Analysis of the relationship of extrahepatic portosystemic shunt morphology with clinical variables in dogs: 53 cases (2009–2012)

Michael B. Kraun, DVM; Laura L. Nelson, DVM, MS;
Joseph G. Hauptman, DVM, MS; Nathan C. Nelson, DVM, MS

Objective—To investigate differences in clinical variables among dogs with extrahepatic portosystemic shunts (EHPSSs) of various morphologies.

Design—Retrospective case series.

Animals—53 dogs with EHPSSs.

Procedures—Medical records of dogs undergoing preoperative CT angiography of an EHPSS over a 3-year period were reviewed. Analysis was performed to investigate relationships of clinical variables with shunt morphology. Morphologies were analyzed individually as well as in several groups.

Results—Shunt morphologies included 10 splenocaval, 9 splenophrenic, 11 splenoazygos, 10 right gastric-caval, 12 right gastric-caval with a caudal loop, and 1 right gastric-azygos with a caudal loop. Several biochemical variables associated with EHPSS were lowest in dogs with splenocaval shunts. Preoperative clinical signs were more common in dogs that had shunts with vena caval than right azygos vein insertion (36/41 [88%] vs 7/12 [58%]) and insertion caudal to the liver than diaphragmatic insertion (29/32 [91%] vs 14/21 [67%]). Neurologic signs were more common when shunts inserted into the vena cava caudal to the liver than in other locations (21/32 [66%] vs 6/21 [29%]) and were most frequent with splenocaval shunts. Urinary tract signs were more common when shunts had right gastric vein origin than gastrosplenic vein origin (14/23 [61%] vs 10/30 [33%]).

Conclusions and Clinical Relevance—Splenocaval shunts caused more clinical abnormalities than did other shunt morphologies. Results suggested that dogs with shunt insertion in the caudal vena cava, especially caudal to the liver, were most likely to have clinical signs. (*J Am Vet Med Assoc* 2014;245:540–549)

Congenital EHPSSs are anomalous vessels that result from defective development of the hepatic vasculature. Extrahepatic PSSs represent an inappropriate functional connection between the embryonic cardinal and vitelline venous systems.[1] After birth of an animal, EHPSSs, similar to intrahepatic shunts and other hepatic vascular anomalies, allow venous blood drained by the portal system to bypass the liver and enter directly into the systemic circulation. The resultant decrease in the delivery of trophic factors to the liver and release of substances typically metabolized by the liver into the systemic circulation cause a pattern of clinical and laboratory abnormalities that have been characterized.[2–4]

Patients with EHPSSs are most commonly small- or toy-breed dogs. Affected dogs are often evaluated because of a suspected EHPSS before they reach 2 years of age, although some patients do not develop clinical signs until they are much older.[5,6] Clinical signs associated with PSSs may range from mild to severe. Some patients have a general failure to thrive, whereas others have more specific clinical signs. Owner-reported abnormalities most commonly relate to 3 body systems: the CNS, gastrointestinal tract, and urinary tract. A subset of patients with congenital EHPSSs has no overt clinical signs, and shunts are discovered only when abnormalities are detected during laboratory testing for routine health screenings or elective surgical procedures. Characteristic clinicopathologic findings associated with EHPSSs include microcytosis (with or without anemia), hypoalbuminemia, low BUN concentration, hypocholesterolemia, hypoglycemia, mild increase in ALT and ALP activities, poorly concentrated urine, and ammonium biurate crystalluria. In cases in which a PSS is suspected, findings of high blood ammonia or SBA concentrations serve as additional evidence of a PSS.

Within the category of EHPSS, a variety of common shunt morphologies are recognized. Historically,

Abbreviations

ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
CTA	CT angiography
EHPSS	Extrahepatic portosystemic shunt
MCHC	Mean corpuscular hemoglobin concentration
PSS	Portosystemic shunt
RDW	RBC distribution width
SBA	Serum bile acids

From the Department of Small Animal Clinical Sciences, College of Veterinary Medicine, Michigan State University, East Lansing, MI 48824.
Presented in abstract form at the 12th Annual Meeting of the Society of Veterinary Soft Tissue Surgery, Grand Haven, Mich, June 2013.
Address correspondence to Dr. Laura Nelson (michae19@cvm.msu.edu).

EHPSSs were classified simply as portocaval (inserting on the caudal vena cava) or portoazygos (inserting on the azygos vein). Common patterns of vessel origin and insertion have been described,[1,7] but the increased use of CTA in veterinary medicine has helped to more specifically characterize shunt morphology.[2–4,8] A link between shunt morphology and degree of clinical illness has long been suspected[2,5,6] and has been suggested in several studies.[2,9–12] In particular, patients with portoazygos or portophrenic (inserting on a phrenic vein that drains into the vena cava at a point cranial to the liver) shunts developed clinical signs when they were much older[9–11] and, anecdotally, were believed to develop fewer clinical signs than patients with portocaval shunts.[2,12] However, those studies relied on intraoperative visual identification of anatomic structures or less precise imaging modalities such as ultrasonography, nuclear scintigraphy, or portovenography to determine shunt origin and insertion. Although these diagnostic methods have been described in the context of shunt diagnosis, they have limitations in terms of characterization of shunt morphology. Intraoperative visual identification has long been considered the criterion-referenced standard for diagnosis of shunt morphology, but the recognition of portophrenic shunts as a common EHPSS morphology and increasing reports of multiple[10,13–17] or complex[8] congenital shunts cast doubt on the accuracy of the diagnosis for intraoperative visual identification. Use of CTA during the preoperative evaluation of dogs with EHPSSs provides an opportunity to critically evaluate the effect of shunt morphology on other variables by ensuring a consistent, accurate diagnosis of shunt morphology.

The purpose of the study reported here was to determine whether a relationship exists between EHPSS morphology (as determined by use of CTA) and patient signalment, clinical signs, laboratory abnormalities, or short-term survival rate. On the basis of findings for previous studies,[9–12,18,19] we suspected that EHPSS morphology would have an influence on the clinical variables examined. However, we tested the null hypothesis that clinical variables would not differ among various EHPSS morphologies.

Materials and Methods

Case selection—Medical records were reviewed to identify all dogs that had undergone plastic banding for EHPSS attenuation at Michigan State University from November 2009 through December 2012. Cases were included if CT with dual-phase contrast angiography was performed before surgery to allow for definitive diagnosis of shunt morphology.

Medical records review—Clinical variables evaluated included patient signalment, clinical signs, clinicopathologic data, and short-term survival rate. Age, sex, neuter status, breed, body weight, and body condition score of each patient were recorded. Medical records were evaluated to determine whether a patient had clinical signs or whether referral for surgery was recommended on the basis of laboratory or radiographic abnormalities identified during routine screening or diagnosis of an unrelated problem. Clinical signs, when present, were assigned into 3 categories (neurologic, gastrointestinal, or urinary). Examples of neurologic signs included seizures, disorientation, running into objects, circling, uncoordinated gait, and behavior changes. Gastrointestinal signs included vomiting, diarrhea, and inappetence. Urinary signs included polyuria and polydipsia, pollakiuria, stranguria, and hematuria. Each clinical sign in a patient was recorded and assigned into the appropriate category. Preoperative medical management strategies (especially use of a low-protein diet, lactulose, antimicrobials, or anticonvulsants) used for each dog were recorded. Finally, a history of cystotomy or ammonium biurate urolithiasis was recorded.

