Comparison of computed tomographic angiography and intraoperative mesenteric portovenography for extrahepatic portosystemic shunts

Andrew Parry
Willows Referral Service, Highlands Road, Shirley, Solihull, West Midlands B90 4NH

Robert N. White
School of Veterinary Medicine and Science, University of Nottingham, Sutton Bonington Campus, Leicestershire LE12 5RD

SUMMARY

Objectives: Comparison of intraoperative mesenteric portovenography and computed tomographic angiography for the documentation of the portal vasculature in patients with single extrahepatic portosystemic shunts.

Methods: Retrospective study of patients with extrahepatic portosystemic shunts that underwent pre-operative computed tomographic angiography and intra-operative mesenteric portography. Studies were compared for identification of the intra- and extrahepatic portal vasculature.

Results: Computed tomographic angiography demonstrated all four portal vein tributaries and sub-tributaries. Intra-operative mesenteric portography demonstrated the cranial mesenteric vein but inconsistently, the gastroduodenal vein (12/49 dogs, 0/10 cats), splenic vein (46/49 dogs, 8/10 cats) and caudal mesenteric vein (3/49 dogs, 2/10 cats). Computed tomographic angiography showed the intrahepatic portal vein with shunts emanating from the left gastric vein, splenocaval shunts or shunts involving the left colic vein. It showed intrahepatic portal branching in 5/12 patients with shunts involving the right gastric vein. Intra-operative mesenteric portography showed the intrahepatic portal vein in 29/59 patients and was outperformed by computed tomographic angiography in all cases except those patients with a shunt involving the right gastric vein.

Clinical significance: In cases that have undergone diagnostic pre-operative computed tomographic angiography there is no indication for diagnostic pre-ligation intra-operative mesenteric

portovenography. On the contrary, portovenography performed following the temporary full ligation of the shunt provides clinical useful information and might be considered an integral investigation during shunt attenuation surgery.

Keywords: Intraoperative mesenteric portovenography, computed tomographic angiography, portosystemic shunt

INTRODUCTION:

There are numerous reports describing imaging modalities that can be used to evaluate and describe the anatomy of congenital portosystemic shunts in small animals. These include ultrasonography (Lamb 1996, Szatmári & Rothuizen 2006), magnetic resonance angiography (MRA) (Sequin *et al.* 1999, Bruehschwein *et al.* 2010, Mai & Weisse 2011), findings on intra-operative mesenteric portovenography (IOMP) (White *et al.* 2003, White & Parry 2013, 2015, 2016a, 2016b), and direct gross observations at surgery (White & Parry 2013, 2015, 2016a, 2016b). In addition to these, computed tomographic angiography (CTA) has been shown to be a highly detailed and accurate method of evaluating the portal vasculature and it is often used to replace or augment the other techniques described (Frank *et al.* 2003, Zwingenberger & Schwarz 2004, Zwingenberger *et al*. 2005, Echandi *et al.* 2007, Nelson & Nelson 2011, White & Parry 2013, Fukushima *et al.* 2014, White & Parry 2015, 2016a, 2016b).

In a recent study, the morphology of the normal extrahepatic portal vein was compared using IOMP and CTA. It was concluded that CTA consistently showed more detail of the extrahepatic portal vein and its tributaries (Parry & White 2015).

The purpose of this study was to compare the findings of IOMP and CTA for the identification of both the extrahepatic and intrahepatic portal venous system in dogs and cats with a single congenital extrahepatic portosystemic shunt (EHPSS), and to assess whether CTA can replace IOMP for shunt characterisation.

METHODS:

This retrospective study reviewed dogs and cats seen by the authors between 2009 and 2015 for the investigation and management of congenital PSS. The inclusion criteria were that all cases must have a congenital PSS, have undergone recorded IOMP and preoperative CTA.

Data on breed, signalment (age, sex, neutering status), imaging investigation, type of portosystemic shunt and gross surgical findings were collected and reviewed.

