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CLINICAL RESEARCH

Short- and long-term outcome and quality of life assessment in dogs undergoing transvenous coil embolization of congenital intrahepatic portosystemic shunts

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Abstract

Objective: To evaluate short- and long-term outcomes and health-related quality of life (Hr-QoL) in dogs with congenital intrahepatic portosystemic shunts (cIHPSS) treated using percutaneous transcatheter embolization (PTCE).

Study design: Single center retrospective and prospective study.

Animals: Sixty-one client-owned dogs.

Methods: Medical records were reviewed, and owners completed validated Hr-QoL and congenital portosystemic shunt scoring (Hr-CPSS) questionnaires. Hr-QoL scores ranged from 0 (worst) to 100 (best), and Hr-CPSS from 0 (best) to 100 (worst). Survival was assessed using Kaplan–Meier analysis. Medical or dietary management at final follow-up were recorded.

Results: Median follow-up time was 769 days (interquartile range [IQR]: 297–1865). Median survival time was 1496 days. At last follow-up, 33 of 59 dogs remained on medical management and/or a specialized diet. Median Hr-CPSS significantly decreased from prediagnosis (25 [IQR: 18–51.3]) to post-PTCE (5 [IQR: 3–11]; $p < .001$), but not between post-medical and post-PTCE ($p = .68$). Median Hr-QoL scores improved post-PTCE (100 [IQR: 80–100]) compared to prediagnosis (35 [IQR: 10–50], $p < .0001$), and post-medical (75 [IQR: 40–90], $p = .005$) as well as between prediagnosis and post-medical ($p = .038$). One-, two-, and five-year survival rates were 83%, 66%, and 54%, respectively.

Conclusion: Treatment of cIHPSS with PTCE in dogs was associated with a good long-term survival and significant improvement in QoL and clinical signs.

Impact: The combination of PTCE and targeted medical management provides an effective minimally invasive treatment option for dogs with cIHPSS, supporting improved longevity and quality of life.

1 | INTRODUCTION

Congenital intrahepatic portosystemic shunt (cIHPSS) is a condition, recognized mostly in large breed dogs, related to the presence of an abnormal intrahepatic veno (porto)-venous(systemic) connection.[1,2] They typically manifest through neurologic (hepatic encephalopathy), gastrointestinal, urinary, hematologic abnormalities such as microcytic anemia, and growth-related alterations, all arising from impaired hepatic detoxification and disrupted systemic metabolism.[2] Treatment options include medical therapy, open surgery and percutaneous transcatheter embolization (PTCE) using coils[3–5] or occluder devices.[6] Medical therapy using lactulose, antibiotics and low-protein diet is aimed at alleviating signs related to the presence of the cIHPSS and is associated with a good quality of life (QoL) but longevity is impaired and reported median survival time with medical therapy alone is around 3 years.[7]

Open surgery (using thin film banding, suture, ameroid ring constrictor, hydraulic occluder placement)[8,9] results in partial or complete attenuation of the cIHPSS via extra- or intravascular constriction performed either at the pre- or posthepatic location of the cIHPSS. PTCE results in partial or complete attenuation of the cIHPSS via intravascular space occupying mechanism due to coils placement in the shunt (and secondary thrombosis around these coils), performed at the posthepatic location of the cIHPSS. The over-arching goal of these treatments is to allow shunt closure, medication to be discontinued, and normal diet resumed, with the expectation of a normal life span and preserved QoL. Median survival time following open surgery for cIHPSS is reported to be between 29 and 117 months[10–13] with a one- and two-year survival of 60 and 55%, respectively.[11,14] Reported intraoperative mortality rates ranged from 2% to 27%.[10,15–17]

A systematic review of the different treatments of cIHPSS published in 2017 showed weak evidence regarding the best treatment of cIHPSS in dogs, with only two out of 32 studies directly comparing treatments (medical vs. ligature and ligature vs. ameroid ring constrictor). Better outcome and increased longevity was found in the surgically treated dogs and better long-term composite outcome grades in the ligature group.[18]

PTCE, originally described by Gonzalo-Orden,[19] has since gained popularity due to its minimally invasive nature and the lower risk of hemorrhage during open surgery and hepatic dissection, especially for right-sided or central cIHPSS.[20] Short-term studies show that liver volume increased at 3 months following PTCE and that abnormal clinical signs resolved.[21] Medium- to long-term studies show that, despite partial attenuation being very common,[3] the median survival time (MST) was long (2204 days),[3] and the 5-year survival rate excellent (up to 80%).[8] PTCE has been described for large and small breed dogs alike. A recent study of 20 small- and toy-breed dogs (mean weight: 6.3 kg) undergoing PTCE showed excellent results with clinical signs resolving in 95% of the dogs and a one- and two-year survival rate of 92%.[22]

Objective comparison of various treatments has been attempted using changes in biochemical values (e.g., ammonia, bile acids, protein C)[23] over time following partial or complete attenuation of cIHPSS. However, studies have shown that these tests may have limited value in assessing intervention success.[24,25] Furthermore, access to some of these tests, such as protein C,[23] is not widely available.

