ANATOMICAL CLASSIFICATION OF CANINE CONGENITAL EXTRAHEPATIC PORTOSYSTEMIC SHUNTS BASED ON CT ANGIOGRAPHY: A SVSTS AND VIRIES MULTI-INSTITUTIONAL STUDY IN 1128 DOGS

C Weisse, VMD, DACVS[1]; WA Fox-Alvarez, DVM, DACVS[2]; FR Vilaplana Grosso, LV, DECVDI, DACVR[2]; K Asano, DVM, PhD, DJCVS[3]; K Ishigaki, DVM[3]; AL Zwingenberger, DVM, DACVR, DipECVDI[4]; KA Carroll, BVetBiol/BVSc (Hons 1)[5]; VF Scharf, DVM, DACVS[5]; V Lipscomb, MA, VetMB, Dipl. ECVS[6]; ML Wallace, MS, DVM, DACVS-SA[7]; A Aly[8], B Biscoe, DVM, DACVR, DACVR-EDI[9]; JR Davidson, DVM, MS, MEd, DACVS, DACVSMR[10]; S Arai, DVM, PhD, DACVS-SA[11], N Amato, DVM, DACVS[12], SD Ryan, BVSc(Hons), DACVS[13], S Woods[1], Anjile An[14]

[1] Animal Medical Center, NY, NY.

[2] College of Veterinary Medicine, University of Florida, Gainesville, FL.

[3] Nihon University, Fujisawa, Kanagawa, Japan.

[4] University of California, Davis School of Veterinary Medicine, Davis, CA.

[5] NCSU Veterinary Hospital, Raleigh, NC.

[6] Royal Veterinary College, Hatfield Herts, England.

[7] College of Veterinary Medicine, University of Georgia, Athens, GA.

[8] Cornell University College of Veterinary Medicine, Ithaca, NY.

[9] Animal Imaging, Irving, TX.

[10] Texas A&M University, College of Veterinary Medicine & Biomedical Sciences, College Station, TX.

[11] College of Veterinary Medicine, University of Minnesota, St. Paul, MN.

[12] Ethos Veterinary Health, Massachusetts Veterinary Referral Hospital, Woburn, MA.

[13] UVet Veterinary Hospital, University of Melbourne, Werribee, VIC, Australia.

[14] Weill Cornell Medicine, New York Presbyterian, New York, NY.

Short Title: Anatomical Classification of Canine Congenital EHPSS Based on CT Angiography

Keywords: Canine, Portosystemic Shunt, EHPSS, portal vein, portal anatomy, shunt anatomy

Please address all correspondence to Dr. Chick Weisse, Animal Medical Center, 510 East 62nd street, NY, NY 10065, USA. Chick.weisse@gmail.com

Abbreviations: Extrahepatic portosystemic shunts, EHPSS; computed tomography, CT; The Society of Veterinary Soft Tissue Surgeons, SVSTS; The Veterinary Interventional Radiology and Interventional Endoscopy Society, VIRIES; Date of birth, DOB; Cranial mesenteric vein, CrMV, Caudal mesenteric vein, CdMV; Left colic vein, LCV; Main portal vein, PV; Gastrosplenic vein, GSV; Left gastric vein, LGV; Splenic vein, SV; Short gastric veins, SGV; Gastroduodenal vein, GDV; Right gastric vein, RGV; right or left gastroepiploic veins, GEV; Pancreatic vein, PancV; Caudal vena cava, C; Phrenic vein, P; Azygos vein, A; Hepatic vein, HV; Phrenicoabdominal vein, PhAV; Iliac vein, IlV; Gonadal vein, G; Aberrant left gastric-caval shunt, aLGC; Portal perfusion

score, PPS; Portosystemic shunt, PSS; United Kingdom, UK; Standard deviation, SD; Left Gastric-Phrenic, LGP; Left Gastric-Azygos, LGA; Left Gastric-Caval, LGC; aberrant Left Gastric-Caval with Right Gastric Vein contribution, aLGC +RGV; aberrant Left Gastric-Caval with Right Gastric Vein and Short Gastric Vein contributions, aLGC +RGV +SGV; Portocaval, PC

Abstract:

Canine congenital extrahepatic portosystemic shunt (EHPSS) morphologies have not been fully elucidated. The goal of this retrospective, multi-institutional study was to use CT angiography to create an anatomical-based nomenclature system for canine congenital EHPSS. These shunt morphologies were then evaluated to identify any significant association with patient age, sex, breed, weight, or subjective portal perfusion score. Data collected respectively from the SVSTS and VIRIES list-serves included patient DOB, sex, breed, weight, CT date, and reported diagnosis. A single author (CW) viewed all CT scans and classified shunts based upon the shunt portal vessel(s) of origin, the shunt systemic vessel(s) of insertion, and any substantial portal vessels contributing to the shunt. Additionally, hepatic portal perfusion was subjectively scored between 1 (poor/none) and 5 (good/normal) based upon caliber of the intrahepatic PVs. 1182 CT scans were submitted from 13 different institutions. Due to exclusion criteria, 100 (8.5%) were removed leaving 1082 CT scans to be included. 45 different EHPSS anatomies were identified with 5 classifications accounting for 85% of all shunts (LGP [27%], LGA [19%], LGC [15%], aLGC +RGV [12%], and aLGC +RGV +SGV [11%]). Shunt origin involved the left gastric vein

(LGV) in 95% of the described classifications. Significant differences were identified among the 5 most common shunt types with respect to age at time of CT scan ($p<0.001$), sex ($p=0.009$), breed ($p<0.001$), weight ($p<0.001$), and subjective portal perfusion score ($p<0.001$). An anatomical classification system for canine EHPSS may enable improved understanding, treatment comparisons, and outcome prediction for these patients.