Extracted laboratory data were based on findings of a previous unpublished study. For consistency, data for testing performed at Michigan State University were preferred; when use of other data was necessary, reference ranges were inspected to ensure that they did not differ substantially from those of the diagnostic laboratory at Michigan State University. Hematologic and biochemical data collected included Hct; mean corpuscular volume; MCHC; RDW; total WBC count; concentrations of BUN, creatinine, total calcium, phosphorus, iron, total protein, albumin, globulins, glucose, total bilirubin, and cholesterol; and activities of amylase, ALT, ALP, and AST. The highest values of each patient for preoperative and postoperative SBA analysis were recorded. The highest preoperative and postoperative ammonia concentrations were also recorded, when available. Urine specific gravity and the presence or absence of crystalluria were recorded. When crystalluria was present, the type of crystal was identified.

Images obtained during preoperative CTA for each patient were reviewed by a board-certified veterinary radiologist (NCN). Shunt morphology was classified into 1 of 6 categories (splenocaval, splenophrenic, splenoazygos, right gastric-caval, right gastric-caval with a caudal loop, or right gastric-azygos with a caudal loop; **Figure 1**) on the basis of descriptions provided elsewhere.[7,8] Additionally, the presence or absence of urinary calculi was recorded; when calculi were present, location of the calculi (kidneys, ureters, urinary bladder, or urethra) also was recorded.

The date of surgery was recorded for each patient. Concurrent cystotomy and results of biochemical analysis of calculi were recorded. The date of the most recent follow-up examination and whether a patient was alive at the time of the last follow-up examination were also recorded.

Statistical analysis—Statistical analysis was performed with commercially available computer-based statistical software.[a] Values of $P < 0.05$ were considered significant. Shunt morphologies were evaluated individually as well as in groups (by origin and by insertion). Specifically, shunts were grouped on the basis of splenic vein versus right gastric vein origin, vena caval versus azygos vein insertion, insertion into the vena cava caudal to the liver versus diaphragmatic (phrenic vein or azygos vein) insertion, and phrenic vein versus azygos vein insertion.

Some data were nonparametric. Therefore, data were reported as median values. When individual

shunt morphologies were compared, continuous variables were evaluated by use of a Kruskal-Wallis 1-way ANOVA. Post hoc evaluation of factors found to be significant was performed by use of a 2-tailed Wilcoxon rank sum test. Post hoc testing incorporated Bonferroni correction for multiple comparisons to minimize the likelihood of a type I error. Discrete variables were analyzed by use of χ^2 tests, with a Fisher exact test applied when appropriate (counts < 5). Post hoc testing of factors found to be significant was performed by use of a Fisher exact test with Bonferroni correction.

When shunt morphology was grouped by origin or insertion, continuous variables were compared with a 2-tailed Wilcoxon rank sum test. Discrete variables were analyzed by use of χ^2 tests, with a Fisher exact test applied when appropriate.

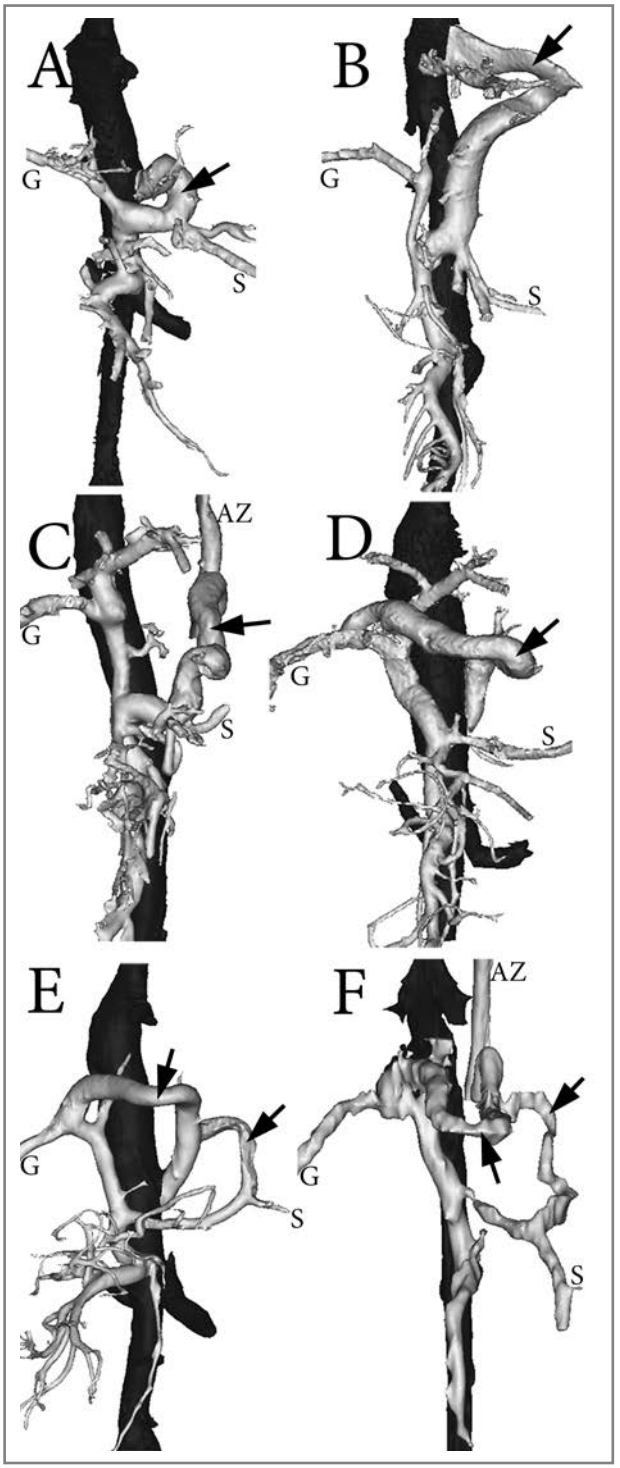

Figure 1—Three-dimensional depictions of 6 common EHPSS morphologies (splenocaval [A], splenophrenic [B], splenoazygos [C], right gastric-caval [D], right gastric-caval with a caudal loop [E], and right gastric-azygos with a caudal loop [F]) as viewed from the ventral aspect. In each panel, the main shunting vessel or vessels are indicated (arrows). Notice the caudal vena cava (black structure) and portal vein and other vasculature structures (white-gray structure) in each depiction. AZ = Azygos vein. G = Gastroduodenal vein. S = Splenic vein.

Results

Study population—Medical records review initially yielded 55 dogs that met the requirements for inclusion in the study. However, 2 of these dogs were subsequently excluded from the study population. One dog had previously undergone unsuccessful shunt attenuation surgery, which had the potential to alter shunt morphology; the other dog had 2 EHPSSs (a splenoazygos shunt and a shunt that connected the caudal mesenteric vein and left external iliac vein). Therefore, the final study population comprised 53 dogs with a single, congenital EHPSS.

Imaging findings—Shunt morphologies of the 53 dogs were 10 splenocaval, 9 splenophrenic, 11 splenoazygos, 10 right gastric-caval, 12 right gastric-caval with a caudal loop, and 1 right gastric-azygos with a caudal loop. Because only 1 dog had a right gastric-azygos shunt with a caudal loop, data for this patient were excluded from the statistical analysis of individual shunt morphologies; however, data for this patient were included in the analyses of shunts grouped by origin or insertion. Portal vein atresia was suspected in 1 dog with a splenocaval shunt. Thirty-two dogs had urinary calculi or mineralization. Calculi were identified in the bladder of 26 dogs, kidneys of 23 dogs, urethra of 1 dog, and ureters of 1 dog. Sixteen dogs had calculi in multiple locations.