Composite outcome grades including information about medications/diet and clinical signs have been used to assess success of surgical intervention on cIHPSS and compare treatments.[26] However these grades can be perceived as relatively crude (only 4 different grades) and may not reflect the true perception of the quality of life. For example, a dog that would show one post attenuation neurologic sign, even episodically, would automatically be graded as poor. Recently, a health-related quality of life (Hr-QoL) questionnaire and congenital portosystemic shunt scoring (CPSS) system have been published for assessing clinical outcome following extra- and intrahepatic portosystemic shunt surgical treatment[27] reporting a large improvement of the QoL for both diseases. However, there is no study reporting the detailed Hr-QoL of dogs following cIHPSS treatment with PTCE.

The primary objective of this study was to report the long-term (> 30 days) outcome and Hr-QoL of dogs with

cIHPSS following treatment by PTCE using these qualitative assessment methods. The secondary objective was to report intra- and postoperative complications rates, changes over time in selected biochemical values and composite outcome grades.

2 | MATERIALS AND METHODS

2.1 | Study subjects and questionnaires

This study was approved by the Ethical review board at the University of Bristol (VIN/19/032). Records of dogs with cIHPSS who underwent treatment using PTCE were reviewed. PTCE was performed as previously described.[3] Briefly, dogs were positioned in dorsal (left- and right-sided shunts) or lateral (central division shunts) recumbency and access was gained via the femoral or jugular vein. A range of guide wires and intravascular catheters were employed to access, further image and measure the cIHPSS at its confluence with the caudal vena cava (CVC). A self-expanding nitinol alloy stent was then deployed within the CVC to cover the entry point of the cIHPSS. Thrombogenic coils were then delivered into the cIHPSS to progressively attenuate shunt flow at the level of the stent. Respiration was paused during digital subtraction and stent deployment. During the procedure, portal pressure and central venous pressure were monitored, and regular selective angiography was performed. Decision to cease coils delivering was made based on objective rise in portal pressure, or the gradient between portal pressure and central venous pressure or subjective visual assessment of reduction in flow on angiography. Jugular or femoral access sites were repaired using 5/0 or 6/0 polypropylene suture, or ligated, and overlying subcutaneous tissue and skin were sutured or glued. The dogs received standard antibiotic prophylaxis protocol with administration of amoxicillin- clavulanate at the time of induction and then every 2 h until the end of the procedure. Postoperatively, the dogs were transferred to the intensive care unit and aftercare over the 72-h prior to discharge was focused primarily on monitoring for neurologic changes or clinical signs suggestive of portal hypertension.

Dogs were excluded from this study if they were treated with open surgery or medical treatment alone. For dogs alive at the time of data collection, a detailed Hr-QoL questionnaire (previously published - Appendix A) and CPSS score were requested from their owners. Owners were asked to describe QoL at each of three time-points: prior to medical treatment, after instituting medical treatment but before PTCE, and after PTCE. Each animal was given a QoL score from 0 (worst) to 100 (best) and a CPSS score from 0 (best) to congenital portosystemic shunt scoring 100 (worst). The owners were given the choice to consent to completing the questionnaire. During the study period, the three time-points questionnaires were completed either retrospectively at the time of follow-up (for dogs included between 2010 and 2016) for this study or prospectively (for dogs included between 2017 and 2022).

2.2 | Outcome grades

Based on data acquired, dogs were classified into one of four outcome grades: excellent (no clinical signs, no medical or dietary treatment for the shunt), good (no clinical signs, no medication, on specific diet), fair (no clinical signs, receiving medical management including medications related to medical management of the signs of the shunt such as lactulose, antibiotics or proton pump inhibitors +/− specific diet), or poor (clinical signs present, on medication +/− specific diet).

2.3 | Complications

Perioperative (intraoperative or immediate postoperative) deaths, peri- and postoperative complications were recorded. Complications were graded as major (life threatening) and minor (self-resolving or non-life threatening).