1. INTRODUCTION

Congenital extrahepatic portosystemic shunts (EHPSS) are typically solitary abnormal communications between the portal and systemic circulatory systems present at birth that can result in a variety of clinical signs related to hepatic insufficiency.[1-5] Following medical management for patient stabilization, surgical attenuation of the vessel is typically recommended to redirect portal blood flow to the liver and improve hepatic function. A successful surgery relies on a detailed understanding of both the normal and abnormal vascular anatomy to make certain the correct vessel is attenuated at the correct location to avoid persistent shunting.

Nomenclature systems using CT angiography have previously been developed for EHPSS, and have notably identified the left gastric vein as the portal vessel most commonly involved in these anomalies.[3-5] Unfortunately, these nomenclature systems have failed to gain widespread adoption, perhaps due to confusion associated with terminology originally based on ultrasonographic evaluation[3], or classifications based upon letters and numbers that are not easily recognizable.[4] The lack of widespread adoption of suitable nomenclature for the normal canine portal vascular anatomy has led to further confusion.[3,4] CT angiography has also been used to evaluate the degree of portal vein development at the level of the porta hepatis among different shunt conformations, however the study population was too small to allow meaningful statistical comparisons to be made.[3] An internationally-accepted, congenital EHPSS nomenclature system based on vascular anatomy could provide improved understanding, treatment comparisons, and

outcome prediction for patients with these anomalies. The goal of this study, like one previously performed in cats[6], was to use CT angiography to create an anatomical-based nomenclature system for canine congenital EHPSS. These shunt morphologies were then evaluated to report individual shunt prevalence and identify any significant association with patient age, sex, breed, weight, or subjective portal perfusion score.

2. METHODS

2.1 Selection and description of subjects

To obtain meaningful data for this retrospective, multi-institutional study, a large population of canine patients from a variety of international geographic locations were recruited through two, well-populated veterinary societies; The Society of Veterinary Soft Tissue Surgeons (SVSTS) and The Veterinary Interventional Radiology and Interventional Endoscopy Society (VIRIES). Criteria for study inclusion were canine patients <12kgs at time of CT study with a diagnostic quality CT angiogram demonstrating 3 or fewer congenital EHPSS and no history of previous shunt surgery. Exclusion criteria included the presence of liver tumors, multiple (>3) EHPSS, or ascites. A "shunt" was defined as an abnormal connection between two separate circulatory systems.[7] The shunts were subsequently named for 1) the most peripheral portal vessel(s) of origin, 2) the most peripheral systemic vessel(s) of insertion, and 3) any substantial portal vessels contributing to the shunt. "Contributing" vessels were those portal vessels determined subjectively to be contributing portal blood to the shunt as demonstrated by increased size (abnormally

conspicuous) compared to what would be expected based upon normal portal anatomy, however not the most peripheral portal vessel of origin or systemic vessel of insertion.

2.2 Data recording and analysis

Data collected included patient date of birth, sex, breed, weight at time of the CT study, CT date, and reported diagnosis if available. A single author (CW, DACVS) viewed all CT scans to confirm inclusion criteria were satisfied utilizing transverse, sagittal, and dorsal views. Shunt subtypes were named by a single author (CW, DACVS) based on portal vessels of origin and systemic vessels of insertion (**FIGURE 1**). Possible portal vessels of shunt origin identified included the cranial mesenteric vein (CrMV), caudal mesenteric vein (CdMV), left colic vein (LCV), main portal vein (PV), gastrosplenic vein (GSV), left gastric veins (LGV), splenic vein (SV), short gastric veins (SGV), left gastroepiploic vein (LGEV), gastroduodenal vein (GDV), right gastric vein (RGV), right gastroepiploic veins (RGEV), and pancreatic vein (PancV). Possible systemic vessels of shunt insertion identified included the caudal vena cava (CdVC), phrenic vein (Phrenic), azygos vein (Azyg), hepatic vein (HV), phrenicoabdominal vein (PhAV), iliac vein (IlV), and gonadal vein (GoV). Contributing portal vessels were then identified. For example, if an EHPSS was identified between the left gastric vein and the caudal vena cava with portal blood contribution from the right gastric vein, then the shunt would be named a "left gastric-caval shunt with right gastric vein contribution", or "LGC +RGV". Additionally, as described previously[3,4] the left gastric vein can be "aberrant" and insert on the caudal vena cava rather than the gastrosplenic vein. In this scenario, any "aberrant" vessel was labelled with a

lower-case “a”. For example, an aberrant left gastric-caval shunt would be labelled “aLGC” (**FIGURE 2**).