Computed tomography angiography was performed under anaesthesia using a 16 slice multidetector unit (Brightspeed, General Electric Medical Systems, Milwaukee) as described previously (White and Parry 2016a, 2016b). Briefly, images were acquired using a 0.625 mm or 1.25 mm slice collimation, depending on the size of the animal, 120 kVp and variable mAs. Patients were positioned in sternal recumbency. Scanned field of view (SFOV) and displayed field of view (DFOV) were selected according to the size of the animal. The collimator pitch was 0.938. Pre- and post-intravenous contrast (600mg I/kg, Iopromide, Ultravist, Bayer PLC, Berkshire) images were obtained using a standard algorithm (medium frequency reconstruction kernel) and a 512 x 512 matrix, and viewed using a window and level optimised for soft tissue (window 400HU, level 50HU). Contrast was injected at a speed of 2.0 - 3.0 ml/s (depending on the size of the animal and consequently the size of intravenous catheter placed) using a pressure injector (Medrad Stellant CT injection system, Bayer Healthcare Medical Care Indianola, PA). To optimise contrast enhancement, a transverse slice over the mid-abdomen was selected and repetitively examined whilst contrast injection was performed. At the onset

of opacification of the portal vessels, a complete abdominal dual phase CTA examination was performed using proprietary bolus tracking software with an automated trigger threshold of 120HU to start the scan. The trigger region of interest was positioned over the portal vein at the level of the porta hepatis in all dogs and cats, in the central aspect of the vessel to allow for respiratory motion. A further tissue pool phase was then performed without using bolus tracking. Studies were assessed in their native format, using multiplanar reformatting (MPR) and surface shaded volume rendering. Vascular maps were obtained and post processing was limited to removal of arterial vessels and unnecessary portions of the caudal vena cava (CVC) from the maps. All CTA studies were reviewed by both authors.

For IOMP, the jejunal vein was cannulated with a large bore catheter (20 or 22 gauge) and the mesenteric venous pressure was measured using a saline filled central venous manometer. IOMP was carried out using a mobile image intensification unit (OEC Fluorostar 7900, General Electric Medical Systems, Milwaukee) to obtain ventrodorsal images of the cranial abdomen (White *et al.* 1996, White *et al.* 1998). Patients were positioned in dorsal recumbency. A bolus of non-ionic iodinated contrast agent (iohexol (Omnipaque, GE Healthcare) or iopromide) was injected into the jejunal vein for each portovenogram. The total dose of iodine did not exceed 600 mg I/kg. The contrast was injected by hand using a 10 or 20 ml syringe. A mask was applied to create a digital subtraction angiogram. Angiograms were recorded digitally and were reviewed by both authors as video loops.

The CTA and IOMP images were evaluated by both authors, using a method adapted from those described previously (Parry & White 2015, Macdonald *et al.* 2002, Zwingenberger & Schwarz 2004, Lee *et al.* 2006). Extrahepatic portal vein arborisation was assessed for the presence or absence of the extrahepatic portal vein and its tributaries. The vessels were named by comparison with the published descriptions (Evans & de Lahunta 2010, Wolschrijn 2010, Bezuidenhuit 2013). Intrahepatic portal vein arborisation was assessed for the presence or absence of a portal vein entering the liver; principal

right and left portal branches; branching of the principal portal branches; primary, secondary and tertiary branching of the principal branches; and opacification of the right and left lobes of the liver (Macdonald *et al.* 2002). The IOMP and CTA data were reviewed in a random order using simple randomisation of the data.