2.4 | Clinicopathological data

Blood work, including biochemical and hematological data, were collected at various time points during case management, according to clinician decision making at that time. For each case, one preoperative and one postoperative (taken at least 3 months after intervention) sample was collected (pairwise comparisons). Preoperative blood work was compared to the last postoperative blood work for the following parameters: hematocrit (Hct), albumin, red blood cells (RBC), mean corpuscular volume (MCV), white blood cells (WBC), and cholesterol. Assumptions on normal distribution of these data were checked, or non-parametric tests were used where appropriate.

2.5 | Follow-up information

Closure of the shunt was assessed using computed tomographic angiography (CTA) or ultrasound imaging.

Information about the medication and diet that dogs were receiving at the time of last assessment were recorded.

2.6 | Statistical analysis

Data are expressed as mean ± SD (normally distributed data) or median and interquartile range (IQR) (non-normally distributed data). QoL scores and CPSS were compared using Friedman and Wilcoxon signed rank tests. Survival was represented using Kaplan Meier survival curves and log rank tests. Covariates (shunt division, hepatic encephalopathy presence, seizures) were compared with log-rank tests. Dogs alive at the time of last contact, or those that died for non-shunt-related reasons were right-censored. Biochemical parameters were compared using pairwise tests, with Benjamini-Hochberg correction. $p < .05$ was considered statistically significant.

3 | RESULTS

Over the period January 2010 to June 2022, 90 dogs were diagnosed with cIHPSS at the Langford Vets Teaching Hospital. A total of 29 were excluded (22 treated medically alone, including 2 for which PTCE was deemed not feasible [one had a subjectively too large caudal vena cava at the shunt opening to accommodate a stent, one unable to be sufficiently stabilized medically to consider any type of intervention]), seven treated by open surgery, one attempted but unsuccessful surgery, leaving 61 dogs in the study population (Figure 1). Of these, 24 were enrolled retrospectively and 37 prospectively. A total of 17 dogs were operated on in the time period from 2010 to 2015, and 44 operated on in the time period 2016–2022.

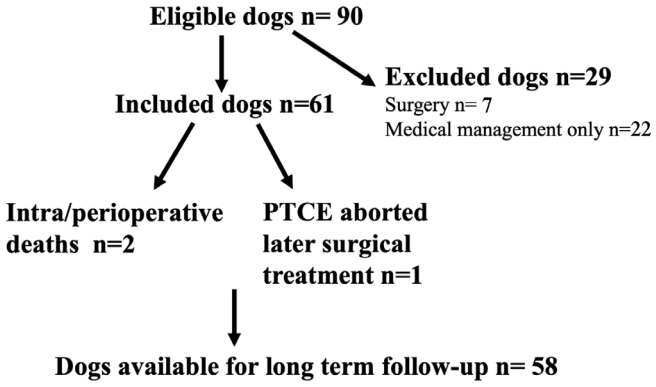

FIGURE 1 Flow chart of the distribution of eligible, included and excluded dogs of the study. PTCE, percutaneous transvenous coil embolization.

All animals received medical treatment prior to PTCE for a minimum of 2 weeks. Male dogs accounted for 30 cases (49%), of which only two were neutered; among the 31 females, five were neutered. The most common breeds were Labrador Retrievers (8, including 1 Labradoodle), Golden Retrievers (5), Border Collies (3), and Bernese Mountain dogs (2).

Median age at surgery was 9 months (3–78 months). Weight at the time of surgery was 16.6 ± 6.6 kg. Preoperative urinary signs were recorded in 26/61 dogs (43%), gastrointestinal signs in 42/61 (69%) and neurologic signs in 50/61 (82%; including 9 with seizures). Concurrent disease was diagnosed in 19/61 dogs (31%). Distribution of shunts was classified as left-sided in 20/61 dogs (33%), right-sided in 31/61 (51%), central-divisional in 8/61 (13%) and multiple or hybrid classification in 2/61 (3%), based on results of CTA and intraoperative angiography. Vascular access was gained by a jugular approach in 55 cases, femoral approach in two cases, and combined approaches in four cases: two jugular and splenic vein/two femoral and splenic vein. A mixture of 8 mm and 5 mm coils were used for each dog except for five dogs who only received 8 mm coils and three dogs who only received 5 mm coils. The median number of coils per case was eight (range: 3–21). For dogs who underwent a second or third intervention, the median number of 8 mm coils was four (1–9) and the median number of 5 mm coils was four (2–6). In one case, a nitinol vascular plug was used (1 of 2 dogs with multiple shunts).