Hepatic portal perfusion received a subjective portal perfusion score (PPS) on a 5-point scale as either poor (1), moderate-poor (2), moderate (3), moderate-good (4), or good (5). This score was subjectively based on 1) the internal diameter of the PV based on contrast filling at the level of the porta hepatis (just cranial to the GDV) in comparison to the internal diameter of the PV prior to the shunt exit from the portal system and 2) the presence/absence of first, second, and third order PV branches within the hepatic parenchyma. Generally, poor PPS was subjectively associated with no visible PV at the level of the porta hepatis and therefore absent first order intrahepatic PV branches. Moderate PPS was subjectively associated with an approximate 50% internal diameter of the PV at the level of the porta hepatis compared to the PV prior to shunt exit from the portal system, and first or second order intrahepatic PV branches. Good PPS was subjectively associated a similar internal diameter (~100%) of the PV at the level of the porta hepatis compared to the PV prior to shunt exit from the portal system, and second or third order intrahepatic PV branches. Moderate-poor and moderate-good subjective PPS fell in-between the previously described scores, respectively (**FIGURE 3**).

A representative example of each of the identified shunt anatomies were then collected and distributed to the contributing authors for input on possible adjustments to the nomenclature system.

2.3 Statistics

Descriptive statistics were used to characterize the study sample with respect to demographic and clinical factors of interest. Continuous variables are represented as median (interquartile range), mean (standard deviation), and range (minimum, maximum). Categorical variables are represented as n (%). The Fisher's exact test, Welch two-sample t-test, and one-way ANOVA were used to examine the association between demographic/clinical variables of interest and stratifying variables of interest (including sex, breed, shunt type, and subjective portal perfusion score). The five most common breeds were identified with all others collapsed into an "other" category, and each of the five most common breeds were compared to all others. The five most common shunts were also identified with all others collapsed, and each of the five most common shunts were compared to all others. All p-values are two-sided with statistical significance evaluated at the 0.05 alpha level. All analyses were performed by one statistician (AA) in R Version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria).

3. RESULTS

Sixteen contributors from thirteen different institutions responded to the request for retrospective case recruitment resulting in 1182 CT scans. After review, 100 cases failed to satisfy inclusion and exclusion criteria and were removed from the study due to insufficient quality of the CT scan (28 cases), body weight exclusion (16 cases), >3 PSS (15 cases), incomplete CT scan (9 cases), ascites (7 cases), liver tumor (7 cases), intrahepatic PSS (7 cases), previous shunt surgery (7 cases), no identifiable PSS (3 cases), or repeat case (1 case). The remaining 1082 cases were ultimately included in the study for data collection and CT review to identify the shunt portal vessel(s) of origin, systemic vessel(s) of insertion, contributing vessels, and subjective PPS. Institutions

providing cases included the University of Florida (178 cases), Nihon University [Japan] (156 cases), University of California, Davis (117 cases), Animal Medical Center (94 cases), North Carolina State University (89 cases), University of Georgia (64 cases), Cornell University (62 cases), Royal Veterinary College [U.K.] (62 cases), Animal Imaging Veterinary Radiology Specialists (58 cases), Texas A&M University (58 cases), Massachusetts Veterinary Specialists (50 cases), University of Melbourne [Australia] (48 cases), and University of Minnesota (46 cases).

575 female dogs (405 neutered and 170 sexually intact) and 507 male dogs (361 neutered and 146 sexually intact) were included, with a mean age of 1427 days (SD 3669). Weight was available in 1082 patients, with a mean of 4.8 kgs (SD 2.6) (**TABLE 1**). When those patients with ages under 90d or over 3650d at the time of CT were removed from the age analysis, a second population of dogs was created for any subsequent age analyses to variables of interest. The 1013 patients (1013/1082; 93.6%) in this age subset had a mean age of 1012 days (SD 873). There was no significant difference in mean age at time of CT scan between females and males (995d vs 1031d, P=0.52) when compared in the subset age population between 90 and 3650d of age.

There were significant differences in males and females in terms of mean weight (P<0.001), portal vein (P=0.003), and contributing vessels (P<0.001). Females on average weighed 4.5kgs compared to males at 5.2kgs, had more left gastric vein portal vessel of origin (70% vs 61%), and higher absence of contributing vessels (72% vs 61%).

The five most common breeds comprised 648/1067 dogs (60.7%) and included Yorkshire terriers (209 dogs; 19.6%), mixed breed dogs (140 dogs; 13.1%), Miniature Schnauzers 117 dogs; 11.0%), Shih Tzus (103 dogs; 9.7%), and Maltese (79 dogs; 7.4%) out of a total of 64 different reported breeds (**TABLES 1, 2**).

The portal vessel of origin was most commonly the left gastric vein (1025 dogs, 94.7%). Specifically, the shunt involved an otherwise anatomically normal left gastric vein (inserting on the gastrosplenic vein) in 722/1082 dogs (66.7%) and an "aberrant left gastric vein" (a left gastric vein that inserts on the caudal vena cava instead of the gastrosplenic vein) in 303/1082 dogs (28.0%). An "aberrant gastrosplenic vein", a gastrosplenic vein that inserts on the caudal vena cava rather than the portal vein, was the portal vessel of origin in 21/1082 cases (1.9%). No other "aberrant" vessels were identified, however the gastrosplenic vein was absent in 9 cases (0.8%). The portal vessel of origin was significantly associated with PPS ($P<0.001$), patient age at time of CT ($P<0.001$), sex ($P=0.003$), breed (<0.001), and absence of contributing vessels ($P<0.001$). Patients with a left gastric vein portal vessel of origin had more "Good" PPS (42% vs 30%) and were older at time of CT (1077d vs 893d).

The systemic vessel of insertion was most commonly the caudal vena cava (509/1082 dogs; 47%), followed by the phrenic vein (340/1082 dogs, 31.4%) and azygos vein (228/1082 dogs; 21.1%). The systemic vessel of origin was significantly associated with PPS ($P<0.001$), and a caudal vena cava systemic vessel of insertion was significantly associated with lower patient age at time of CT ($P<0.001$).