RESULTS:

Forty-nine dogs and 10 cats met the inclusion criteria. Twenty-six dogs had a shunt emanating from the left gastric vein, of which 22 had a left gastrophrenic shunt, 2 had a left gastrocaval shunt, and 2 had a left gastroazygos shunt (White & Parry 2013). Twelve dogs had a shunt involving the right gastric vein, of which 1 dog had a type Ai, 9 dogs had a type Aii and 2 dogs had a type Aiii (no dogs had a type B shunt) (White & Parry 2015). Eight dogs had a splenocaval shunt (White & Parry 2016a). Three dogs had a shunt involving the left colic vein, of which 2 dogs had a shunt entering the caudal vena cava and 1 dog had a shunt entering the cranial rectal vein (White & Parry 2016b). Of the 10 cats, 7 had a left gastrophrenic shunt, 1 cat had a splenocaval shunt, and 2 cats had a shunt involving the left colic vein (of which one inserted into the caudal vena cava and one inserted in to the common iliac vein). Vascular shunt anatomy was depicted equally well using both CTA and IOMP and, as such, shunt classification was the same for both imaging modalities. The age, breed and sex distribution of the patients with various different shunt types were consistent with previous studies.

Findings on CTA - extrahepatic portal venous system:

In all cases CTA showed the anomalous shunt vessel and the principal vessels associated with it. CTA documented the extrahepatic portal vein and all four of its main tributaries (the caudal mesenteric vein, the cranial mesenteric vein, the splenic vein and the gastroduodenal vein) in all cases. In addition, CTA allowed for the further subdivision of the four main venous tributaries. Identification of this subdivision was not affected by shunt type.

The cranial pancreaticoduodenal vein was identified in all dogs and cats. The right gastroepiploic vein was identified in 41/49 dogs and 9/10 cats and the right gastric vein was identified in 42/49 dogs and 8/10 cats. These tributaries formed the gastroduodenal vein.

CTA documented the left gastric vein in all dogs and cats, the left gastroepiploic vein in 44/49 dogs and 9/10 cats and the pancreatic branches in 38/49 dogs and 7/10 cats. These tributaries formed the splenic vein.

CTA documented the jejunal veins (49/49 dogs and 10/10 cats), the iliocolic vein (39/49 dogs and 8/10 cats) and the caudal pancreaticoduodenal vein in all dogs and cats. These tributaries formed the cranial mesenteric vein.

Lastly CTA documented the left colic vein (46/49 dogs and 9/10 cats), the right colic vein in 38/49 dogs and 6/10 cats, the cranial rectal vein in 40/49 dogs and 7/10 cats and the middle colic vein in 29/49 dogs and 4/10 cats. These tributaries formed the caudal mesenteric vein. Findings are visible on figure 1, 2 and 3 and table 2.

Findings on CTA - intrahepatic portal venous system:

In all cases, CTA documented the presence of a portal vein entering the liver (figure 1). There was however variation in appearance of intrahepatic arborisation according to shunt type. In all left gastrophrenic, left gastrocaval, left gastroazygos, splenocaval shunts and shunts involving the left colic vein, CTA documented the presence of the portal vein entering the liver, the principal right and left portal branches, the primary, secondary and tertiary branching of the principal branches and the opacification of the right and left lobes of the liver (figure 2). In those shunts involving the right

gastric vein, CTA documented the presence of the portal vein entering the liver and opacification of the left and right lobes of the liver in all cases, whereas, the principal right and left portal branches were only identified in 5/12 dogs and the primary, secondary and tertiary branching of the principal branches in 3/12 dogs. This data is summarised in table 2.

Findings on IOMP - extrahepatic portal system:

IOMP showed the anomalous shunt vessel and the principal vessels associated with it, but no other extrahepatic vasculature (figure 1, 2 and 3). This information is summarised in table 1.

Findings on IOMP - intrahepatic portal venous system:

There was a degree of heterogeneity in the appearance of the intrahepatic portal vasculature. Shunts involving the right gastric vein were associated with excellent intrahepatic portal opacification, with documentation of the presence of the portal vein entering the liver, the principal right and left portal branches, the primary, secondary and tertiary branching of the principal branches and the opacification of the right and left lobes of the liver (figure 3). For splenocaval shunts and shunts involving the left colic vein, there was invariably no contrast enhancement of the intrahepatic portal vasculature (figure 1). For shunts emanating from the left gastric vein (left gastrophrenic, left gastrocaval and left gastroazygos shunts) the results were more variable (figure 2). Opacification of the portal vein at the porta hepatis was present in 17/33 cases, while in the remaining 16 cases no contrast could be observed reaching the liver. Of the 17 cases with contrast reaching the liver, 15 cases showed opacification of the principal right and left portal branches, and of these 15, 5 cases had opacification of both the left and right lobes of the liver, with documentation of primary, secondary and tertiary branches of the portal vein. In the remaining 10 studies, only the right primary, secondary

and tertiary branches of the portal branches underwent opacification. As a consequence, in these 10 cases, only the right liver lobe underwent opacification.

This data is summarised in table 2.

DISCUSSION:

CTA and IOMP were equally able to depict the vascular anatomy of the shunt and agreed in all classifications. There was however variation in the appearance of both the intrahepatic and extrahepatic portal vasculature when the two methods of imaging were compared. With reference to the extrahepatic portal vasculature, the results are similar to a recent study comparing the two modalities in patients with normal portal anatomy, which concluded that CTA documented extrahepatic portal vasculature more completely than IOMP (Parry & White 2015).

The selective versus non-selective methods of angiography differ in the mechanism by which portal vascular opacification is achieved. CTA is a method of non-selective angiography; the contrast agent is injected into a peripheral systemic vein passing multiple capillary networks before reaching the portal venous system. By this time, the contrast is likely to be present within the entire portal system. During CTA, contrast detection will depend on the degree of contrast dilution, the sensitivity of the scanner's ability to detect the contrast and the timing of the acquisition of the scans relative to contrast injection. IOMP is a selective angiography technique involving the detection of contrast injected directly into a mesenteric vein. IOMP will delineate the flow of contrast from its injection site to the hepatic capillary network and subsequently the post hepatic caudal vena cava. The documentation of the portal vasculature is dependent on the tributary vein selection for administration of contrast agent. Typically, a jejunal vein is selected, as this vein can be sacrificed on termination of the technique without any ill effects. As a consequence, due to normal venous flow, the cranial mesenteric vein and

extrahepatic portal vein will be identified consistently without filling of other portal tributaries (Parry and White 2015). Whilst every effort was made to standardise the technique of IOMP in this study, variation in patient size, catheter size and size of syringe (10ml or 20ml) will have some effect on the speed of injection of contrast in to the selected jejunal vein. This limitation of the study cannot be avoided given the retrospective nature of the study.

There was considerable variation in the appearance of the intrahepatic portal vasculature. All intrahepatic portal branches were identified using CTA for all shunt types described except those involving the right gastric vein. In this shunt type, documentation of smaller intrahepatic portal vessels was less consistent than with other shunt types. Proposed reasons for this variation are as follows. Firstly, whilst contrast enhancement of vessels was good in all cases, there was some variation between patients and it would be reasonable to postulate that in those patients showing less overall contrast enhancement of the portal vascular system there would be a corresponding reduction in visibility of the smaller vessels both within and outside the liver. Secondly, the scanned field of view (SFOV) and displayed field of view (DFOV) was different in each case as it varied according to the size of patient, despite a consistent 512 x 512 reconstruction matrix. As such, spatial resolution of each case would vary to a certain extent, and consequently smaller intrahepatic and extrahepatic branches might be inconsistently identified. Thirdly, surface shaded volume rendered images use a process called segmentation to build detailed vascular maps. Segmentation applies edge enhancement, noise reduction and regional enhancement through the discrimination of relevant density values, contour refinement and three-dimensional reconstruction using a set of partial differential equations. This process is automated and used to build the vascular maps. Applying such automated windowing and levelling techniques can alter which density values that are included in the maps and thereby might allow for errors in interpretation of the surface shaded volume rendered images generated. For this reason, native (transverse), multiplanar reconstruction images and volume rendered images were included in the study. Another potential source of interpretation error might be associated with

movement blur caused by breathing during scan acquisition. Although no specific scan acquisition protocols were used to protect against movement blur from breathing, examination confirmed that in no cases was scan interpretation affected by this issue in this study. Lastly, in patients with a portosystemic shunt a proportion of the portal blood will bypass the liver entering directly into a systemic vein. In cases where the 'shunting' proportion of blood is high there will be a comparative reduction in intrahepatic portal blood flow. It would not be surprising, therefore, that in patients with an EHPSS there would be a reduction in the documentation of the intrahepatic portal vasculature for both CTA and IOMP.

