be given. Finally CT and MRI techniques will be explained briefly.

SAMENVATTING

Aangezien de klinische symptomen en laboratoriumbevindingen niet specifiek zijn, zijn beeldvormingstechnieken, zoals portografie, echografie, nucleaire scintigrafie, computertomografie (CT), of magnetische resonantie (MR), noodzakelijk om een definitieve diagnose te bekomen van portosystemische shunts (PSS's). Nucleaire scintigrafie is de gouden standaard voor de detectie van PSS's maar is niet nuttig om het onderscheid te maken tussen de verschillende shunttypen. Omwille van de hoge sensitiviteit, hoewel invasief zijnde, werd portografie beschouwd als de gouden standaard voor de differentiatie van PSS's. De recente ontwikkeling van een standaardprotocol voor echografie en het routinematig gebruik van dopplertechnieken resulteerden in dezelfde sensitiviteit als bij portografie. Met het bijkomend voordeel dat ze snel en niet-invasief is, wordt tegenwoordig meer echografie uitgevoerd. Echografie kan beschouwd worden als een "nieuwe" gouden standaard, afhankelijk van de ervaring van de radioloog. Computertomografie en MR geven gedetailleerde anatomische informatie. In dit vierde deel over portosystemische shunts bij honden en katten wordt een uitvoerig overzicht gegeven van de literatuur over echografie en nucleaire scintigrafie. Tot slot worden de CT- en MRI-technieken kort besproken.

ABDOMINAL ULTRASONOGRAPHY

Due to its availability, its noninvasiveness and the fact that anesthesia is not frequently needed, ultrasound can be used routinely when searching for a PSS ("shunt hunt") (Lamb, 1996; d'Anjou *et al.,* 2004).

Several older reports have shown considerable variation in the accuracy of US for the detection of PSS's, with a sensitivity ranging between 74% and 95%, with a specificity of between 67% and 100% (Wrigley *et al.,* 1987; Holt *et al.,* 1995; Tiemessen *et al.,* 1995; Lamb, 1996; d'Anjou *et al.,* 2004), and with an accuracy of 95% in dogs and 100% in cats (Lamb *et al.,* 1996; d'Anjou *et al.,* 2004). Ultrasound had positive and negative predictive values of 98% and 89%, respectively, in identifying PSSs (d'Anjou *et al.,* 2004). In 92% and 93% of the cases, Lamb (1996) could correctly distinguish intra- and extrahepatic shunts in dogs and cats (Lamb *et al.,* 1996), respectively. d'Anjou et al. (2004) was able to differentiate extrahepatic CPSSs, intrahepatic CPSSs, and APSSs correctly in 98% of the patients. A systematic approach can result in the diagnosis of CPSSs and APSSs with 100% sensitivity, 100% specificity and 100% accuracy (Szatmári, 2004d). Therefore, US can now be considered the gold standard because of its (already previously mentioned) advantages compared with portography. The reported accuracy of US has progressively increased over the last two decades (Table 1), a fact which can be explained by the more sophisticated US equipment currently being used, with its improved gray-scale resolution and routine use of color Doppler, as well as by the increasing experience of radiologists and their better understanding of the behavior and manifestations of PSS's (Holt *et al.,* 1995; Broome *et al.,* 2004; d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004a).

An experienced radiologist and a systematic approach are important to avoid false-negative results (Holt *et al.,* 1995). First, withholding food for 12 hours before the US study minimizes interference from gastrointestinal tract contents. Sedation is often needed in non-compliant animals during a "shunt hunt", but should be performed with care because of decreased hepatic drug metabolism (Holt *et al.,* 1995; Tillson and Winkler, 2002).

Second, a systematic scanning protocol is mandatory. One reason for the reported varying accuracy of US is the lack of use of a standardized protocol for examination of the portal system in dogs. Szatmári *et al*. (2004a) developed a standard protocol in 7 planes for US examination of the portal system in dogs, which is summarized in Table 2. It was found that congenital extrahepatic right gastric-caval shunts cannot be readily imaged from a right intercostal approach because visualization of the cranial shunt loop requires that the dog should lie in right lateral recumbency, whereas visualization of the caudal shunt loop required examination with the transducer orientated longitudinally in the right flank (Szatmári *et al.,* 2004a and 2004b). Furthermore, in right lateral recumbency, a search can be performed for the left testicular or ovarian vein entering the left renal vein from caudally (Szatmári *et al.,* 2004a). For identifying portoazygos shunts, right craniodorsal intercostal and/or subcostal approaches are the most useful (d'Anjou *et al.,* 2004).

It was concluded that the four sites that should always be imaged if a PV anomaly is suspected are the right portal branch, the left testicular or ovarian vein, the PV at the level of the celiac artery (splenic vein), and the portal vein immediately caudal to the portal bifurcation (right gastric vein and gastroduodenal vein) (Szatmári *et al.,* 2004a).