Ultimately, 363/1082 (33.5%) dogs were identified as having additional portal vessels contributing blood flow to the shunt (719/1082 or 66.5% had no contributing vessels). The most common contributing vessel was the right gastric vein (317/1082 dogs; 29.3%), followed by the short gastric vein (166/1082 dogs; 15.3%) and the pancreatic vein (23/1082 dogs; 2.1%). More than one contributing vessel was identified in 154 dogs (154/1082; 14.2%). Contributing vessels were more often identified when the portal vessel of origin was aberrant in nature (325/363 shunts, 90.0%). Aberrant LGV (aLGV) shunt portal vessels of origin had associated contributing

vessels in 304/306 shunts (99.4%). Additionally, the systemic vessel of insertion also was associated with contributing vessels. While 317/509 (62%) CdVC systemic vessel of insertion shunts were associated with contributing vessels, only 16/228 (7.0%) and 22/339 (6.5%) of azygos or phrenic shunt insertions were associated with contributing vessels, respectively. The presence of additional portal vessels contributing blood flow to the shunt was significantly associated with age at time of CT ($P<0.001$), sex ($P<0.001$), body weight ($P<0.001$), breed ($P<0.001$), shunt type ($P<0.001$), portal vessel of origin ($P<0.001$), pre-hepatic shunt insertion ($P<0.001$), and PPS ($P=0.002$).

43 unique shunt conformations were identified. The 5 most common shunts, LGP (295/1082 dogs; 27.3%), LGA (208/1082 dogs; 19.2%), LGC (165/1082 dogs; 15.3%), aLGC +RGV (131/1082 dogs; 12.1%), and aLGC +RGV +SGV (118/1082 dogs; 10.9%) accounted for 917/1082 dogs or 84.8% of all reviewed cases (**FIGURE 1, TABLE 1**). Significant differences were identified among the 5 most common shunt types with respect to age at time of CT scan ($P<0.001$) (**FIGURE 4**), breed ($P<0.001$), weight ($P=0.008$), sex ($P=0.01$), and subjective portal perfusion score ($P<0.001$) (**FIGURE 5**). Specifically, LGP and LGA shunts were older at time of CT than LGC, aLGC +RGV or aLGC +RGV +SGV shunts. Additionally, LGP and LGA shunts had significantly higher mean subjective PPS, and LGC and aLGC +RGV had significantly lower mean subjective PPS. LGA shunts were more common in female dogs while aLGC +RGV +SGV were more common in male dogs. Finally, Maltese dogs were disproportionally associated with an aberrant left gastric vein (aLGV) portal vessel of origin (78%) and were more likely to have contributing portal vessels present (80%) when compared to other dog breeds. Double shunts (12/1082; 1.1%) and triple shunts (1/1082; 0.1%) were identified but uncommon.

Subjective portal perfusion scores (PPS) were available for 1078/1082 (99.6%) dogs. In 4 dogs, PPS could not be determined due to motion artifact or limited ability to clearly discern the portal vasculature from hepatic arterial vessels. PPS were recorded as Good (413/1078 dogs; 38.3%), Moderate-Good (167/1078 dogs; 15.5%), Moderate (137/1078 dogs; 12.7%), Moderate-Poor (92/1078 dogs; 8.5%), or Poor (269/1078 dogs; 25.0%). The median numeric PPS was 4.0 (IQR: 2.0, 5.0) (**TABLE 1**). Significant differences were identified between PPS and age at time of CT (P<0.001) (**FIGURE 6**), weight (P<0.001), shunt type (P<0.001) (**FIGURE 5**), portal vessel of origin (P=0.003), systemic vessel of insertion (P<0.001), and pre-hepatic versus post-hepatic shunt insertion (P<0.001). Dogs with Good PPS had the highest mean age (1308d, SD: 917), and dogs with Poor (430d, SD: 440) and Moderate-Poor (931d, SD: 824) PPS had the lowest age at time of CT (**FIGURE 6**). In relation to shunt type, LGP (P<0.001), LGA (P<0.001), LGC (P<0.001), and aLGC +RGV +SGV (P=0.032) had significant differences in PPS when compared to the other shunts; 58% (vs 31% of other shunts) of LGP dogs and 45% (vs 37%) of LGA shunts had Good PPS, whereas only 18% (vs 42%) of LGC, 29% (vs 40%) of aLGC +RGV, and 27% (vs 40%) of aLGC +RGV +SGC shunts had Good PPS (**FIGURE 5**). 100% (22/22) of portocaval shunts (direct communications between the portal vein and caudal vena cava) had Poor PPS, compared to 25% of all shunts in general. Shi Tzus had significantly different PPS than other breeds (P<0.001), with 59% Good PPS compared to 36% of all others.

4. DISCUSSION

Based upon literature review, this is the largest population of canine congenital EHPSS evaluated using CT angiography. Although the original 1182 scans were ultimately reduced to 1082 cases

296 due to exclusion criteria, the multi-institutional and multi-national origin of these cases should
297 provide a reasonable cross-section of the nature of these vascular anomalies in dogs.