Variation between the two modalities may in part be due to patient positioning, which will have an effect on intra-abdominal and intra-thoracic pressure. For CTA examination, patients were always positioned in sternal recumbency, and for IOMP, patients were invariably positioned in dorsal recumbency. Whether this alteration in position has a profound effect on contrast enhancement of the portal system is yet to be established.

Another potential cause of variation between the two modalities is the unusual blood supply of the liver. The liver receives approximately 80% of its blood supply from the portal vein and 20% from the hepatic arteries (Evans & de Lahunta 2013). Opacification of the liver during IOMP will entirely be due to the portal vascular supply. On the other hand, CTA will combine arterial and portal supply and will likely lead to a higher concentration of contrast agent in the interstitial space compared to IOMP.

Interestingly, CTA showed a reduction in intrahepatic contrast enhancement in cases where shunts involved the right gastric vein, whereas patients with this shunt type consistently had good intrahepatic vascular enhancement on IOMP. Preferential flow of contrast might be an explanation for this anomaly. With IOMP, portal blood (and hence contrast agent) will flow from a region of relatively high pressure (at the point of injection into a mesenteric vein) to a region of lower pressure

(that is, the systemic circulation). This mechanism of preferential flow will account for the appearance of the extrahepatic portal vasculature.

Due to the relatively high pressure across the hepatic capillary network compared to systemic venous pressure, patients with an EHPSS would be expected to have contrast moving through the shunt into the systemic venous circulation rather than passing into the intrahepatic portal vasculature (unless the anomalous shunt vessel was very small), and so, IOMP should be very inaccurate at assessing intrahepatic portal vasculature in such patients.

It is not possible to assess whether the absence of documentation of the intrahepatic portal vasculature is due to an anatomical absence of intrahepatic portal vessels, or simply an absence of contrast enhancement due to preferential flow. Both White *et al.* (2003) and Lee *et al.* (2006) showed that intrahepatic portal vasculature is better documented after temporary shunt ligation, compared to pre-ligation, based on IOMP findings in dogs. Furthermore, Lee *et al.* (2006) confirmed that a well-developed intrahepatic portal vasculature identified on IOMP following the temporary full ligation of an EHPSS could be used as a positive prognostic indicator for clinical outcome. Lipscomb *et al.* (2009) showed similar findings in cats. Since CTA is a non-selective technique, contrast is not administered under pressure into the portal circulation as with IOMP and may be expected to underestimate the presence of portal vasculature (Zwingenberger *et al.* 2013).

CTA did delineate intrahepatic portal vasculature better than IOMP in all cases except those patients with an EHPSS involving the right gastric vein. With IOMP, there was variation in the visibility of the intrahepatic portal vasculature, depending on shunt type. The intrahepatic portal vasculature was not identified in patients with a splenocaval shunt or shunts involving the left colic vein, but was consistently identified in those patients with a shunt involving the right gastric vein. Approximately half of those patients having a left gastrophrenic, left gastrocaval or left gastro-azygos shunt had

intrahepatic portal vasculature that opacified on IOMP. It is interesting that approximately one third of the patients in this latter category had contrast enhancement of the right aspect of the liver (in the territory of the right intrahepatic portal division) without opacification of the remainder of the liver.