Table 1. The reported sensitivity, specificity and accuracy of US has progressively increased over the last two decades. (D = dogs; C = cats; EH = extrahepatic; IH = intrahepatic)

Report	Number of animals	Sens	Spec	Accuracy
Wrigley *et al.*, 1987	PSS: 21D	40%		
Holt *et al.*, 1995	Total: 52D + 11C PSS: EH 33; IH 11	EH 80.5% IH 100%	EH 66.7%	
Tiemessen *et al.*, 1995	Total: 36D PSS: 14D	74%		86%
Lamb, 1996	Total: 82D PSS: 38D	95%	98%	94%
Lamb *et al.*, 1996	Total: 22C PSS: 14C (EH 6; IH 8)	100%		100%
d'Anjou *et al.*, 2004		92% EH 90% IH 100%	98% EH 97% IH 100%	95%
Szatmári *et al*., 2004a	Total: 90D PSS: 78 (61 CPSS + 17 APSS)	100%	100%	100%

Table 2. Standard planes for ultrasonographic examination of the portal system in dogs. (RK = right kidney; Ao = aorta; CVC = caudal vena cava; PV = portal vein; LK = left kidney; rPV = right portal vein branch; lPV = left portal vein branch; CrMA = cranial mesenteric artery; CA = celiac artery; HA = hepatic artery)

Standard planes		Steps	Objectives
Transverse intercostal planes/ left lateral recumbency	Plane 1	1) transducer placed in one of last right intercostal spaces 2) find liver without RK 3) visualize Ao, CVC and PV cross-sections	- image CVC and PV trunk
	Plane 2	1) start from plane 1 2) follow PV by angling/sliding transducer cranially until longitudinal image of rPV appears	- image rPV
	Plane 3	1) start from plane 2 2) hold PV and CVC in image 3) slide transducer cranially, until CrMA is seen originating from Ao 4) first B-mode, then repeated with color Doppler mode	- look for a direct connection between PV and CVC - look for a vessel that originates from the PV with a hepatofugal flow direction ⇒ image congenital extrahepatic PSSs
Longitudinal plane/ left lateral recumbency	Plane 4	1) transducer immediately caudal to last rib (often firm pressure required) 2) transducer directed craniomedially 3) first find Ao, after ventral angulation, subsequently find longitudinal views of CVC, PV, rPV, and lPV 4) (large breeds/ deep-chested dogs: alternative: rotate transducer 90º starting from plane 1)	- image PV - image left-divisional congenital portocaval intrahepatic PSSs - image congenital extrahepatic PSSs
Longitudinal plane/ dorsal recumbency	Plane 5 (Alternative for plane 4)	1) slightly tilt dog towards radiologist 2) image RK and caudate liver lobe 3) angle transducer ventromedially, to subsequently image CVC and PV 4) PV can be followed cranially until bifurcation	
Longitudinal plane/ right lateral recumbency	Plane 6 (Only necessary when right gastric vein PSS is suspected from plane 3)	1) transducer immediately caudally to last left rib 2) image PV at liver hilus (difficult!!) 3) alternative to find right gastric-caval PSSs: a) find origin of CA from Ao (cranial to LK); b) follow HA (widest branch of CA) with color mode from origin to liver; c) HA crosses wide shunt-loop	- image congenital extrahepatic right gastric-caval and right gastric-azygos PSSs
	Plane 7	1) transducer immediately ventral to lumbar muscles caudal to LK 2) find longitudinal image of CVC 3) slide transducer cranially to image left renal vein entering CVC 4) search (B-mode and color mode) for left ovarian/ testicular vein entering left renal vein from caudally	- image the dilated left gonadal vein - i.e. image spleno-renal collaterals

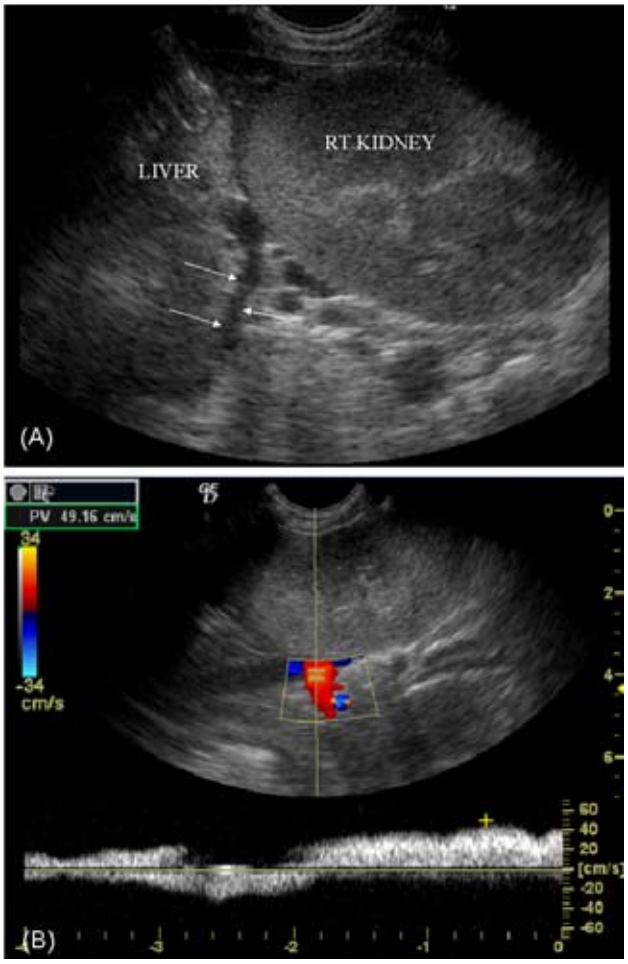

Figure 1. Ultrasonographic images of a 7-month old dog with an extrahepatic CPSS. (A) A shunting vessel (white arrows) is visible caudal to the porta hepatis and cranial to the right kidney. (B) Its angle is 90° to the vena porta, and a bloodflow velocity of 40-50 cm/sec was recorded. The portal blood flow spectrum has lost its uniformity and has a more pulsatile aspect. Note also the hyperechogenicity and the poor corticomedullary distinction of the right kidney. (Rt = right)

The combination of an experienced radiologist, sophisticated equipment and a systematic scanning protocol can result in a scanning time of only 15 to 30 minutes, which is not longer than a routine US examination (Szatmári *et al.,* 2004b).