298 The signalment of these dogs was similar to what has been previously reported for canine
299 EHPSS.[8-12] Yorkshire Terriers were the most common breed represented followed by mixed breed
300 dogs, miniature Schnauzers, Shih Tzus, and Maltese dogs together accounting for about 60% of
301 all the dogs in this study population, however 62 breeds were ultimately represented demonstrating
302 the wide variety of canine breeds affected by this disease. While there has not been a clearly
303 recognized sex predisposition for canine EHPSS reported previously, females were over-
304 represented in this study population (53% female versus 47% male) however these numbers were
305 not compared to individual hospital patient populations to determine if this represented a
306 significant difference. Interestingly, some shunts were more common in certain sexes such as
307 LGA (females) and aLGC +RGV +SGV (males). Shih Tzus were on average older, and had more
308 Good PPS compared to other breeds, and Maltese dogs were more likely to have aberrant left
309 gastric vein shunt origins as well as the presence of contributing vessels.
310
311 Patient age at the time of the CT scan should be considered separately from patient age at
312 the time of diagnosis, which is the variable most often reported in EHPSS studies. However, as
313 canine EHPSS are typically treated soon after diagnosis, one can infer that many (but not all) of
314 these patients received the CT scan within a couple of months following diagnosis. The mean age
315 at time of CT was 1427d (3.9y). Because of the often-inaccurate dates of birth (DOB) in medical
316 records, and the unlikely event of diagnosing and performing a CT scan within 90 days of life,
317 those patients DOBs under 90d of age or over 3650d of age at the time of CT were removed from
318 the data to define a second population of dogs for age comparisons to other variable of interest. In

this second population with 69 fewer dogs, the mean age at time of CT was 1012d (2.8y). In both calculations, these ages are higher than often reported previously in dogs with congenital EHPSS.[8-12] The ages here could be overestimated due to CT timing, or wrong due to incorrect dates of birth sometimes present in patient medical records. Alternatively, these higher ages could be due to increased interest among the pet-owning population to seek diagnostic and therapeutic options for their pets, or a bias for older pets to undergo more advanced imaging when a congenital EHPSS might be less suspected.

Shunt morphology is difficult to compare to previous studies as there is no standardized nomenclature, however involvement of the left gastric vein was the most common portal vessel of origin (95%) similar to what has been previously reported.[3,4] Additionally, an "aberrant" left gastric vein that inserts on the vena cava, phrenic vein, or azygos vein rather than the gastrosplenic vein was also identified commonly in this study cohort (303/1082; 28%) as previously described.[3,4] The "gastrosplenic" vein has also been called the splenic vein, but the authors chose "gastrosplenic" to differentiate between these two vessels; Vitums description of the canine portal system in 1949 includes the term "gastrosplenic" vein for this vessel, supporting our use of this terminology.[13] Aberrant gastrosplenic veins (not inserting on the portal vein) have not been described previously but were identified in 2% of cases, suggesting the possibility that other portal vessels of origin may be aberrant in nature during development.

"Contributing" vessels were defined as those portal vessels determined to be contributing portal blood to the shunt as demonstrated by increased size (abnormally conspicuous) compared to what would be expected based upon normal portal anatomy, however not the most peripheral portal vessel of origin or systemic vessel of insertion. These vessels have historically been used in different shunt nomenclature systems however the authors believe this leads to confusion when

identifying the appropriate location to perform shunt attenuation. In one canine study performed at a major veterinary teaching hospital, 8/20 dogs (40%) had thin film banding surgical attenuation performed at a sub-optimal location allowing persistent shunting through alternate vessels.[11] This emphasizes the importance of discerning the actual shunt from contributing vessels and placing any attenuation device beyond (distal) to any portal vessels that might continue to permit visceral blood to shunt systemically. Instead, in the proposed anatomical nomenclature system, these "contributing" vessels are named and identified in surgery to ensure attenuation is performed beyond these vessels. Contributing vessels were absent in 719 dogs (~66%) but present in 363 dogs (~34%); This should alert the surgeon that these vessels are commonly present and should not be mistaken for multiple shunts or the need for multiple attenuation sites in general. The most common contributing vessels were the RGV (~29%), the SGV (~15%), and the PancV (~2%). While the RGV has been historically associated with canine EHPSS,[3,4] involvement of the SGV has not been. The authors felt CT angiography was sensitive enough to identify the SGV as originating from the dorsal root of the splenic vein near the head of the spleen. Interestingly, Vitums reported in 1959 the presence of gastric rootlets bridging the fundus of the stomach and dorsal root of the splenic vein (SGVs), often with one larger rootlet containing radicles between the caudal root of the left gastric vein and the dorsal end of the spleen (head of the spleen).[13] This communication is what the authors believe to be a SGV contribution to a shunt, seems comparable to what has been described as a "caudal loop",[3] and is what is often confirmed in surgery (**FIGURE 2**). In addition, contributions from the pancreatic and gastroepiploic veins have not been previously reported based on review of the literature.