The dynamics of the portal circulation are complex. Blood within the portal vein is not homogeneously mixed, but is streamlined in character, with discrete channels of flow permitting the liver to receive blood from discrete viscera. The blood flow through the tributaries of the portal vein has been studied in dogs with normal portal anatomy and no EHPSS (Mogicato *et al.* 2014). In the normal dog there appears to be a preferential flow of portal blood into the liver dependent on which tributary of the portal vein the blood is entering the liver from. Using IOMP, the study concluded that the cranial mesenteric, caudal mesenteric and splenic veins primarily supply the right lateral lobe and the caudate process of the caudate lobe and secondarily the left lateral lobe, left medial lobe and the quadrate lobe (Mogicato *et al.* 2014). Daniel and others (2004) noted non-uniform distribution of sodium pertechnetate during per-rectal portal scintigraphy in normal dogs and postulated that this portal streamlining may be the cause. Echandi and others (2007) showed variation in intrahepatic contrast enhancement in normal dogs after injection of contrast agent in to the splenic pulp and consequent CTA. In this latter study, contrast agent preferentially enhanced the left divisional intrahepatic branch. Whether the viscosity of the contrast agent plays a role in streamlining has, to the authors knowledge, not been investigated.

Portal streamlining has also been used to explain infection and metastases from visceral organs of the abdomen described in humans (Gates *et al.* 1971). This effect may in part account for variation in hepatic portal opacification. It is postulated that shunts involving the right gastric vein would have an increased flow of blood through the right gastric vein close to the porta hepatis, and consequently better documentation of the intrahepatic portal circulation may be expected. Similarly, those cases

with shunts involving the left colic vein and splenocaval shunts would be expected to have little or no intrahepatic portal vascular opacification.

With shunts involving the left gastric vein, variation in intrahepatic portal vascular opacification may be expected. Mehl and others (2005) showed that dogs with a portoazygos shunt were more likely to have smaller differences in portal pressure before and after shunt ligation than those patients with portocaval shunts. Berent and Tobias (2012) state that gastrophrenic and portoazygous shunts are often found in dogs with minimal to mild clinical signs and relatively normal blood work results. They suggested that compression of the shunts during normal respiratory movements or gastric filling may obstruct the shunt resulting in intermittent normalisation of portal blood flow. In such cases, better intrahepatic blood flow would be expected in EHPSSs that involve the left gastric vein with or without the azygos vein. Whilst CTA demonstrated good intrahepatic portal vasculature in this category, IOMP performed much less well. Assessment of such cases on CTA after temporary ligation of the EHPSS would provide significant information on this matter, but to the authors' knowledge such a study has yet to be performed.

CTA gave more information about extrahepatic portal vasculature in all cases and, in the majority of cases, more information about intrahepatic portal vasculature than IOMP. Clinically this information is valuable. It suggests that there is no logical rationale for acquisition of a pre-ligation IOMP if a pre-surgical CTA has been obtained. This allows for reduced patient morbidity due to a significant reduction in the administered dose of contrast agent and smaller reductions in both surgical and anaesthetic times in what are often very compromised patients. The authors suggest, therefore, that CTA can replace the requirement for an IOMP obtained prior to ligation of the shunt vessel in the majority of individuals with uncomplicated congenital EHPSSs.

An IOMP obtained after the temporary full ligation of the shunt, however, should still be considered a very important part of the surgery. Obtaining this IOMP will confirm both that the shunting vessel has been correctly recognised and that only one shunting vessel is present. In addition, it will provide information regarding the development of intrahepatic portal vascularity and information regarding portal venous pressure. Both of these factors are important in deciding whether a shunt should be attenuated and, if so, whether it should be fully ligated or partially closed. The degree of development of the intrahepatic portal vasculature has also been shown to influence the prognosis for the case in the longer term (White *et al.* 2003, Lee *et al.* 2006, Lipscomb *et al.* 2009).