Two-dimensional, gray-scale US alone is sufficient to detect most intra- and extrahepatic shunts. The sensitivity of US, however, is increased by using duplex- and color Doppler, which aids in the detection of turbulent flow in the CVC and the detection of blood flow in abnormal extrahepatic vessels adjacent to the CVC (Holt *et al.,* 1995; Tiemessen *et al.,* 1995; Lamb, 1996; Lamb *et al.,* 1996; Szatmári *et al.,* 2003; Szatmári *et al.,* 2004b; Szatmári *et al.,* 2004c; d'Anjou *et al.,* 2004).

B-mode gray-scale US

The presence of a shunting vessel is the most important diagnostic sign and it may be determined in the majority of dogs with intra- or extrahepatic shunts (Lamb, 1996). Even if the scanning protocol suggested by Szatmári *et al*. (2004a) is used, accurate US recognition of CPSSs is possible only if the abnormal vessel is followed from its origin to its termination. Finding the point where a CPSS enters the CVC may be easier than finding its origin (Lamb, 1996). The description of the several appearances of the different CPSS's can be found in the chapter about shunt morphology of the third article about PSSs in dogs and cats.

In addition to direct visualization of the shunting vessel (Figure 1A), findings such as reduced liver size and visibility of intrahepatic portal branches can be observed (Holt *et al.,* 1995; Tiemessen *et al.,* 1995; Lamb, 1996; Lamb *et al.,* 1996; d'Anjou *et al.,* 2004). Uroliths and renomegaly are other common findings in dogs and cats with CPSSs (Tiemessen *et al.,* 1995; d'Anjou *et al.,* 2004). Ascites has been reported with portal hypertension and APSSs. However, it is uncommon in patients with CPSSs (Tiemessen *et al.,* 1995; d'Anjou *et al.,* 2004). When color- and duplex Doppler US is performed, changes in mean portal blood flow (PF) velocity, PF variability, turbulence in the CVC, and a dilated CVC and PV have been associated with CPSSs (Holt *et al.,* 1995; Tiemessen *et al.,* 1995; Lamb, 1996; Lamb *et al.,* 1996; d'Anjou *et al.,* 2004).

The liver was considered small in 84% of the dogs and in 22% of the cats with CPSSs. Microhepatica is less common in dogs with microvascular dysplasia when compared with dogs with a CPSS or idio-pathic noncirrhotic portal hypertension (portal hypoplasia) (d'Anjou *et al.,* 2004). The intrahepatic portal branches were subjectively assessed as attenuated in 38% of the dogs and 11% of the cats with a CPSS, and in 25% of the patients with idiopathic noncirrhotic portal hypertension (d'Anjou *et al.,* 2004). The kidneys were found to be enlarged in as much as 59% of the affected dogs (d'Anjou *et al.,* 2004). In cats, renomegaly is less common (Lamb, 1998). The prevalence of urolithiasis or mineralization on US is high in dogs with CPSS's (Lamb *et al.,* 1996). Uroliths can be detected in 40 to 74% of dogs and 13% of cats during an abdominal US investigation (Center, 1996b). Its positive predictive value was 97% in dogs suspected of having a CPSS (d'Anjou *et al.,* 2004).

The portal vein/aorta (PV/Ao) and portal vein/caudal vena cava (PV/CVC) ratios measured at the level of the porta hepatis were found to be smaller in animals with extrahepatic PSSs, compared with normal animals, patients with HMD, and patients with an intrahepatic PSS ($P<0.001$) (d'Anjou *et al.,* 2004). All the dogs and cats with a PV/Ao ratio of ≤ 0.65 had an extrahepatic PSS or idiopathic noncirrhotic portal hypertension. The dogs and cats with PV/Ao and PV/CVC ratios of ≥ 0.8 and ≥ 0.75, respectively, did not have an extrahepatic PSS (d'Anjou *et al.,* 2004). Shunting vessels originating from the splenic vein were always found to have a larger diameter than the PV caudal to the shunt origin. The PV segment cranial to the shunt origin had a smaller diameter than the PV segment caudal to the shunt origin in all dogs with splenic-caval shunts (Szatmári *et al.,* 2004b).

