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

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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 gastro-duodenal 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
ehepatis 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 into 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
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:


**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.