The shunt systemic vessel of insertion most commonly involved the CdVC (509/1082; 47.0%), phrenic vein (340/1082; 31.4%), and azygos vein (228/1082; 21.1%). Recognizing that

these 3 vessels comprise 99.5% of all canine EHPSS insertions should help facilitate identification in surgery of the ideal location for attenuation to occur. Left gastric vein shunt insertions on the phrenic and azygos veins should not be surprising as natural connections between radicles of these vessels have been described to occur naturally in Vitums anatomical paper describing the normal canine portal vein.[13] Understanding this anatomy should help the surgeon identify the best location for shunt attenuation, as close to the systemic vessel of insertion as possible, however perhaps not beyond that point for fear of systemic collaterals developing around an attenuation site. Insertion onto the CdVC can be explained by anatomic variation when the left gastric vein is aberrant and does not join the gastrosplenic vein directly; it is unclear if there are normal connecting radicles between a normal LGV and CdVC as described above for the phrenic and azygos veins, but these were not described by Vitums.[13]

Ultimately 43 unique canine EHPSS conformations were identified, and the five most common shunts accounted for ~85% of all cases. Like cats, the LGP was the most common shunt (27% of dogs) identified. The LGA was the second most common shunt (19% of dogs), however this subtype was identified uncommonly in cats (only 2%).[6] Contributing vessels were also much less common in cats (3%) compared to approximately 1/3 of dog shunts.[6] Although double (~1%) and triple (~0.1%) shunts were uncommon, they were identified in 13 patients. Based on this study alone, we cannot confirm if these were solely congenital in nature or acquired due to portal hypertension; This is currently under continued investigation. The primary author has successfully treated dogs with double shunts previously so this should alert the surgeon that more than one congenital shunt is possible and may be amenable to surgical correction. This is the reason dogs with 3 or fewer shunts were included in this study population.

Subjective PPS was significantly associated with patient age at time of CT, breed, weight, shunt type, pre- versus post-hepatic shunt insertion, and presence of contributing vessels. This information needs to be more objectively elucidated as inherent portal perfusion present at the time of surgery may be important in the patient's ability to develop subsequent improved hepatic perfusion following shunt attenuation. Unfortunately, the authors couldn't identify an accurate and reproducible "objective" measurement of portal perfusion using retrospectively acquired CT images considering different image acquisition methods, variability of Hounsfield units between machines, etc. Dogs with lower subjective PPS were younger at the time of CT scan, perhaps suggesting less portal perfusion could be associated with more severe or observable clinical signs earlier in life. Dogs with portoazygos shunts have also been documented to be diagnosed later in life[14] and this was also confirmed in our study population comparing LGA shunts to other conformations. Patient weight has also been associated with portoazygos versus portocaval shunts with lighter patients being more likely to have portocaval shunts.[14] In our study, patient weight was also significantly associated with shunt morphology (P=0.008). Dogs with pre-hepatic shunt insertions also demonstrated reduced subjective PPS compared to those with post-hepatic shunt insertions (P<0.001). This could be explained by increased vascular resistance redirecting blood flow to the liver in post-hepatic shunt insertion patients.

Shunt conformations were significantly associated with subjective PPS (P<0.001) (**FIGURE 5**). Relating subjective PPS to certain shunts and breeds could be useful for predicting outcomes in these patients. Previous studies have demonstrated the importance of portal perfusion prior to shunt attenuation[15] as well as the ability of the portal system to develop following partial

shunt attenuation[12], however it remains unclear if different shunt morphologies or breeds are important in predicting outcomes. For example, in Lee et al. 17 dogs receiving initial partial suture shunt attenuation received a second surgery in which 3/17 (17.6%) remained unable to tolerate complete shunt ligation. With the more popular use of progressive attenuation devices, it is possible that a considerable number of patients are ultimately receiving complete or near complete shunt attenuation when their intrinsic portal vascularity may not tolerate it. Unfortunately, there is often insufficient follow-up diagnostic imaging in most cases to determine the nature of persistent clinical signs or biochemical abnormalities that are often attributed to underlying liver disease rather than persistent shunt blood flow, acquisition of acquired shunting, or a combination of the two. Identifying the patients that will ultimately not tolerate complete shunt attenuation will help us better understand the nature of this disease process and may alter our treatment recommendations such as more slowly progressive attenuation devices. A better understanding of the difference between shunt morphologies must be preceded by a more universal and repeatable nomenclature system to facilitate accurate comparisons.

Interestingly, overall PPS tended to be better in dogs (median 4, IQR: 2, 5) than in our concurrent study of EHPSS morphology in cats (median 2, IQR: 1, 5), and age at time of CT was higher in dogs (mean 1012d, SD 873) than in cats (mean 650d, SD 793).[6] If the subjective PPS system is reliable across imaging of these species, then this could be one explanation for a perceived better prognosis in dogs following shunt surgery when compared to outcomes reported for cats.[16-19]

There are inherent limitations of a retrospective study of this nature which are important to consider when interpreting the results reported above. Medical records were the sole source of data which were not individually confirmed with the client or referring veterinarian. CT machines

or imaging protocols were not standardized for these patients. Subjective portal perfusion determination was performed by the same author (CW), however there were no objective measures used to test this system. Based upon previous publications and the primary author's experience, it is generally accepted that CT angiography tends to underestimate the degree of portal perfusion later identified at the time of surgery[12-14], however each case was likely similarly affected by this limitation. Ideally, a more objective, standardized, repeatable protocol for measuring portal perfusion will be developed in the future.