Conflict of interest:

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

REFERENCES:

Berent, A.C. & Tobias, K.M. (2012) Hepatic vascular anomalies. In: Veterinary Surgery: Small Animal (Volume two), Ed Tobias, K.M. & Johnston, S.A. Missouri, Elsevier Saunders. p 1631

Bezuidenhout, A. J. (2013) Veins. In: Miller's anatomy of the dog, 4th edn. Eds Evans, H.E. and de Lahunta, A. Elsevier Saunders, St Louis. pp 519 – 520

Bruehschwein, A., Foltin, I., Flatz, K., Zoeliner, M. & Matis, U. (2010) Contrast-enhanced magnetic resonance angiography for diagnosis of portosystemic shunts in 10 dogs. *Veterinary Radiology and Ultrasound* **51**, 116-121

Daniel, G. B., DeNovo, R. C., Sharp, D. S., Tobias, K. & Berry, C. (2004) Portal streamlining as a cause of nonuniform hepatic distribution of sodium pertechnetate during per-rectal portal scintigraphy in the dog. *Veterinary Radiology and Ultrasound* **45**, 78 – 84

Echandi, R. L., Morandi, F., Daniel, W. T., Paquette, J. L. & Daniel, G. B. (2007) Comparison of transplenic multidetector CT portography to multidetector CT-angiography in normal dogs. *Veterinary Radiology and Ultrasound* **48**, 38 – 44

Evans, H. E. & de Lahunta A. (2010) Portal venous system. In: Guide to the dissection of the dog, 7th edn. W.B. Saunders Company, Philadelphia. pp 169 – 170

Evans, H. E. & de Lahunta, A. (2013) The digestive apparatus and abdomen. In: Miller's anatomy of the dog, 4th edn. Eds Evans, H.E. and de Lahunta, A. Elsevier Saunders, St Louis. pp 331

Frank, P. Mahaffey, M., Egger, C. et al. (2003) Helical computed tomography portography in ten normal dogs and ten dogs with a portosystemic shunt. *Veterinary Radiology and Ultrasound* **44**, 392-400

Fukushima, K. Kanemoto, H., Ohno, K, et al. (2014) Computed tomographic morphology and clinical features of extrahepatic portosystemic shunts in 172 dogs in Japan. *Veterinary Journal* **199**, 376-381

Gates, G. F., Dore, E.K. (1971) Portal streamlining after mesenteric vein injection with ^{198}Au colloid. *Journal of Nuclear Medicine* **12**, 357 – 358

Lamb, C. R. (1996) Ultrasonographic diagnosis of congenital portosystemic shunts in dogs: results of a prospective study. *Veterinary Radiology and Ultrasound* **37**, 281-288

Lee, K. C., Lipscomb, V. J., Lamb, C. R., Gregory, S. P., Guitian, J. & Brockman, D. J. (2006) Association of portovenographic findings with outcome in dogs receiving surgical treatment for single congenital portosystemic shunts: 45 cases (2000-2004). *Journal of the American Veterinary Medical Association* **229**, 1122-1129

Lipscomb, V. J., Lee, K. C., Lamb, C. R. & Brockman, D. J. (2009) Association of mesenteric portovenographic findings with outcome in cats receiving surgical treatment for single congenital portosystemic shunts. *Journal of the American Veterinary Medical Association* **234**, 221-228

Macdonald N. J., Burton, C. A. & White, R. N. (2002) Comparison of visual analog and numeric scoring scales for assessing intraoperative mesenteric portovenography. *Veterinary Radiology and Ultrasound* **43**, 534-540

Mai, W. & Weisse, C. (2011) Contrast-enhanced portal magnetic resonance angiography in dogs with suspected congenital portal vascular anomalies. *Veterinary Radiology and Ultrasonography* **52**, 284-288

Mehl, M.L., Kyles, A.E., Hardie, E.M., Kass, P.H., Adin, C.A., Flynn, A.K., De Cock, H.E. & Gregory, C.R. (2005) Evaluation of ameroid ring constrictors for treatment for single extrahepatic portosystemic shunts in dogs: 168 cases (1995 – 2001). *J Am Vet Med Assoc* **226**, 2020 – 2030