Perioperative deaths were reported in two dogs (3.2%). Major intraoperative complications occurred in 3/61 dogs (5%), including caval perforation (2) and transient portal hypertension (1). Caval perforations were recorded in 2013 and 2016. One caval perforation led to intraoperative death. The other was successfully treated by emergency sternotomy and caval suture. As the dog was positioned in dorsal recumbency, prepped for open surgery, and the site of caval perforation was caudal to the heart, this approach was deemed more appropriate. This dog later underwent surgical cIHPSS treatment and excluded from further analysis. Minor intraoperative complications were reported in 5/61 dogs (8%), including stent misplacement (2; stent not covering entirely the shunt opening and stent wrongly deployed in the external iliac vein), inability to catheterize the shunt (3) and subclinical coil migration (2). All these complications occurred between 2011 and 2016 except for one stent mispositioning in 2019 (stent not covering entirely the shunt opening). Major postoperative complications were recorded in 2/60 dogs (3%): intractable seizures – which led to patient death – and severe but transient portal hypertension, which self-resolved in less than 24 h. Minor postoperative complications occurred in 10/60

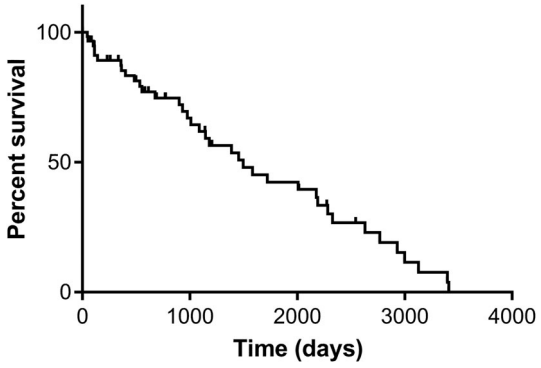

FIGURE 2 Overall Kaplan–Meier survival curve for 61 dogs undergoing percutaneous transvenous coil embolization (PTCE).

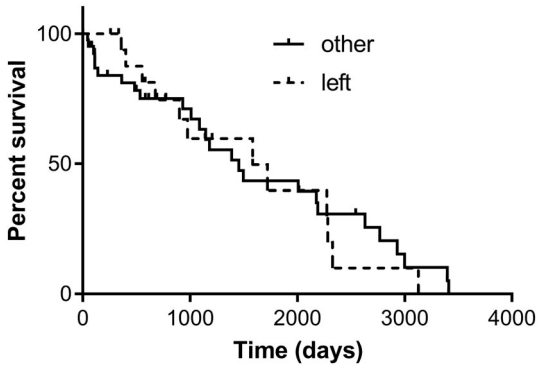

FIGURE 3 Kaplan–Meier survival curves for dogs treated with percutaneous transvenous coil embolization (PTCE) for left-sided congenital intrahepatic portosystemic shunt (cIHPSS) versus central/right cIHPSS.

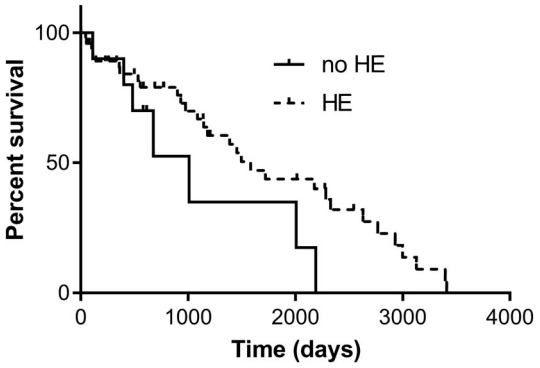

FIGURE 4 Kaplan–Meier survival curves for dogs with or without preoperative hepatic encephalopathy (HE) signs treated with percutaneous transvenous coil embolization (PTCE).