Signalment—At the time of surgery, age of dogs ranged from 2 months to 8 years, with a median of 2 years. Body weight ranged from 0.9 to 17.5 kg (2.0 to 38.5 lb), with a median of 3.8 kg (8.4 lb). Of the 53 dogs, 12 were sexually intact males, 10 were neutered males, 11 were sexually intact females, and 20 were spayed females. There were no significant differences in age ($P = 0.16$), body weight ($P = 0.29$), sex ($P = 0.67$), or neuter status ($P = 0.40$) among dogs with various shunt morphologies (**Table 1**).

Twelve dog breeds were represented in the study population: Yorkshire Terrier (n = 11), Shih Tzu (7), Miniature Schnauzer (5), Maltese (4), Pug (3), Chihuahua (2), Jack Russell Terrier (2), Papillon (2), Pembroke Welsh Corgi (2), West Highland White Terrier (1), Havanese (1), and Entlebucher Mountain Dog (1). The remaining 12 patients were mixed-breed dogs. A significant ($P = 0.02$) association was found between breed and shunt morphology, but the relatively small patient population and large number of represented

Table 1—Results of analysis (*P* values) for relevant variables in 53 dogs with EHPSSs of various morphologies and comparisons among groups of EHPSS morphologies.

Variable	Individual morphology	Vena caval vs azygos vein	Caudal to liver vs diaphragmatic	Phrenic vein vs azygos vein	Splenic vein vs right gastric vein
Age	0.16	0.61	0.26	0.73	0.71
Albumin concentration	0.01	0.03	0.05	0.19	0.24
Alive at last recheck examination	0.49	0.56	0.43	—	0.26
ALP activity	0.12	0.11	0.29	0.15	0.86
ALT activity	0.11	0.47	0.68	0.14	0.11
Preoperative ammonia concentration	0.27	0.06	0.25	0.44	0.48
Ammonium biurate crystals	0.66	0.74	0.92	1.00	0.28
Amylase activity	0.63	0.73	0.58	0.90	0.48
AST activity	0.75	0.63	0.55	0.44	0.70
Body condition score	0.07	0.18	0.03	1.00	0.46
Body weight	0.28	0.93	0.38	0.55	0.75
Breed	0.02	0.46	0.68	0.14	0.04
BUN concentration	0.55	0.08	0.08	0.29	0.56
Calcium concentration	0.54	0.70	0.84	0.48	0.21
Cholesterol concentration	0.83	0.75	0.57	0.51	0.85
Clinical signs	0.25	0.04	0.04	0.64	0.34
Clinical signs duration	0.32	0.53	0.41	0.14	0.28
Gastrointestinal signs	0.99	0.97	0.92	1.00	0.82
Neurologic signs	0.04	0.04	0.01	1.00	0.88
Urinary signs	0.19	0.34	0.39	0.67	0.05
Creatinine concentration	0.27	0.07	0.05	0.50	0.61
Globulins concentration	0.34	0.40	0.14	0.97	0.59
Glucose concentration	0.92	0.87	0.74	0.62	0.33
Hct	0.02	0.16	0.06	1.00	0.43
Iron concentration	0.20	0.64	0.88	0.50	0.10
MCHC	0.01	0.41	0.58	0.37	0.17
MCV	0.56	0.09	0.19	0.27	0.46
Neuter status	0.40	0.89	0.53	1.00	0.58
Phosphorus concentration	0.42	0.24	0.16	0.76	0.97
Previous cystotomy	0.48	0.68	0.66	1.00	0.40
Previous treatment					
Antimicrobials	0.36	0.06	0.06	0.40	0.69
Anticonvulsants	0.28	0.23	0.80	0.27	0.23
Lactulose	0.25	0.13	0.34	0.39	0.29
Low-protein diet	0.34	0.82	0.96	1.00	0.93
RDW	0.20	0.17	0.20	0.60	0.03
SBA concentration					
Postoperative	0.45	0.36	0.10	0.86	0.96
Preoperative	0.55	0.48	0.12	0.86	0.50
Sex	0.67	0.19	0.33	0.40	0.41
Total bilirubin concentration	0.19	0.08	0.07	0.51	0.20
Total protein concentration					
Serum biochemical analysis	0.09	0.19	0.21	0.80	0.73
CBC	0.03	0.07	0.02	0.60	0.74
Urinary calculi on CT	0.44	0.40	0.12	1.00	0.23
Urine specific gravity	0.72	0.29	0.52	0.41	0.98
WBC count	0.62	0.39	0.66	0.57	0.65

Values were considered significant at $P < 0.05$.
— = All dogs were alive; no *P* values were calculated.

breeds prevented more detailed analysis of relationships between breed and shunt morphology. Manual review of the data for obvious patterns revealed that 10 of 11 Yorkshire Terriers had shunts with splenic vein origin, whereas all 4 Malteses included in the study had right gastric-caval shunts. Although splenic and right gastric shunts were significantly ($P = 0.04$) associated with breed, no significant (critical value for Bonferroni post hoc correction, $P = 0.005$) difference was found when data for Yorkshire Terriers and Malteses were compared directly.

History and reason for evaluation—Ten (19%) dogs were referred for shunt evaluation and surgery on the basis of incidental laboratory findings, whereas the remaining 43 (81%) dogs had clinical signs of an EHPSS. Neurologic signs were evident in 27 (51%) dogs, urinary signs in 24 (45%) dogs, and gastrointestinal signs in 13 (25%) dogs. Sixteen (30%) dogs had clinical signs for multiple categories. At the time of surgery, median duration of clinical signs of illness in affected dogs was 3 months (range, 1 week to 4 years). Duration of clinical signs did not differ significantly ($P = 0.32$) on the basis of shunt morphology. Management strategies included low-protein diets (n = 28), lactulose (32), antimicrobials (26), and anticonvulsants (11), with > 1 form of medical management for many dogs. Eleven dogs had a history of cystotomy, which was used

in all 11 dogs for removal of ammonium biurate cystoliths. Of these 11 dogs, 9 had recurrence of calculi in the bladder at the time of preoperative CTA; 1 additional dog did not have recurrence of cystoliths but did have evidence of calculi in the kidneys on CT images.

The presence of neurologic signs was the only category of history or clinical signs significantly (P = 0.04) impacted by specific shunt morphology. Analysis of results of Bonferroni post hoc tests revealed that neurologic signs were most prevalent in dogs with splenocaval shunts, but the difference was not significant (**Figure 2**).

Several significant differences were detected when shunts were grouped by origin and insertion. Preoperative clinical signs were detected in a significantly (P = 0.04) higher proportion of dogs with shunts inserting on the caudal vena cava (36/41 [88%]) than the proportion of dogs with shunts inserting on the right azygos vein (7/12). A significantly (P = 0.04) higher proportion of dogs with shunts inserting caudal to the liver had clinical signs (29/32 [91%]), compared with the proportion of dogs with diaphragmatic (phrenic vein and azygos vein) shunts that had clinical signs (14/21 [67%]). Additionally, neurologic signs were detected in a significantly (P = 0.01) higher proportion of dogs in which shunts inserted caudal to the liver (21/32 [66%]), compared with the proportion of dogs in which shunts had a diaphragmatic insertion (6/21 [29%]). Within the diaphragmatic group, no difference was detected between phrenic vein and right azygos vein shunts. The proportion of dogs with urinary signs was significantly (P = 0.046) different for dogs with shunts of right gastric vein origin (14/23 [61%]), compared with the proportion of dogs with shunts of splenic vein origin (10/30 [33%]).