Mogicato, G., Vautravers, G., Meynaud-Collard, P., Deviers, A. & Sautet, J. (2014) Blood flows in tributaries of the portal vein: anatomical and angiographic studies in normal beagle dogs. *Anatomia Histologia Embryologia* **44**, 460-467

Nelson, N. C. & Nelson, L. L. (2011) Anatomy of extrahepatic portosystemic shunts in dogs as determined by computed tomography angiography. *Veterinary Radiology and Ultrasonography* **52**, 498-506

Parry, A. T. & White, R. N. (2015) Portal vein anatomy in the dog: comparison between computed tomographic anagiography (CTA) and intraoperative mesenteric portovenography (IOMP). *Journal of Small Animal Practice* **56**, 657-661

Seguin, B., Tobias, K. M., Gavin, P. R. & Tucker, R. L. (1999) Use of magnetic resonance angiography for diagnosis of portosystemic shunts in dogs. *Veterinary Radiology and Ultrasound* **40**, 251-258

Szatmári, V. & Rothuizen, J. (2006) Ultrasonographic identification and characterization of congenital portosystemic shunts and portal hypertensive disorders in dogs and cats. In: WSAVA Standards for Clinical and Histological Diagnosis of Canine and Feline Liver Disease. Saunders Elsevier, Edinburgh. pp 15-39

White, R. N., Macdonald, N. J. & Burton, C. A. (2003) Use of intraoperative mesenteric portovenography in congenital portosystemic shunt surgery. *Veterinary Radiology and Ultrasound* **44**, 514-521

White, R. N. & Parry, A. T. (2013) Morphology of congenital portosystemic shunts emanating from the left gastric vein in dogs and cats. *Journal of Small Animal Practice* **54**, 459-467

White, R. N. & Parry, A. T. (2015) Morphology of congenital portosystemic shunts involving the right gastric vein in dogs. *Journal of Small Animal Practice* **55**, 430-440

White, R.N. and Parry, A.T. (2016a) Morphology of splenocaval congenital portosystemic shunts in dogs and cats. *Journal of Small Animal Practice* **57,** 28 – 32

White, R. N. & Parry, A. T. (2016b) Morphology of congenital portosystemic shunts involving the left colic vein in dogs. *Journal of Small Animal Practice* **57,** 247 – 254

Wolschrijn, C. F. (2010) The abdomen of the dog and cat. In: Textbook of veterinary anatomy. 4th edn. Eds Dyce, K.M., Sack, W.O. and Wensing, C.J.G. Saunders Elsevier, St. Louis. p 450

Zwingenberger, A. L., Daniel, L., Steffey, M. A., Mayhew, P. D., Mayhew, K. N., Culp, W. T. N., Hunt, G. B., (2013) Correlation between liver volume, portal vascular anatomy, and hepatic perfusion in dogs with congenital portosystemic shunt before and after placement of ameroid constrictors. *Veterinary Surgery* **43**, 926 – 934

Zwingenberger, A L. & Schwarz, T. (2004) Dual-phase CT angiography of the normal canine portal and hepatic vasculature. *Veterinary Radiology and Ultrasound* **45,** 117 – 124

Zwingenberger, A L., Schwarz, T. & Saunders, H.M. (2005) Helical computed tomographic angiography of canine portosystemic shunts. *Veterinary Radiology and Ultrasound* **46,** 27-32

Figure Legends:

Figure 1: CTA and IOMP from a patient with a splenocaval shunt. a. The CTA shows the intrahepatic and extrahepatic portal vasculature. b. The IOMP shows the anomalous vessel and the principal vessels associated with it. The intrahepatic portal vasculature is not identified.

Figure 2: CTA and IOMP from a patient with a left gastrocaval shunt. a. The CTA shows the intrahepatic and extrahepatic vasculature. b. In this patient the contrast allows identification of the right divisional branch of the intrahepatic portal vein much more completely than the left.

Figure 3: IOMP of a patient with a right gastrocaval shunt (type Ai). There is excellent visualisation of the intrahepatic portal vasculature.