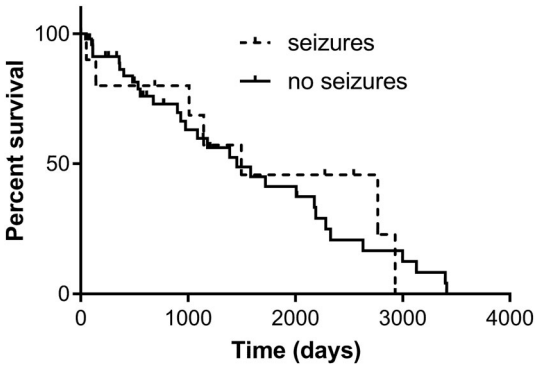

FIGURE 5 Kaplan–Meier survival curves for dogs with or without preoperative seizures treated with percutaneous transvenous coil embolization (PTCE).

dogs (17%) and included surgery site complications (e.g., bruising, swelling). Five minor postoperative complications occurred in the period from 2010 to 2015 (5/17), and five minor postoperative complications occurred in the period of 2016–2022 (5/44).

Further intervention was performed in 16/58 dogs (27%), all for additional coil placement. In 3/16 dogs, placement of a second stent to correct intraoperative mispositioning (2) or displacement due to the initial stent being undersized (1) was performed.

Median follow-up time was 769 (interquartile range [IQR]: 297–1865) days. Median survival time (MST) was 1496 days (Figure 2). MST was not different between the left divisional (1583 days) and central/right divisional (1455 days) shunts ($p = .65$) (Figure 3). There was also no difference in survival between dogs who experienced signs of hepatic encephalopathy (1583 days) ($n = 50/61$) or seizures (1496 days) ($n = 10/61$) before treatment and those who did not (1011 and 1455 days, respectively) (Figures 4 and 5). IQRs were not calculated for those MSTs as more than 75% of the dogs were still alive at the time of calculation. Of the 59 dogs included in the study (excluding perioperative deaths), full datasets of prediagnosis, post-medication and post-PTCE QoL scores and CPSS scores were available in 28 and 16/59 dogs respectively, 1/59 dogs had only premedication and post-surgical QoL and CPSS scores, 7/59 dogs had only post-surgical QoL and CPSS scores, and for 23/59 dogs QoL and CPSS scores were not available. For 40/59 dogs, composite grading data was available, for the remaining 19 dogs only survival data was available. Dogs for which CPSS and QoL data were not available did not seem to subjectively differ in terms of signalment, surgical factors or in the available postoperative outcome data.

Median CPSS scores were compared across prediagnosis, post-medical and post-PTCE time points using a Friedman test, restricted to dogs with complete dataset (Table 1). A significant difference was observed between time points ($p = .002$). Post hoc Wilcoxon signed-rank tests showed a significant improvement in Hr-CPSS between prediagnosis and post-medical evaluation ($p = .005$), as well as between prediagnosis and

	Prediagnosis	Post medical management	Post PTCE
Median	25	16.5	5
Q1	18	4.3	3
Q3	51.3	22.8	11

TABLE 1 Median, first (Q1) and third (Q3) quartile CPSS in dogs pre-cIHPSS diagnosis, post-cIHPSS medical management and post-cIHPSS PTCE.

Abbreviations: cIHPSS, congenital intrahepatic portosystemic shunt; CPSS, congenital portosystemic shunt scoring; PTCE, percutaneous transvenous coil embolization.