Laboratory data—Preoperative CBC data were available for 52 dogs. In general, abnormal findings included hypoproteinemia (median, 5.8 mg/dL; reference range, 6.0 to 7.4 mg/dL), low MCHC (median, 32.6 mg/dL; reference range, 33.0 to 36.0 mg/dL), high RDW (median, 14.4%; reference range, 11.0% to 13.0%), and

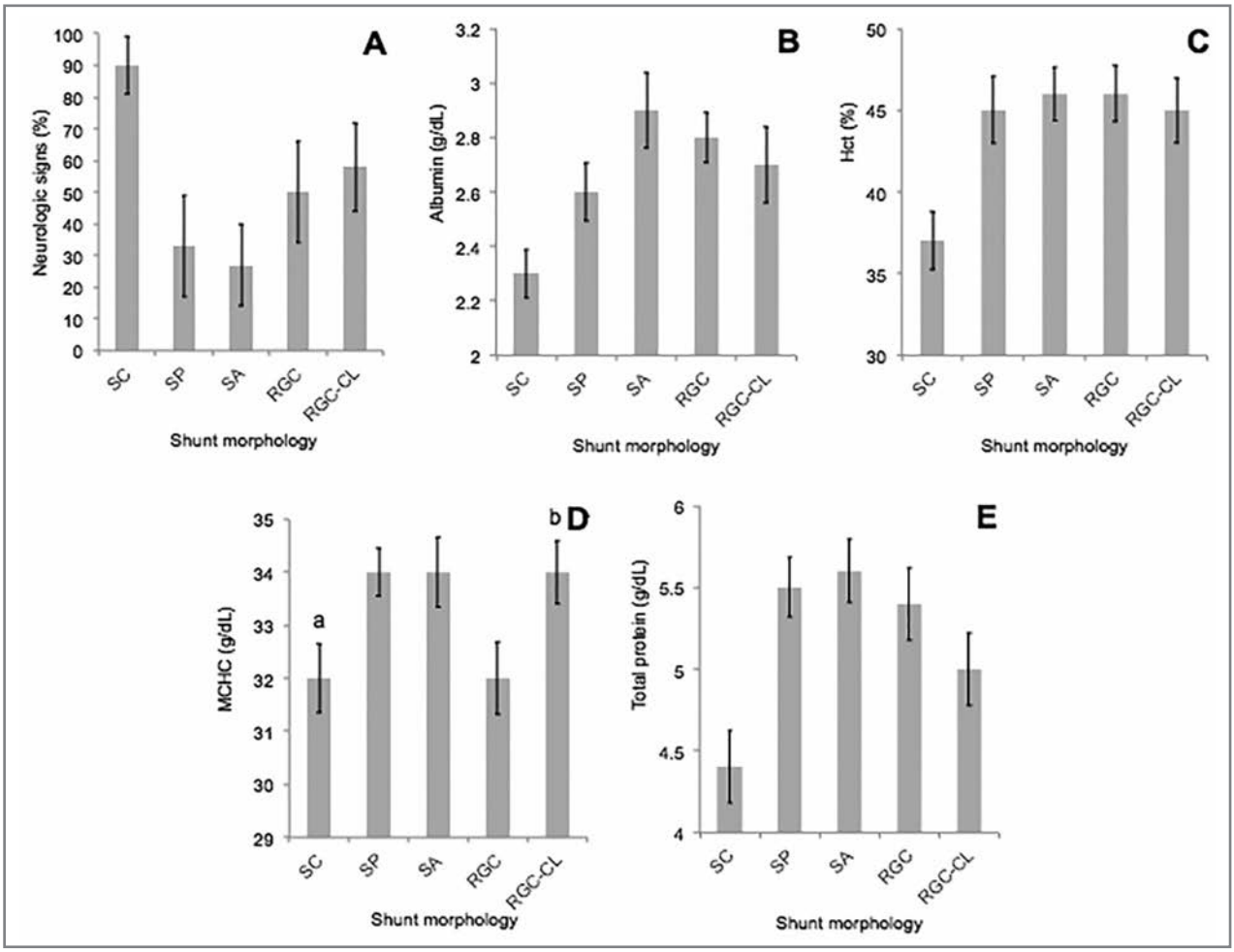

Figure 2—Median and SEM values for clinical variables (neurologic signs [A], albumin concentration [B], Hct [C], MCHC [D], and total protein concentration [E]) in 53 dogs with EHPSSs of various morphologies. Results for neurologic signs represent the percentage of dogs with each morphology that had neurologic signs. A significant association was identified between shunt morphology and neurologic signs (P = 0.04), albumin concentration (P = 0.01), Hct (P = 0.02), MCHC (P = 0.01), and total serum protein concentration (P = 0.03). [a,b]Values with different letters differ significantly (P = 0.003; Kruskal-Wallis 1-way ANOVA followed by a 2-tailed Wilcoxon rank sum test with Bonferroni correction). RGC = Right gastric-caval. RGC-CL = Right gastric-caval with a caudal loop. SA = Splenoazygos. SC = Splenocaval. SP = Splenophrenic.

leukocytosis (median, 13,300 cells/μL; reference range, 5,900 to 11,600 cells/μL).

Results of preoperative serum biochemical analysis were available for all 53 dogs. Typically, dogs had a low serum creatinine concentration (median, 0.5 mg/dL; reference range, 0.7 to 2.0 mg/dL), hypocalcemia (median, 9.37 mg/dL; reference range, 9.40 to 10.90 mg/dL), hyperphosphatemia (median, 5.0 mg/dL; reference range, 2.1 to 4.6 mg/dL), hypoproteinemia (median, 5.3 mg/dL; reference range, 5.6 to 7.5 mg/dL), hypoalbuminemia (median, 2.7 mg/dL; reference range, 2.8 to 4.0 mg/dL), high ALP activity (median, 168 U/L; reference range, 13 to 107 U/L), high ALT activity (median, 121 U/L; reference range, 14 to 102 U/L), and high AST activity (median, 71 U/L; reference range, 19 to 34 U/L).

Urinalysis data were available for 35 dogs (urine specific gravity alone was measured in 3 additional dogs). Median urine specific gravity was 1.025. Crystalluria was detected during microscopic examination of samples for 12 dogs (5 with ammonium biurate crystals, 3 with bilirubin crystals, 6 with struvite crystals, and 6 with amorphous crystals). Five dogs had crystalluria with > 1 type of crystal (3 dogs had 2 types of crystals, 1 dog had 3 types of crystals, and 1 dog had 4 types of crystals).