Color- and duplex Doppler US

Portal blood flow velocity (PF) and its direction may be measured in dogs using color- and duplex

Doppler US (Figure 1B; Lamb, 1996; Lamb *et al.,* 1996; Szatmári *et al.,* 2003 and 2004b). Portal blood flow mean velocity in normal dogs is between 15 ± 3 cm/s and 18 ± 8 cm/s (d'Anjou *et al.,* 2004), and between 10 and 18 cm/s in normal cats (Lamb, 1998; d'Anjou *et al.,* 2004). If the velocity can be measured with confidence, it can be useful in localizing the PSS. The mean PF velocity is increased in most dogs with an intrahepatic shunt, presumably the result of a decreased flow resistance (Szatmári *et al.,* 2003; d'Anjou *et al.,* 2004). It is reduced or reversed in most dogs with an extrahepatic shunt (Holt *et al.,* 1995; d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004b and 2004c). Decreased or reversed PF has been described in dogs with portal hypertension and APSSs (Boothe *et al.,* 1996; Lamb, 1996; d'Anjou *et al.,* 2004). Hepatofugal (reversed) PF appears to be highly specific for PSSs. However, PF cannot distinguish CPSSs from APSSs (d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004b and 2004c). PF evaluation of extrahepatic PSSs is difficult because of the small size of the portal vein and the cranial position of the porta hepatis secondary to microhepatica (Lamb, 1996). A vessel adjacent and parallel to the aorta containing blood flow directed cranially is consistent with an enlarged azygos vein containing shunting blood, representing an extrahepatic portoazygos shunt (d'Anjou *et al.,* 2004).

Normal portal blood flow is relatively uniform and non-pulsatile (Lamb, 1996; Lamb *et al.,* 1996). This results in a relatively constant shape of the PF spectrum. The CVC normally contains variable pressure and blood flow due to changing right atrial and pleural pressures during the cardiac and respiratory cycles. In animals with a portocaval PSS, the portal system is connected to the cyclic systemic circulation. Hence, the PV is exposed to these pressure changes, which results in a more variable PF (Figure 1B, Lamb, 1996; Lamb *et al.,* 1996; Lamb, 1998). Therefore, this feature can be used to assist in a diagnosis of CPSS when the shunting vessel is not visible (Lamb *et al.,* 1996).

Abnormal PF velocity and/or flow fluctuation was reported to be 70% sensitive and 71% specific in the detection of PSSs in dogs (Lamb, 1996). Portal blood flow velocity variability was found to be a better predictor of portosystemic shunting compared with increased or reduced PF velocity (Lamb, 1996).

Termination of the shunting vessel at the CVC is suggested by the presence of turbulence. This turbulence is characterized by random, chaotic, and multidirectional flow on Doppler imaging. It occurs at high velocities. On color Doppler images, turbulent blood flow appears as a mosaic pattern with green hues (Holt *et al.,* 1995; d'Anjou *et al.,* 2004). Forty-two to 88% of dogs with a shunt terminating into the CVC showed turbulence at this level (Lamb, 1996; d'Anjou *et al.,* 2004). The presence of turbulence in the CVC of dogs had positive and negative predictive values of 91% and 84%, respectively, for the presence of any PSS terminating into that vein (d'Anjou *et al.,* 2004). Therefore, this feature can be used to guide the search for extrahepatic PSSs (Lamb, 1996).

When applying color Doppler to detect turbulence in the CVC and to evaluate the direction of flow in the PV and its tributaries, its parameters have to be adjusted. The color gain has to be set so that color signals are seen inside the lumen of the vessel, but not outside the vessel. The pulse repetition frequency (PRF) has to be increased to differentiate aliasing from flow turbulence (d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004a).

Intrahepatic shunts are more consistently identified with US (sensitivity and specificity of 100%) when compared with extrahepatic shunts (sensitivity of 90% and specificity of 97%) (Holt *et al.,* 1995; Lamb, 1996; Tillson and Winkler, 2002; d'Anjou *et al.,* 2004). Left-, central-, and right-divisional intrahepatic shunts can be differentiated in most patients. Central-divisional PSSs are the most difficult intrahepatic shunts to identify. They require color Doppler US to visualize turbulent flow (d'Anjou *et al.,* 2004).

Multiple acquired PSSs (APSSs)

The diagnosis of APSSs with US is more challenging (Lamb and Daniel, 2002; d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004a). The collateral vessels do not occur in such consistent locations as CPSSs. They only occasionally arise directly from the PV. Moreover, these collaterals are usually small and tortuous and often hidden among the intestines. Hence, their origin and termination can only rarely be revealed (Lamb and Daniel, 2002; Szatmári *et al.,* 2004a). Their number (>2), their pattern of distribution and their relatively small size (less than 0.4cm) suggest the presence of APSSs rather than CPSSs (d'Anjou *et al.,* 2004). Moreover, in all patients with APSSs, reduced or reversed portal flow secondary to portal hypertension could be found (Boothe *et al.,* 1996; Lamb, 1996; d'Anjou *et al.,* 2004).

The underlying cause may be observed ultrasonographically if there are abnormalities affecting the hepatic parenchyma or the PV, such as signs of cirrhosis, hepatoportal fistula, or PV thrombosis. Other US signs that may be observed in dogs with APSS's include splenic congestion, ascites, pancreatic edema, and urolithiasis (Lamb and Daniel, 2002). The typical US appearance of congenital intrahepatic arterioportal fistula is ascites, mild diffuse hepatomegaly, the presence of extremely dilated and tortuous anechoic tubular structures in a liver lobe, retrograde (hepatofugal) and abnormally pulsatile blood flow in the PV, and APSSs (Johnson, 1999; Szatmári *et al.,* 2000; Szatmári *et al.,* 2004b).