This study identified the most common extrahepatic portosystemic shunt morphology in dogs based upon CT angiography. The left gastric vein was again confirmed to be the most common portal vessel of origin (95%) and the 5 most common shunts accounted for 85% of all morphologies identified. Significant differences were identified among the 5 most common shunt types with respect to age at time of CT scan ($p<0.001$), sex ($p=0.009$), breed ($p<0.001$), weight ($p<0.001$), and subjective portal perfusion score ($p<0.001$); younger dogs were identified to have worse subjective portal perfusion scores which were also associated with different shunt morphologies. Shih Tzus were older and had greater PPS compared to other breeds, and Maltese dogs were more likely to have aberrant left gastric vein shunt origins as well as the presence of contributing vessels. Median subjective portal perfusion scores were generally better in dogs (median 4, IQR: 2, 5) than those previously reported in cats (median 2, IQR: 1, 5) with EHPSS.[6] An anatomical classification system for canine EHPSS may enable improved understanding, treatment comparisons, and outcome prediction for these patients.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Sarah Woods for exceptional assistance with data gathering and organization.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Weisse

(b) Acquisition of Data: Weisse, Fox-Alvarez, Vilaplana Grosso, Asano, Ishigaki, Zwingenberger, Carroll, Scharf, Lipscomb, Wallace, Aly, Biscoe, Davidson, Arai, Amato, Ryan, Woods, An

(c) Analysis and Interpretation of Data: Weisse, An

Category 2

(a) Drafting the Article: Weisse

(b) Reviewing Article for Intellectual Content: Weisse, Fox-Alvarez, Vilaplana Grosso, Asano, Ishigaki, Zwingenberger, Carroll, Scharf, Lipscomb, Wallace, Aly, Biscoe, Davidson, Arai, Amato, Ryan, Woods, An

Category 3

(a) Final Approval of the Completed Article: Weisse, Fox-Alvarez, Vilaplana Grosso, Asano, Ishigaki, Zwingenberger, Carroll, Scharf, Lipscomb, Wallace, Aly, Biscoe, Davidson, Arai, Amato, Ryan, Woods, An

Category 4

(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and

resolved: Weisse, Fox-Alvarez, Vilaplana Grosso, Asano, Ishigaki, Zwingenberger, Carroll, Scharf, Lipscomb, Wallace, Aly, Biscoe, Davidson, Arai, Amato, Ryan, Woods, An

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

Preliminary results were presented as an Abstract at the VIRIES Annual Conference in 2023.

EQUATOR NETWORK DISCLOSURE

An EQUATOR network checklist was not used for preparing this manuscript.

DATA AVAILABILTY STATEMENT

The supporting data for this study can be acquired by contacting chick.weisse@gmail.com.

ORCID

Chick Weisse https://orcid.org/0000-0001-5202-9962

Federico Vilaplana Grosso https://orcid.org/0000-0001-5443-5059

Allison Zwingenberger https://orcid.org/0000-0002-8982-2558

Kenneth Carrol https://orcid.org/0000-0002-0977-1261

Mandy Wallace https://orcid.org/0000-0002-5286-4287

REFERENCES

1. Weisse C, Berent A. Hepatic vascular anomalies. In: Ettinger SJ, Feldman EC, and Cote E, editors. Textbook of veterinary internal medicine: Eight edition. Elsevier, St Louis, 2017: 1639-1658.

2. Berent AC, Tobias KM. Hepatic vascular anomalies. In: Tobias KM, Johnston SA, editors. Veterinary surgery: small animal. Elsevier, St Louis, 2012:1624–1658.

3. Nelson NC, Nelson LL. Anatomy of extrahepatic portosystemic shunts in dogs as determined by computed tomography angiography. *Vet Radiol Ultrasound*. 2011;52:498–506.

4. White RN, Parry AT. Morphology of congenital portosystemic shunts involving the right gastric vein in dogs. *J Small Anim Pract*. 2015;56:430–440.

5. White RN, Parry AT. Morphology of congenital portosystemic shunts emanating from the left gastric vein in dogs and cats. *J Small Anim Pract*. 2013;54:459–467.

6. Weisse C, Asano K, Ishigaki K, et al. Anatomical Classification of Feline Congenital Extrahepatic Portosystemic Shunts Based on CT Angiography: An SVSTS and

VIRIES Multi-Institutional Study in 231 Cats. Oral presentation at: ACVS Annual Conference; October, 2023; Louisville, KY.

7. "Shunt." *Merriam-Webster.com Dictionary*, Merriam-Webster, https://www.merriamwebster.com/dictionary/shunt. Accessed 6 May, 2022.

8. Otomo A, Singh A, Jeong J, et al. Long-term clinical outcomes of dogs with single congenital extrahepatic portosystemic shunts attenuated with thin film banding or ameroid ring constrictors. *Veterinary Surgery* 2020;49:436-444.

9. Matiasovic M, Chanoit GPA, Meaking LB, et al. Outcomes of dogs treated for extrahepatic congenital portosystemic shunts with thin film banding or ameroid rings constrictor. *Veterinary Surgery* 2020;49:160-171.

10. Traverson M, Lussier B, Huneault L, et al. Comparative outcomes between ameroid ring constrictor and cellophane banding for treatment of single congenital extrahepatic portosystemic shunts in 49 dogs (1998-2012). *Veterinary Surgery* 2018;47:179-187.

11. Nelson NC, Nelson LL. Imaging and clinical outcomes in 20 dogs treated with thin film banding for extrahepatic portosystemic shunts. *Veterinary Surgery* 2016;45:736-745.

12. Lee KC, Lipscomb VJ, Lamb CR et al. Association of portovenographic findings with outcome in dogs receiving surgical treatment for single congenital portosystemic shunts: 45 cases (2000–2004). *J Am Vet Med Assoc* 2006; 229:1122–1129.