Preoperative SBA data were available for all 53 dogs. Postoperative SBA data were available for only 38 dogs, with the most recent sample obtained a mean of 6 months (range, 1 to 15 months) after shunt attenuation surgery. Median SBA concentration (higher value of preprandial and postprandial SBA concentrations) was 249 μmol/L (range, 65 to 453 μmol/L; reference range, 0.5 to 23.4 μmol/L) before surgery and 30 μmol/L (range, 1.5 to 401.6 μmol/L) after surgery. Preoperative plasma ammonia concentrations were available for 12 dogs; values at 6 weeks after surgery were available for only 2 dogs. Median ammonia concentration was 128 μmol/L (range, 22 to 291 μmol/L; reference range, 0 to 21 μmol/L) before surgery and 41 μmol/L (range, 26 to 55 μmol/L) after surgery.

A significant association was identified between shunt morphology and albumin concentration (P = 0.01), Hct (P = 0.02), MCHC (P = 0.01), and total serum protein concentration (P = 0.03; **Tables 2 and 3**). Post hoc analysis revealed that median values in each category were lowest in dogs with splenocaval shunts, but these values differed significantly (P = 0.003) among morphologies only for MCHC (Figure 2).

Several significant differences for laboratory data were detected when shunts were grouped by origin and insertion. Albumin concentrations were significantly (P = 0.03) lower in dogs with caval shunts than in those with azygos vein shunts. Concentrations of total serum protein (P = 0.02) were significantly lower in dogs with shunts inserting caudal to the liver than in dogs with shunts with diaphragmatic insertion. Finally, dogs with

Table 2—Analysis of clinical variables with continuous data for 53 dogs, by EHPSS morphology.

Variable	Splenocaval	Splenophrenic	Splenoazygos	RGC	RGC-CL	*P* value*
Age (wk)	29 (13–200)	155 (12–335)	129 (20–358)	97 (9–426)	134 (18–391)	0.16
Albumin (g/dL)	2.3 (1.7–2.7)	2.6 (2.1–3.3)	2.9 (1.9–3.6)	2.8 (2.2–3.1)	2.7 (1.5–3.4)	0.01
ALP (U/L)	214 (79–1,159)	189 (33–423)	102 (26–438)	258 (42–696)	79 (21–740)	0.12
ALT (U/L)	90 (21–209)	147 (79–1,354)	84 (46–1,266)	131 (17–529)	162 (57–500)	0.11
Preoperative ammonia (μmol/L)	154 (84–186)	231 (231–231)	31 (22–92)	131 (56–291)	167 (92–242)	0.27
Amylase (U/L)	286 (133–332)	375 (94–683)	343 (163–800)	299 (188–628)	349 (182–1,499)	0.63
AST (U/L)	78 (43–158)	108 (47–972)	60 (28–799)	63 (26–250)	96 (40–254)	0.75
Body condition score†	4 (3–5)	5 (4–6)	5 (4–6)	4 (3–8)	5 (4–6)	0.07
Body weight (kg)‡	2.7 (1.4–4.6)	3.9 (2.6–10.5)	4.7 (0.9–11)	3.9 (0.9–9.4)	4.8 (1.7–17.5)	0.29
BUN (mg/dL)	7 (2–20)	8 (6–14)	10 (4–18)	7 (5–17)	7 (2–20)	0.55
Calcium (mg/dL)	9.3 (8.2–10.3)	9.2 (8.8–9.8)	9.5 (8.2–10.6)	9.6 (9.1–10.1)	9.5 (7.9–10.3)	0.54
Cholesterol (mg/dL)	121 (62–200)	131 (105–268)	127 (48–244)	122 (88–259)	111 (77–198)	0.83
Creatinine (mg/dL)	0.4 (0.2–1.1)	0.5 (0.3–0.9)	0.6 (0.3–0.8)	0.5 (0.2–0.7)	0.5 (0.1–0.8)	0.27
Clinical signs duration (wk)	12 (3–187)	52 (4–167)	10 (1–90)	16 (2–208)	5 (2–108)	0.32
Globulins (g/dL)	2.1 (1.6–3.6)	2.7 (2.0–3.5)	2.8 (1.5–3.6)	2.5 (1.5–3.2)	2.6 (1.8–4.0)	0.34
Glucose (mg/dL)	86 (46–116)	82 (61–106)	87 (25–155)	92 (67–118)	89 (54–102)	0.92
Hct (%)	37 (30–49)	45 (33–52)	46 (41–58)	46 (38–52)	45 (36–59)	0.02
Iron (μg/dL)	97 (38–196)	91 (55–164)	127 (48–396)	111 (71–225)	170 (109–289)	0.20
MCHC (g/dL)	32 (27–34)	34 (31–34)	34 (28–35)	32 (27–35)	34 (32–38)	0.01
MCV (fL)	63 (56–71)	64 (57–70)	66 (61–71)	66 (54–73)	62 (54–70)	0.56
Phosphorus (mg/dL)	6.3 (3.1–8.3)	4.8 (2.2–7.3)	4.5 (2.0–7.1)	5.1 (3.4–8.2)	4.5 (3.3–7.5)	0.42
RDW (%)	14.1 (11.8–15.9)	14.3 (12.6–17.7)	13.6 (11.8–16.2)	15.3 (12.5–17.9)	15.8 (13.0–19.0)	0.20
SBA (μmol/L)						
Postoperative	25 (2–48)	39 (24–99)	27 (2–402)	36 (7–146)	16 (4–76)	0.45
Preoperative	186 (98–445)	267 (173–449)	269 (65–426)	253 (70–410)	243 (112–453)	0.55
Total bilirubin (mg/dL)	0.2 (0.1–0.5)	0.2 (0.1–0.4)	0.3 (0.1–1.1)	0.2 (0.1–0.4)	0.2 (0.1–0.3)	0.19
Total protein (g/dL)						
Serum biochemical analysis	4.4 (3.3–5.9)	5.5 (4.5–6.1)	5.6 (4.0–6.2)	5.4 (3.9–6.0)	5.0 (4.1–6.6)	0.03
CBC	5.2 (4.4–5.9)	5.6 (5.1–7.2)	6.6 (4.5–7.1)	5.8 (4.9–7.4)	5.6 (5.2–6.4)	0.09
Urine specific gravity	1.016 (1.008–1.045)	1.026 (1.006–1.035)	1.030 (1.008–1.038)	1.026 (1.018–1.061)	1.022 (1.011–1.040)	0.72
WBC count ($\times 10^3$ WBCs/μL)	14.9 (9.6–19.7)	14.0 (5.5–31.4)	12.8 (5.8–19.5)	14.1 (8.9–29.3)	12.4 (4.4–20.5)	0.62

Values reported are median (range).
*Values were determined by use of a Kruskal-Wallis test and were considered significant at $P < 0.05$. †Scored on a scale of 1 to 9.
RGC = Right gastric-caval. RGC-CL = Right gastric-caval with a caudal loop. ‡To convert values to pounds, multiply by 2.2.

Table 3—Analysis of clinical variables with discrete data for 53 dogs, by EHPSS morphology.