Szatmári *et al*. (2004b) found that dilation of the left testicular or ovarian vein due to splenic-renal collateral circulation was a highly specific and sensitive indicator of APSSs, and its US visualization was easy. This vein runs parallel to the CVC and enters the left renal vein half-way from caudally. In normal dogs, the left testicular or ovarian vein is so thin that it cannot be visualized on US (Szatmári *et al.,* 2004b). Additionally, many small tortuous veins are often observed in the retroperitoneum near the left kidney around the left renal vein, or medial to the spleen (Boothe *et al.,* 1996; Lamb and Daniel, 2002; Ferrell *et al.,* 2003; d'Anjou *et al.,* 2004; Szatmári *et al.,* 2004b).

Intraoperative US

Intraoperative US using duplex Doppler of the PV during attenuation of intrahepatic (Szatmári *et al.,* 2003) and extrahepatic (Szatmári *et al.,* 2004c) CPSS's was described. Intraoperative US offers detailed real-time information about anatomy and hemodynamics of the PSS and the intrahepatic portal branches. It therefore provides a potentially useful alternative to mesenteric portovenography (Szatmári *et al.,* 2003).

The improved circulation of the hypoperfused portal branches can be immediately evaluated following shunt attenuation. Time-averaged PF mean velocity pre- (6.5-33.7 cm/s) and post- (5.0-9.5 cm/s) shunt attenuation suggest that this narrow range of post-ligation velocities can be used as an alternative to intra-operative measurements of portal pressure (Szatmári *et al.,* 2003).

Szatmári *et al*. (2004c) determined intraoperatively the pre- and post-ligation PF velocities and flow directions in the shunting vessel and in the PV cranial and caudal to the shunt origin in dogs with CPSSs. All dogs had continuous hepatofugal flow in the shunt before attenuation. Hepatofugal portal flow was caused by blood that flowed from the gastroduodenal vein towards the shunt. Shunt attenuation changed hepatofugal flow to hepatopetal in the shunt in 12 of 17 dogs. In all animals where the hepatofugal flow became hepatopetal, hyperammonemia resolved. If the flow direction remains hepatofugal after shunt occlusioncranial to the shunt origin, severe hypoplasia of the portal branches can be expected. After hepatopetal flow in the cranial PV and shunt is established, further shunt narrowing is contraindicated. Caudal to the shunt, increase of the portal congestion index (cross-sectional area divided by the time-averaged mean velocity) >3.5 times should be avoided.

NUCLEAR SCINTIGRAPHY

Nuclear scintigraphy provides reliable information on the presence of a PSS and offers quantitative data that are not available using imaging techniques like US or positive-contrast portography (Forster-van Hijfte *et al.,* 1996; Frank *et al.,* 2003). Scintigraphy is especially useful for monitoring progressive postoperative closure of a shunt after partial shunt attenuation (Johnson, 1999). However, it cannot produce the anatomical detail of either US or portography (Koblik *et al.,* 1990a; Forster-van Hijfte *et al.,* 1996; Frank *et al.,* 2003; Broome et al. 2004; Cole *et al.,* 2005). Therefore, nuclear scintigraphy cannot differentiate between intra- and extrahepatic shunts. Moreover, determining the exact type of PSS is not possible (Broome *et al*. 2004; Cole *et al.,* 2005; Morandi *et al.,* 2005).

A variety of radioactive tracers have been used to study portal-venous blood flow kinetics. They can be divided into those that are inert (^{24}Na, ^{131}I, ^{133}Xe, ^{99}mTcO4-) and those that are extracted by the liver (^{123}I-IMP, ^{13}NH4+, ^{201}Tl). The former are generally used to measure portal circulation time or to assess the shape of the hepatic transit curves of the tracer. The latter allow more direct quantification of the shunt flow since target organ wash-out and tracer distribution is less of a problem (Koblik *et al.,* 1989 and 1990b).

Radiocolloid scanning using Technetium-99m labeledsulfur colloid (^{99}mTc-Sulfur Colloid) was one of the first methods used in quantitative hepatic scintigraphy to diagnose portosystemic anomalies (Hornof *et al.,* 1983; Koblik *et al.,* 1983; Daniel *et al.,* 1990). Hornof *et al*. (1983) described a method where the diagnosis of PSSs was based on the rate of uptake of ^{99}mTc-Sulfur Colloid in the liver compared to the lung. Normal animals have low lung uptake, whereas animals with a PSS have an increased lung uptake. A second method of diagnosing PSSs using ^{99}mTc-Sulfur Colloid is based on the comparison between hepatic arterial and portal-venous blood flow during the initial transit following a bolus injection of ^{99}mTc-Sulfur Colloid (Koblik *et al.,* 1983). An index of portal flow relative to hepatic arterial flow can be provided (Hepatic perfusion index). The rates of uptake of arterial and portal blood is similar in normal animals. Those with shunts show a decreased uptake by the portal-venous system. An elevation of the Hepatic perfusion index is consistent with reduced portal blood flow, but is not specific for the existence of a PSS.