13. Vitums A. Portal vein in the dog. *Zentralblatt für Veterinärmedizin*, 1959, Vol.6 (8), p.723-741.

14. Van den Bossche L, van Steenbeek FG, Favier RP, et al. Distribution of extrahepatic congenital portosystemic shunt morphology in predisposed dog breeds. *BMC Veterinary Research* 2012;8:112.

15. Kummeling A, Van Sluijs FJ, Rothuizen J. Prognostic implications of the degree of shunt narrowing and of the portal vein diameter in dogs with congenital portosystemic shunts. *Veterinary Surgery* 2004;33:17-24.

16. Kyles AE, Hardie EM, Mehl M, et al. Evaluation of ameroid ring constrictors for the management of single extrahepatic portosystemic shunts in cats: 23 cases (1996–2001). *J Am Vet Med Assoc*. 2002;220: 1341–1347.

17. Havig M, Tobias KM. Outcome of ameroid constrictor occlusion of single congenital extrahepatic portosystemic shunts in cats: 12 cases (1993–2000). *J Am Vet Med Assoc*. 2002;220:337–341.

18. Valiente P, Trehy M, White R, et al. Complications and outcome of cats with congenital extrahepatic portosystemic shunts treated with thin film: Thirty-four cases (2008-2017). *J Vet Intern Med*. 2020;34:117–124.

19. Lipscomb VJ, Jones HJ, Brockman DJ. Complications and long-term outcomes of the ligation of congenital portosystemic shunts in 49 cats. *Veterinary Record*. 2007;160:465-470.

SUPPORTING INFORMATION

Additional supporting information on canine EHPSS anatomy, prevalence, and subjective portal perfusion can be found online at www.dogshunts.com

FIGURE AND TABLE TEXT:

FIGURE 1) Normal canine portal venous anatomy (NORMAL) and the five most common shunt subtypes including left gastric-phrenic (LGP), left gastric-azygos (LGA), left gastric-caval (LGC), aberrant left gastric-caval with right gastric vein contribution (aLGC +RGV), and aberrant left gastric-caval with right gastric vein and short gastric vein contributions (aLGC +RGV +SGV). The recommended location for shunt attenuation is marked in green. Labelled portal vessels include portal vein (PV), gastrosplenic vein (GSV), left gastric vein (LGV), splenic vein (SV), short gastric vein (SG), gastroduodenal vein (GDV), right gastric vein (RGV),

gastroepiploic vein (GEV), right portal vein (RPV), and left portal vein (LPV). Labelled systemic veins include caudal vena cava (CDVC), phrenic vein (Phrenic), and azygos vein (Azyg).

FIGURE 2) Aberrant canine shunt (Green) anatomy and contributing vessel (Green) image examples. A) Illustration demonstrating aberrant left gastric-caval shunt with right gastric vein and short gastric vein contributions (aLGC +RGV +SGV). B+C) CT MIP image (B) and 3D reconstruction image of the same shunt pictured in A. D) Intra-operative image of an aLGC +RGV +SGV shunt demonstrating the PSS entering the vena cava with the primary shunt vessel and enlarged contributing vessels (+RGV and +SGV) labelled. E) Intra-operative image demonstrating the distended short gastric vein (+SGV) originating from the head of the spleen and coursing along gastric fundus. F) Intra-operative image after placement of an ameroid constrictor on the aLGC +RGV +SGV shunt. Labelled vessels include portal vein (PV), left gastric vein (LGV), aberrant left gastric vein (aLGV), splenic vein (SV), short gastric vein (SG), gastroduodenal vein (GDV), right gastric vein (RGV), and caudal vena cava (CDVC).

FIGURE 3) Images demonstrating varying degrees of subjective portal perfusion scores (PPS) with orange circles in three different dogs with left gastric-phrenic (LGP) portosystemic shunts (Green). PPS=5/5 (“GOOD subjective PPS”): This image demonstrates a subjectively normal intrahepatic portal vein (black band) with second and third generation intrahepatic portal branches. PPS=3/5 (“MODERATE subjective PPS”): This image demonstrates a diminished intrahepatic portal vein (black band) approximately half the size of the normal portal vein (white band) with first generation intrahepatic portal branches. PPS=1/5 (“POOR subjective PPS”):

This image demonstrates a visually absent portal vein beyond the gastroduodenal vein insertion. There are no intrahepatic portal branches identified. Labelled vessels include portal vein (PV), left gastric vein (LGV), splenic vein (SV), gastroduodenal vein (GDV), right portal vein (RPV), left portal vein (LPV) and phenic vein (Phrenic).

FIGURE 4) Box and whisker plot comparing patient age at time of CT scan (Y-axis) with shunt subtype (X-axis). Significant differences were identified among the 5 most common shunt types with respect to age at time of CT scan ($p<0.001$).

FIGURE 5) Significant differences were identified among the 5 most common shunt types with respect to subjective portal perfusion score ($p<0.001$). The subjective portal perfusion scores (PPS) identified in greater than 50% of a certain shunt subtype are highlighted with a green box (GOOD subjective PPS) or a red box (POOR subjective PPS).

FIGURE 6) Box and whisker plot comparing patient age at time of CT scan (Y-axis) with subjective portal perfusion scores (X-axis). Significant differences were identified between subjective PPS and age at time of CT ($p<0.001$).

TABLE 1) Canine EHPSS signalment, common shunt types (most common in green), and subjective portal perfusion scores (PPS). *This population subset limited to those dogs between the ages of 90d and 3650d at time of CT scan.

638 TABLE 2) Canine EHPSS shunt type distribution based on most commonly represented breeds.

639