	Splenocaval			Splenophrenic			Splenoazygos			RGC			RGC-CL			
Variable	No.	No. (%)	95% CI (%)	No.	No. (%)	95% CI (%)	No.	No. (%)	95% CI (%)	No.	No. (%)	95% CI (%)	No.	No. (%)	95% CI (%)	*P* value*
Alive at last recheck examination	8	8 (100)	100 to 100	5	5 (100)	100 to 100	9	9 (100)	100 to 100	8	8 (100)	100 to 100	9	8 (89)	68 to 109	0.49
Ammonium biurate crystals	8	0 (0)	0 to 0	6	1 (17)	–13 to 47	5	1 (20)	–15 to 55	8	1 (13)	–10 to 35	8	2 (25)	–5 to 55	0.66
Clinical signs	10	9 (90)	71 to 109	9	7 (78)	51 to 105	11	7 (64)	35 to 92	10	10 (100)	100 to 100	12	10 (83)	62 to 104	0.25
Gastrointestinal signs	10	2 (20)	–5 to 45	9	2 (22)	–5 to 49	11	3 (27)	1 to 54	10	3 (30)	2 to 58	12	3 (25)	0.5 to 50	0.99
Neurologic signs	10	9 (90)	71 to 109	9	3 (33)	3 to 64	11	3 (27)	1 to 54	10	5 (50)	19 to 81	12	7 (58)	30 to 86	0.04
Urinary signs	10	2 (20)	–5 to 45	9	4 (44)	12 to 77	11	4 (36)	8 to 65	10	7 (70)	42 to 98	12	7 (58)	30 to 86	0.19
Neutered	10	3 (30)	2 to 58	9	6 (67)	36 to 97	11	7 (64)	35 to 92	10	6 (60)	30 to 90	12	8 (67)	40 to 93	0.40
Previous cystotomy	10	0 (0)	0 to 0	9	2 (22)	–5 to 49	11	3 (27)	1 to 54	10	3 (30)	2 to 58	12	3 (25)	0.5 to 50	0.48
Previous treatment																
Antimicrobials	10	7 (70)	42 to 98	9	4 (44)	12 to 77	11	3 (27)	1 to 54	10	6 (60)	30 to 90	12	6 (50)	22 to 78	0.36
Anticonvulsants	10	4 (40)	10 to 70	9	3 (33)	3 to 64	11	1 (9)	–8 to 26	10	2 (20)	–5 to 45	12	1 (8)	–7 to 24	0.28
Lactulose	10	9 (90)	71 to 109	9	6 (67)	36 to 97	11	5 (45)	16 to 75	10	6 (60)	30 to 90	12	6 (50)	22 to 78	0.25
Low-protein diet	10	5 (50)	19 to 81	9	5 (56)	23 to 88	11	6 (55)	25 to 84	10	3 (30)	2 to 58	12	9 (75)	51 to 100	0.34
Sex (male)	10	4 (40)	10 to 70	9	4 (44)	12 to 77	11	3 (27)	1 to 54	10	4 (40)	10 to 70	12	7 (58)	30 to 86	0.67
Urinary calculi on CT	10	6 (60)	30 to 90	9	4 (44)	12 to 77	11	6 (55)	25 to 84	10	6 (60)	30 to 90	12	10 (83)	62 to 104	0.44

Values reported are the total number of dogs with EHPSS morphology for which data were obtained and the number (percentage) and 95% confidence interval (CI) of dogs that matched the variable.

*Values were determined by use of a χ^2 test and were considered significant at $P < 0.05$.

shunts with right gastric vein origin had a significantly ($P = 0.03$) higher RDW than did dogs with shunts with splenic vein origin.

Surgery and postoperative data—Surgery for placement of a plastic band[20] intended to gradually attenuate the identified shunt vessel was performed in all 53 dogs. Cystotomy for removal of calculi was performed concurrently in 9 dogs; in each of those 9 dogs, subsequent analysis confirmed the calculi removed were ammonium urate. A single dog (2-year-old spayed female Entlebucher Mountain Dog) developed seizures 2 days after surgery and was euthanized 4 days after surgery. The remaining 52 dogs were discharged from the hospital, and 39 were confirmed to be alive a mean of 30 weeks (range, 2 weeks to 2 years) after surgery. Postoperative follow-up information was not available for the other 13 dogs.

Discussion

To the authors' knowledge, this is the first study in which investigators have used CTA-determined shunt morphology to assess the association between EHPSS morphology and clinical variables in a group of dogs. Other studies have relied on more traditional methods of shunt detection, such as mesenteric portography, abdominal ultrasonography, and nuclear scintigraphy. Detailed descriptions of each of these modalities have been published.[2,4,12,14,21–24] Each modality used to determine PSS morphology has benefits and limitations, but recent improvements in understanding of the complexity of EHPSSs[7,8] suggest that traditional methods of shunt detection are suboptimal for providing detailed determination of specific shunt morphology. A major benefit of CTA over earlier options for imaging of PSSs is that it allows consistent evaluation of all portal tributaries and branches with a single, peripheral injection of contrast agent.[25] Accurate imaging with CTA is possible in all dogs and cats, regardless of size. Production of axial images and the ability to manipulate images following completion of the procedure are particularly useful when examining the abdomen, where a large volume of organs and tissues surround the vasculature.[4,25] Angiography can also be performed by means of MRI, but MRI is more time-consuming, more costly, and less sensitive than CTA.[2,26]

The ability to obtain detailed 3-D images of shunts is useful in research and clinical settings. Computed tomographic angiography provides researchers investigating shunt morphology with an unparalleled ability to confidently determine PSS morphology and to correlate shunt morphology with any number of variables. In a clinical setting, the improved ability to identify complex congenital EHPSSs, such as those described here and in other reports,[10,13–17] reduces the risk of inappropriate placement of an attenuating device and continued shunting after surgery.[8] Preoperative planning with CTA can decrease the surgical time and degree of dissection needed for shunt attenuation.[27] Finally, as more is learned about shunt morphology, preoperative CTA may provide information regarding prognosis.[12]

Review of CTA images of the 53 dogs reported here revealed similar numbers of splenocaval, splenophrenic, splenoazygos, and caudal loop shunts. The increasing use of CTA in veterinary medicine has led us to believe that EHPSS conformations once thought to be unusual are, in fact, quite common. Furthermore, the combined proportions of phrenic vein (9/53 [17%]) and right azygos vein (12/53 [23%]) shunts in the present study were similar to the prevalence of portoazygos shunts reported in other studies.[6,9,10] These findings likely indicate that previous classifications of EHPSSs determined by direct intraoperative visual identification of the shunt vessel were frequently incorrect.

Only 1 dog in the present study had a right gastric-azygos shunt, which also communicated with the splenic vein (caudal loop). There were no right gastric-azygos shunts without a splenic component. In addition, all right gastric-caval shunts inserted caudal to the liver; there were no right gastric-phrenic shunts in this group of dogs. Right gastric-phrenic shunts have been identified recently in some of our patients, but in our patient population, they are encountered rarely, compared with the prevalence of dogs with right gastric shunts with a more caudal insertion. The reason for these findings is unknown but may be related to the specific vascular connections during embryological development. It is known that nonfunctional anas-

tomoses may normally exist between the cardinal and vitelline venous systems and that these anastomoses may become functional in the event of portal hypertension; however, congenital EHPSSs are believed to be a separate entity and unrelated to preexisting anastomoses.[1] It is possible that an unknown underlying factor causes congenital EHPSSs originating from the right gastric vein or gastroduodenal vessels to preferentially insert on the vena cava caudal to the liver. Albeit unlikely, results of the present study may have underestimated the prevalence of right gastric-phrenic and right gastric-azygos EHPSSs, and the findings in this cohort of dogs may not have been representative of the entire population.