Radiolabeled microspheres have also been used to study portal blood flow (Daniel *et al.,* 1990). These studies are performed by intravenous (IV) injection of the labeled microspheres or macro-aggregated albumin into the PV. The particles have to be large enough to be deposited in normal hepatic sinusoids or pulmonary capillaries, but small enough to pass through a PSS (Koblik *et al.,* 1989 and 1990b). Small particles can circulate freely until they impact in a vessel smaller in diameter than themselves. The number of particles impacted in a given tissue is proportional to the volume of blood perfusing that tissue (Daniel *et al.,* 1990). When comparing the lung counts to liver counts, the amount of blood shunting from the portal to the systemic circulation (shunt fraction) can be calculated (Koblik *et al.,* 1989; Daniel *et al.,* 1990).

Per-rectal portal scintigraphy (PRPS)

Nowadays, transcolonic or per-rectal scintigraphy (PRPS) is predominantly performed. Per-rectal scintigraphy is useful for detecting PSS's in dogs and cats (Daniel *et al.,* 1990; Forster-van Hijfte *et al.,* 1996; Lamb and Daniel, 2002; Cole *et al.,* 2005). It is noninvasive, rapid, inexpensive, easy to perform, and both highly sensitive and specific. Moreover, the patients can be imaged without sedation or with sedatives rather than general anesthetics (Daniel *et al.,* 1990; Johnson, 1999; Frank *et al.,* 2003; Cole *et al.,* 2005). These studies have to be performed after at least 2 hours following a warm water enema. The animals are positioned in right lateral recumbency over a large field-of-view gamma camera (Daniel *et al.,* 1990; Koblik *et al.,* 1990a; Cole *et al.,* 2005). Radioactive markers are positioned ventral to the xyphoid and the ictus cordis of the heart, which aids in identification of the liver and heart, respectively (Cole *et al.,* 2005). The site of the radionuclide deposition in the colon has to be shielded from the camera using a lead sheet (Forster-van Hijfte *et al.,* 1996).

The radionuclide should be placed in the distal colon. If the radioisotope is deposited in the proximal aspects of the descending colon or transverse colon, the activity from the colon will appear in the hepatic region of interest (ROI). Furthermore, activity placed in the rectum rather than in the colon may pass via the rectal vessels into the systemic circulation (Daniel *et al.,* 1990; Forster-van Hijfte *et al.,* 1996; Lamb and Daniel, 2002).

^{99}mTcO4- is the radioisotope most commonly used (Lamb and Daniel, 2002). ^{99}mTcO4- is readily available, inexpensive, and has been shown to be rapidly absorbed, unchanged, across the colonic mucosa. It is a radiotracer which is not extracted by the liver, and only a small percentage (<15%) is absorbed from the colon via the colonic and caudal mesenteric veins into the portal circulation (Daniel *et al.,* 1990; Koblik *et al.,* 1990a; Forster-van Hijfte *et al.,* 1996; Daniel *et al.,* 2004; Cole *et al.,* 2005). Therefore, the images are often of low count density (Cole *et al.,* 2005). It was suggested that the rate of tracer distribution is more rapid in cats, compared with dogs (Koblik *et al.,* 1990a).

In normal animals, the radionuclide is taken up into the PV and delivered to the liver. Its transit time from the liver to the heart ranges between 8 and 16 seconds (Daniel *et al.,* 1990; Koblik *et al.,* 1990a; Koblik and Hornof, 1995; Forster-van Hijfte *et al.,* 1996; Lamb and Daniel, 2002; Daniel *et al.,* 2004; Cole *et al.,* 2005). If a macroscopic PSS is present, the transit time should be less than 2 seconds, as the radioisotope bypasses the liver and reaches the heart before or at the same time it reaches the liver (Daniel *et al.,* 1990; Koblik *et al.,* 1990a; Forster-van Hijfte *et al.,* 1996; Ferrell *et al.,* 2003; Daniel *et al.,* 2004). Animals with a liver-to-heart time interval greater than 2 seconds can be considered clinically normal (Koblik and Hornof, 1995).

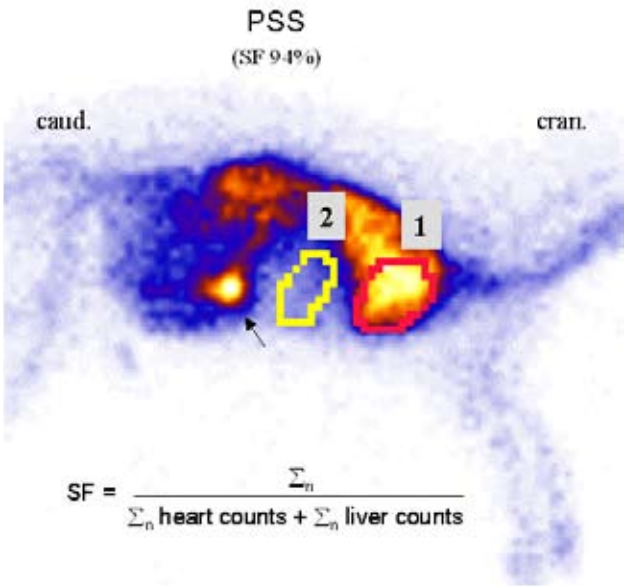

Figure 2. Nuclear trans-splenic portal scintigraphic images of a normal dog (left) and a dog with a CPSS (right). These are composite images of the dynamic acquisition. In the normal dog, the majority of the radionuclide is present in the liver. Only a small amount of activity is present in the heart. In the dog with the PSS, the liver is barely visible and the activity is mostly present in the heart. Regions of interest (ROI) are hand-drawn around the liver (2) and heart (1). A shunt fraction (SF) can be calculated from the sum of counts in the liver and heart ROI, giving an estimate of the percentage of portal blood bypassing the liver. In the normal dog, the SF was 13%; in the affected dog, the SF was 94%. Activity is present in the spleen due to injection in the splenic parenchyma (black arrow).

Additionally, a shunt fraction (SF) can be calculated from the sum of counts in the liver and heart ROI, thus giving an estimate of the percentage of portal blood bypassing the liver (Figure 2; Koblik *et al.,* 1989; Daniel *et al.,* 1990; Van Vechten *et al.,* 1994; Forster-van Hijfte *et al.,* 1996; Daniel *et al.,* 2004; Cole *et al.,* 2005). Shunt fractions below 10% to 15% are considered normal (Daniel *et al.,* 1990; Van Vechten *et al.,* 1994; Daniel *et al.,* 2004; Cole *et al.,* 2005). In dogs with a CPSS, SFs as high as 84% (Daniel *et al.,* 1991) and 78% (Van Vechten *et al.,* 1994; Daniel *et al.,* 2004) have been reported. Mild shunts range from 20-40%, moderate shunts from 40-60%, and severe shunts greater than 60% (Steyn, 2000). In cats, the SF was found to be 52% (Forster-van Hijfte *et al.,* 1996; Tillson and Winkler, 2002). Assessing the SF is particularly helpful in monitoring the progress of postsurgical PSS patients when partial attenuation of the PSS has been performed (Tillson and Winkler, 2002).

False-negative results can occur using PRPS. They can be the result of a small shunt involving only the peripheral portion of the portal system because portal blood from the colon sometimes does not pass through these vessels, for example shunts from the gastric vein to the CVC (common in cats) (Koblik and Hornof, 1995; Johnson, 1999). The scintigraphic study of distal shunts is less susceptible to false-negative results (Koblik *et al.,* 1990a; Johnson, 1999). Also, PRPS is not useful for distinguishing patients with hepatic microvascular dysplasia (HMD) from normal ones, because all of the portal blood reaches the heart after passing through the intrahepatic microvascular shunts (Koblik and Hornof, 1995; Center, 1996a; Johnson, 1999).

Trans-splenic portal scintigraphy (TSPS)

Trans-splenic portal scintigraphy has been developed to overcome the limitations of PRPS. Cole *et al.* (2005) suggested an alternative method for scintigraphic diagnosis of PSS's. Prior to TSPS, all dogs are sedated and placed in right lateral recumbency over the gamma camera. A small area of hair is clipped in the left lateral abdomen and cleaned with alcohol. Radioactive markers are positioned, as with PRPS. ^{99}mTcO4- is injected percutaneously through a shielded needle into the splenic parenchyma under US guidance (Figure 2).

A significantly lower radioactive dose (57 ± 13.9 MBq using PRPS versus 425 ± 36 MBq using TSPS) of ^{99}mTcO4- can be given and significantly higher total (liver and heart) counts are recorded in the liver and heart compared with PRPS. There is significantly better absorption of the radionuclide from the spleen (52.5% ± 19.06) versus colon (9.23% ± 5.66) (at 60s). It is possible to follow the radionuclide bolus and

identify the splenic and portal veins. The radiation exposure levels of the dogs are significantly lower following TSPS. No significant difference between the SF values obtained from the TSPS studies (8.8 ± 5.5%) compared with the PRPS studies (4.6 ± 2.2%) (12-s transit time) can be found. However, there is a significant difference between SF values obtained from the TSPS studies using a 7-s transit time compared with a 12-s transit time, because a longer time interval allows recirculation of the radionuclide and false elevation of the SF (Cole *et al.,* 2005).

As for PRPS, false-negative studies can occur with TSPS in the presence of HMD. Also, shunts originating distal to the splenic vein can be missed with TSPS (Cole *et al.,* 2005; Morandi *et al.,* 2005).

COMPUTED TOMOGRAPHY (CT)

Dual-phase CT angiography is a fast, minimally invasive procedure that images the hepatic and portal vascular systems during a single nonselective peripheral IV injection of contrast medium. It is easier to interpret than Doppler US due to sequential transverse plane imaging, it can be used in a protocol to minimize operator variation, and rapid volumetric data acquisition is possible. However, there are also several disadvantages. Portal flow and pressure cannot be measured, iodinated contrast medium injection is required, artefacts caused by metallic implants and motion are possible, false negatives and positives can occur, and anesthesia is required (Frank *et al.,* 2003; Zwingenberger *et al.,* 2005). Limitations also included inability to resolve two vessels lying very close to each other, and difficulty with the identification of vessels traveling parallel to the axial image plane (Zwingenberger *et al.,* 2005).

With helical CT, unlike traditional sequential CT, it is possible to scan a patient twice (arterial and portal phase) during a single contrast medium injection (Zwingenberger and Schwarz, 2004). Moreover, raw data sets obtained from a helical CT examination can be manipulated, resulting in multiplanar and three-dimensional image reconstructions (Frank *et al.,* 2003; Thompson *et al.,* 2003), which can provide an accurate three-dimensional characterization of portal and hepatic vascular anatomy (Thompson *et al.,* 2003; Zwingenberger and Schwarz, 2004).