Although the age range for dogs in the present study was typical of patients with congenital EHPSSs, the median age (2 years) was older than in many other studies. This finding likely resulted because of the fact that the age of dogs at the time of surgery was used for analysis. In many cases, an EHPSS was not definitively diagnosed (via diagnostic imaging) until the dog was brought to our service for surgery, but EHPSS was presumptively diagnosed in some dogs by another veterinarian and medically managed prior to referral for surgery. Therefore, review of medical records did not allow consistent determination of the exact age at EHPSS diagnosis (definitive or presumptive diagnosis). In dogs with clinical signs associated with an EHPSS, owners reported that clinical signs were evident for a mean of approximately 8 months (median, 3 months) before surgery, which would indicate that the mean age at initial onset of clinical signs was closer to that previously reported. The use of patient age at the time of surgery may also explain the reason that, contrary to other reports,[9–11] we did not find a significant difference in age between dogs with portoazygos or portophrenic shunts and those with shunts inserting caudal to the liver. Therefore, this may represent a type II error. Alternatively, the findings of the previous studies may be incorrect (type I error).

The breeds of affected dogs in the present study were similar to those reported previously. In 1 study,[28] dogs of 33 breeds, including Yorkshire Terrier, Havanese, Maltese, Dandie Dinmont Terrier, Pug, and Miniature Schnauzer, were found to be significantly predisposed to EHPSS development, compared with the predisposition for EHPSS development in mixed-breed dogs. Notably, the odds of a Yorkshire Terrier developing a PSS are approximately 36 times as high as the odds for development of a PSS in all other dog breeds combined.[28] An interesting, albeit nonsignificant, finding in the present study was the predominance of shunts with splenic origin in Yorkshire Terriers and the apparent predisposition of Malteses to develop right gastric-caval shunts. Although these findings in Malteses contradict results of a prior Australian study[19] in which 13 Malteses invariably had EHPSSs arising from the splenic or left gastric veins, they suggest a genetic influence and possibly regional differences in PSS development. Heritability of shunts has been documented in Yorkshire Terriers[28] and Cairn Terriers[29] and is also suspected in other breeds that have a high prevalence of this condition.[28] Aberrant expression of several genes in dogs with PSS was recently reported,[30] but additional studies are needed to provide more insight in this area.

Similar to suspicions raised by other investigators,[2,12] the present study suggested an influence of EHPSS morphology on several clinical variables. Both the historical and laboratory data for the study reported here suggested that portocaval shunts, especially those inserting on the vena cava caudal to the liver, resulted in more serious clinical signs than did EHPSSs with azygos vein or phrenic vein insertion. This finding is confirmation of the anecdotal beliefs posited by other investigators. No significant differences could be delineated between portophrenic and portoazygos shunts. Neurologic signs also were significantly more frequent in dogs with shunts inserting caudal to the liver. Although results of post hoc analysis were not significant, splenocaval shunts may be associated with more severe clinical signs than are other EHPSS morphologies. Several possible explanations exist for these findings. A logical conclusion is that the severity of clinical signs parallels the amount of blood diverted from the portal circulation to the systemic circulation.

According to Poiseuille's law, blood flow through a vessel is directly proportional to the diameter of the vessel and the pressure difference between the ends of the vessel; blood flow is inversely proportional to the length of the vessel and viscosity of the blood.[31] Normal portal venous pressure and central venous pressure differ among individuals. Typical portal venous pressure is approximately 6 to 8 mm Hg,[32] and normal central venous pressure is approximately 0 to 5 mm Hg,[33] which creates a mild pressure gradient for PSSs. However, this should not differ on the basis of shunt morphology. As has been proposed previously,[12] it is likely that portophrenic and portoazygos shunts are partially compressed by the diaphragm during respiration and by gastric distension after eating, which results in improved hepatic perfusion via the portal vein. The azygos vein is a narrower vessel and has less capacity than the caudal vena cava,[34] which likely creates resistance to flow and inhibits shunting of blood from the portal system. Finally, PSSs originating from the gastroduodenal or right gastric veins, and those inserting cranial to the liver, must travel a greater distance than those with splenic origin or caudal insertion, and their length provides resistance to flow in accordance with Poiseuille's law.

In the present study, dogs with right gastric shunts had a higher frequency of urinary signs than did dogs with shunts of splenic vein origin. The reason for this discrepancy is unclear. One possible explanation may relate to the difference in structures drained by the various portal tributaries. The tributaries of the portal system are responsible for venous drainage of the gastrointestinal tract, pancreas, and spleen.[34] The gastroduodenal and right gastric veins primarily drain blood from the stomach, duodenum, and pancreas, whereas the splenic and left gastric veins primarily drain the spleen and stomach. It is possible that concentrations of nutrients and toxins in the portal blood may differ on the basis of the specific tributary in which they are contained. To test this hypothesis, it would be necessary to obtain intraoperative blood samples from right- and left-sided EHPSSs and to perform assays to compare concentra-

tions of various compounds. Alternatively, it is possible that the difference in urinary signs represented a type I error and that right gastric and splenic EHPSSs cause an equal number of urinary signs.

Because of the large data set in the present study, a Bonferroni correction for multiple comparisons was used in post hoc testing to reduce the likelihood of a type I error. As the number of comparisons performed within a data set increases, it becomes more likely that there will be a significant difference between the groups being compared simply by chance. This leads to the potential for false-positive results (ie, type I error). To compensate for this problem, a Bonferroni correction adjusts the critical *P* value on the basis of the number of inferences made, thus requiring stronger evidence (ie, lower *P* value) for differences to be deemed significant. However, a Bonferroni correction can be excessively conservative, especially when large numbers of tests are performed, which can lead to an extremely low critical *P* value ($P = 0.005$ in most of the analyses for the study reported here). Therefore, in an effort to reduce the likelihood of a false-positive result, we may have overcompensated, which resulted in false-negative results (ie, type II error). For example, initial analysis of the data appeared to indicate that dogs with splenocaval shunts had significantly lower albumin concentration, Hct, MCHC, and total serum protein concentration than did dogs with other shunt morphologies. After application of a Bonferroni correction, almost every significant finding was negated. Therefore, it was likely that in several instances, the failure to detect significant differences despite apparently significant *P* values represented a type II error.

Additional limitations to the study primarily resulted from its retrospective design. In some instances, there were inconsistencies in the amount of data available for each dog. Furthermore, we relied on the accuracy of the data available in the medical record. In some cases that were also included in a previous unreported study, owner questionnaires were available to provide details about the type and duration of clinical signs. However, in most cases, specifics of the history and clinical signs had to be interpreted from the medical record. In future studies, it would be beneficial to have all owners complete detailed questionnaires at each visit to improve the accuracy of data. Fortunately, much of the data collected was objective (eg, laboratory and imaging data), which does not diminish in value when evaluated retrospectively. A final limitation of the study was the small population of patients. Although dogs with an EHPSS are commonly examined at our institution, the relative novelty of CTA in veterinary medicine limited the number of cases available for evaluation, which meant that the study population may not have accurately represented all patients with EHPSSs.

Results of the present study were supportive of previous suspicions that EHPSS morphology influences a number of clinical variables. Dogs with shunt insertion in the caudal vena cava, especially caudal to the liver, were most likely to develop clinical signs. Specifically, splenocaval shunts appeared to cause more clinical abnormalities than did other shunt morphologies. Additional studies are needed to further investigate EHPSS morphology and pathophysiology. Finally, a randomized prospective study of surgical and medical treatment protocols is warranted to determine the best method of treatment, provide detailed information about short- and long-term outcome, and determine the effect, if any, of shunt morphology on patient outcome.

a. SAS, version 9.1, SAS Institute Inc, Cary, NC.

References

1. Payne JT, Martin RA, Constantinescu GM. The anatomy and embryology of portosystemic shunts in dogs and cats. *Semin Vet Med Surg (Small Anim)* 1990;5:76–82.
2. Berent AC, Tobias KM. Hepatic vascular anomalies. In: Tobias KM, Johnston SA, eds. *Veterinary surgery: small animal*. St Louis: Elsevier Health Sciences, 2011;1624–1658.
3. Berent AC, Weisse C. Hepatic vascular anomalies. In: Ettinger SJ, Feldman EC, eds. *Textbook of veterinary internal medicine*. 7th ed. St Louis: Elsevier Health Sciences, 2009;1649–1671.
4. Berent AC, Tobias KM. Portosystemic vascular anomalies. *Vet Clin North Am Small Anim Pract* 2009;39:513–541.
5. Center SA, Magne ML. Historical, physical examination, and clinicopathologic features of portosystemic vascular anomalies in the dog and cat. *Semin Vet Med Surg (Small Anim)* 1990;5:83–93.
6. Worley DR, Holt DE. Clinical outcome of congenital extrahepatic portosystemic shunt attenuation in dogs aged five years and older: 17 cases (1992–2005). *J Am Vet Med Assoc* 2008;232:722–727.
7. Szatmári V, Rothuizen J, van den Ingh TSGAM, et al. Ultrasonographic findings in dogs with hyperammonemia: 90 cases (2000–2002). *J Am Vet Med Assoc* 2004;224:717–727.
8. Nelson NC, Nelson LL. Anatomy of extrahepatic portosystemic shunts in dogs as determined by computed tomography angiography. *Vet Radiol Ultrasound* 2011;52:498–506.
9. Van den Bossche L, van Steenbeek FG, Favier RP, et al. Distribution of extrahepatic congenital portosystemic shunt morphology in predisposed dog breeds. *BMC Vet Res* (serial online) 2012;8:112. Available at: www.biomedcentral.com/1746-6148/8/112. Accessed Feb 1, 2014.
10. Mehl ML, Kyles AE, Hardie EM, et al. Evaluation of ameroid ring constrictors for treatment for single extrahepatic portosystemic shunts in dogs: 168 cases (1995–2001). *J Am Vet Med Assoc* 2005;226:2020–2030.
11. Baade S, Aupperle H, Grevel V, et al. Histopathological and immunohistochemical investigations of hepatic lesions associated with congenital portosystemic shunt in dogs. *J Comp Pathol* 2006;134:80–90.
12. Sura PA, Tobias KM, Morandi F, et al. Comparison of $99mTcO_4(-)$ trans-splenic portal scintigraphy with per-rectal portal scintigraphy for diagnosis of portosystemic shunts in dogs. *Vet Surg* 2007;36:654–660.
13. Leeman JJ, Kim SE, Reese DJ, et al. Multiple congenital PSS in a dog: case report and literature review. *J Am Anim Hosp Assoc* 2013;49:281–285.
14. Morandi F, Cole RC, Tobias KM, et al. Use of $99mTcO_4(-)$ trans-splenic portal scintigraphy for diagnosis of portosystemic shunts in 28 dogs. *Vet Radiol Ultrasound* 2005;46:153–161.
15. Johnson CA, Armstrong PJ, Hauptman JG. Congenital portosystemic shunts in dogs: 46 cases (1979–1986). *J Am Vet Med Assoc* 1987;191:1478–1483.
16. Ferrell EA, Graham JP, Hanel R, et al. Simultaneous congenital and acquired extrahepatic portosystemic shunts in two dogs. *Vet Radiol Ultrasound* 2003;44:38–42.
17. Wilson K, Scrivani PV, Léveillé R. What is your diagnosis? Portocaval and portoazygous shunts and microhepatica in a dog. *J Am Vet Med Assoc* 1997;211:415–416.
18. Hunt GB. Effect of breed on anatomy of portosystemic shunts resulting from congenital diseases in dogs and cats: a review of 242 cases. *Aust Vet J* 2004;82:746–749.
19. Tisdall PL, Hunt GB, Bellenger CR, et al. Congenital portosystemic shunts in Maltese and Australian cattle dogs. *Aust Vet J* 1994;71:174–178.

20. Smith RR, Hunt GB, Garcia-Nolen TC, et al. Spectroscopic and mechanical evaluation of thin film commonly used for banding congenital portosystemic shunts in dogs. *Vet Surg* 2013;42:478–487.
21. Wrigley RH, Konde LJ, Park RD, et al. Ultrasonographic diagnosis of portacaval shunts in young dogs. *J Am Vet Med Assoc* 1987;191:421–424.
22. Lamb CR. Ultrasonographic diagnosis of congenital portosystemic shunts in dogs: results of a prospective study. *Vet Radiol Ultrasound* 1996;37:281–288.
23. Holt DE, Schelling CG, Saunders HM, et al. Correlation of ultrasonographic findings with surgical, portographic, and necropsy findings in dogs and cats with portosystemic shunts: 63 cases (1987–1993). *J Am Vet Med Assoc* 1995;207:1190–1193.
24. Tiemessen I, Rothuizen J, Voorhout G. Ultrasonography in the diagnosis of congenital portosystemic shunts in dogs. *Vet Q* 1995;17:50–53.
25. Zwingenberger AL. CT diagnosis of portosystemic shunts. *Vet Clin North Am Small Anim Pract* 2009;39:783–792.
26. Seguin B, Tobias KM, Gavin PR, et al. Use of magnetic resonance angiography for diagnosis of portosystemic shunts in dogs. *Vet Radiol Ultrasound* 1999;40:251–258.
27. Frank P, Mahaffey M, Egger C, et al. Helical computed tomographic portography in ten normal dogs and ten dogs with a portosystemic shunt. *Vet Radiol Ultrasound* 2003;44:392–400.
28. Tobias KM, Rohrbach BW. Association of breed with the diagnosis of congenital portosystemic shunts in dogs: 2,400 cases (1980–2002). *J Am Vet Med Assoc* 2003;223:1636–1639.
29. van Straten G, Leegwater PAJ, de Vries M, et al. Inherited congenital extrahepatic portosystemic shunts in Cairn Terriers. *J Vet Intern Med* 2005;19:321–324.
30. van Steenbeek FG, Van den Bossche L, Grinwis GCM, et al. Aberrant gene expression in dogs with portosystemic shunts. *PLoS ONE* (serial online) 2013;8:e57662. Available at: www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0057662. Accessed Feb 1, 2014.
31. Overview of the circulation; medical physics of pressure, flow, and resistance. In: Guyton AC, Hall JE, eds. *Textbook of medical physiology*. Philadelphia: Elsevier Health Sciences, 2010;161–170.
32. Sakamoto Y, Sakai M, Watari T. Three minimally invasive methods of measuring of portal vein pressure in healthy dogs. *J Vet Med Sci* 2012;74:1299–1302.
33. Waddell LS, Brown AJ. Hemodynamic monitoring. In: Silverstein D, Hopper K, eds. *Small animal critical care medicine*. St Louis: Elsevier Health Sciences, 2008;859–864.
34. Bezuidenhout AJ. Veins. In: Evans HE, De Lahunta A, eds. *Miller's anatomy of the dog*. 4th ed. St Louis: Saunders, 2012;505–534.