Dual-phase scans provide excellent vascular opacification. The aorta, CVC, hepatic arteries, hepatic veins, cranial and caudal mesenteric veins, splenic vein, gastroduodenal vein, and PV branches were all consistently well visualized on the CT images. This procedure was able to provide anatomically specific data (Frank *et al.,* 2003; Zwingenberger and Schwarz, 2004). The consistent scan plane and orientation assist non-radiologists in understanding the course of the vessel within the abdomen. Moreover, CT can also image vessels that cross the diaphragm into the thorax (Zwingenberger *et al.,* 2005). Therefore, the information gained from the CT images resulted in a subjective decrease in surgical time and degree of dissection necessary (Frank *et al.,* 2003).

The ability to create diagnostic images which are free of motion artefacts during maximal vessel opacification is dependent on carefully planned helical CT protocols. To acquire such images, the contrast medium injection and scanner parameters must be thoroughly coordinated (Thompson *et al.,* 2003). The total time from entry to exit from the CT room was 20 to 60 minutes (Frank *et al.,* 2003; Zwingenberger *et al.,* 2005).

Dual-phase CT angiography of the hepatic vasculature is performed by imaging the liver immediately after IV contrast medium injection (arterial phase) and a subsequent repeat examination (portal phase) (Frank *et al.,* 2003). The arterial phase of the dual-phase scan images the hepatic arteries and veins, and the portal phase highlights the PV with its tributaries and intrahepatic branches. There are three steps involved in acquiring the dual-phase scan. The first step is a survey helical scan for orientation. This is followed by a dynamic scan, which is used for timing purposes. Finally, the dual-phase helical scan is performed (Zwingenberger and Schwarz, 2004).

In normal dogs, the median time of appearance of contrast medium in the cranial abdominal aorta was 8.6s and the median time of appearance of contrast medium in the hepatic artery occurred 0.4s later. The median time of peak enhancement in the cranial abdominal aorta was 12.0s. The median time of appearance of contrast medium in the PV was 14.6s (Zwingenberger and Schwarz, 2004). The time for maximum enhancement of the PV for normal dogs ranged from 33.0-60s (Frank *et al.,* 2003; Zwingenberger and Schwarz, 2004).

For patients with a PSS, the time to maximum enhancement of the PV was in the range of 16.5-70.5s (Frank *et al.,* 2003). The shunting vessel was identified in all dogs in several reports (Frank *et al.,* 2003; Thompson *et al.,* 2003; Zwingenberger *et al.,* 2005). Computed tomography detected its origin and termination in 13 of 15 PSSs (Zwingenberger *et al.,* 2005).

MAGNETIC RESONANCE IMAGING

Magnetic resonance angiography (MRA) is another non-invasive technique that can be used to identify dogs with macrovascular shunts. It provides functional representation of blood vessels without the use of contrast media. Furthermore, it is able to differentiateintra- from extrahepatic PSSs, and to evaluate the anatomic location of single PSSs. The overall sensitivity and specificity of MRA are, respectively, 80% and 100%, which decreases to 63% and 97% in cases of multiple extra-hepatic PSSs, and to 79% and 100% in cases of single CPSSs. It enables the correct classification of intra- or extrahepatic PSSs in 83% of patients, and determines the origin and insertion of the shunting vessel in 57% and 97% of the cases (Seguin *et al.,* 1999). The expensive equipment, and the need for anesthesia are the major limitations of MRA.

CONCLUSION

Due to its high sensitivity in detecting PSSs (85%, 91% and 100% in dorsal, right lateral, and left lateral recumbency, respectively) (Scrivani *et al.,* 2001) and its simple interpretation, portography was considered the gold standard in dogs suspected of having a PSS.

However, it is time-consuming, invasive and requires radiation.

Ultrasound has been used for diagnostic imaging of dogs with CPSSs since the 1980s. Several older studies showed considerable variation in the accuracy of US for the detection of PSSs, with sensitivities ranging from 74% to 95% and specificities from 67% to100%(Holt*etal.,*1995;Tiemessen*etal.,*1995;Lamb, 1996; d'Anjou *et al.,* 2004). The reason for these variable, and sometimes low, values is the fact that in these studies a right intercostal approach was used, which can easily lead to a false-negative diagnosis. Szatmári *et al.* (2004a) developed a standard protocol in 7 planes for US examination of the portal system in dogs. This systematic approach performed by an experienced radiologist may result in diagnosis of CPSSs and APSSs with 100% sensitivity, 100% specificity and 100% accuracy (Szatmári, 2004d). Hence, because it is quick and noninvasive, because it does not require anesthesia or ionizing radiation, and because it has the same sensitivity as portography, US can now be considered the "new" gold standard for the differentiation of PSSs. Moreover, it enables the simultaneous evaluation of the abdominal organs and, when using Doppler, it can be used to assess abnormal blood flow (Szatmári *et al.,* 2003, Szatmári *et al.,* 2004a).

Nuclear scintigraphy is the gold standard for detecting PSSs, but it is not useful for distinguishing CPSSs from APSSs, or intrahepatic from extrahepatic shunts.

CT and MRI provide detailed anatomic information. However, unlike US, these modalities cannot give information on the direction of blood flow in the vessels. Moreover, both procedures are time-consuming, use expensive equipment,and require general anesthesia.

LITERATURE

An extended literature list can be obtained from the authors.