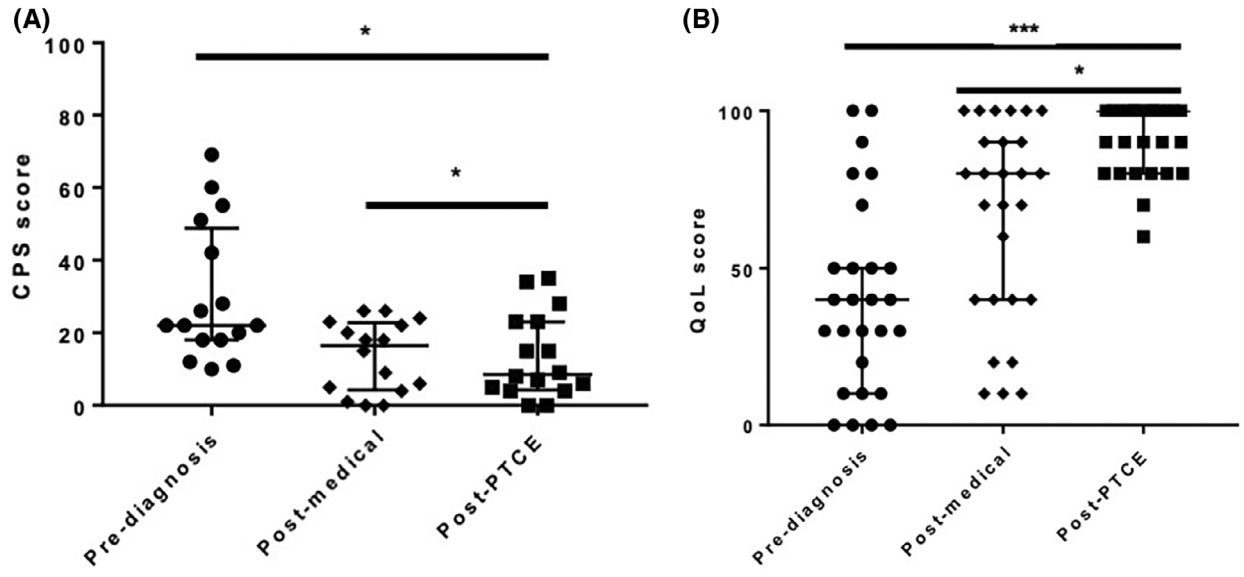

FIGURE 6 Scatter plots prediagnosis, post-medical and post-percutaneous transvenous coil embolization (PTCE). (A) Individual paired congenital portosystemic shunt scoring (Hr-CPSS) and (B) health-related quality of life (Hr-QoL) scores.

	Prediagnosis	Post medical management	Post PTCE
Median	35	75	100
Q1	10	40	80
Q3	50	90	100

TABLE 2 Median, first (Q1) and third (Q3) quartile quality of the life scores in dogs pre-cIHPSS diagnosis, post-cIHPSS medical management and post-cIHPSS PTCE.

Abbreviations: cIHPSS, congenital intrahepatic portosystemic shunt; PTCE, percutaneous transvenous coil embolization.

post-PTCE evaluation ($p < .0001$). No significant difference was observed between post-medical and post-PTCE CPSS ($p = .68$) (Figure 6A).

Median Hr-QoL scores were compared across prediagnosis, post-medical treatment and post-PTCE time points using a Friedman test, restricted to dogs with complete dataset (Table 2). A significant difference was observed between time points ($p < .0001$). Post hoc Wilcoxon signed-rank tests showed a significant increase between post-medical and prediagnosis Hr-QoL scores ($p = .038$), and between post-medical and post-PTCE Hr-QoL scores ($p = .005$). A significant increase between post-PTCE and prediagnosis Hr-QoL scores was also evidenced ($p < .0001$) (Figure 6B). At last follow-up, 33 of 59 dogs (excluding the perioperative deaths) remained on medical management and/or a specialized diet including 23/59 dogs (39%) on medical treatment and 21 (36%) on special diet. Information was not available for 16 dogs. Medications included lactulose (21), antibiotics (12), anticonvulsant drugs (4), omeprazole (4), allopurinol (1). Composite grading was available in 40 dogs, and scored excellent in 4/40, good in 9/40, fair 16/40 and poor in 11/40 dogs. Seven dogs graded as "poor" with available CPSS and QoL scores, had median QoL score of 80 (range: 10–100) and CPSS score of 23 (range: 4–52). The one-, two- and five-year survival rates were 83%, 66%, and 54%, respectively. Poor results were due to persistence of signs that could be related to liver dysfunction.

Postoperative imaging was performed in 43 dogs (median 186 days postoperatively, range: 58–2471) consisting

of either one or a combination of the following modalities: CTA (17), ultrasound (21) and portovenography (7). One dog had CT and US. Four dogs had CT and subsequent portovenography. No shunting was documented in 25/43 (58%) of the dogs, residual shunting in 15/43 (35%; including 2 cases of acquired shunting) with marked reduction of flow compared to preoperative findings, and suspected residual shunting in 1/43 (2%). In 2/43 dogs, imaging (ultrasound) was unable to reliably determine if residual shunting or acquired shunting were present and further investigations were declined by the owners. Five of the seven portovenography findings were consistent with complete occlusion of the shunt. In the remaining two cases, subjective trivial shunting was found but further coiling was declined by the owners.

Blood work pairwise comparison was performed in 47 dogs (at least one pre- and one postoperative sample). It showed a significant increase in Hct (from 35.6 ± 8.1 to 41.4 ± 6.4 $p < .001$), albumin (from 23 ± 4.3 g/L to 27 ± 3.2 g/L, $p = .0002$), and cholesterol (from 3.3 ± 1.4 mmol/L to 5.1 ± 2.5 mmol/L; $p = .0001$) and a significant reduction in WBC count (from 16 ± 6.1 10^3/μL to 14 ± 5.7 10^3/μL; $p = .02$), whilst RBC and MCV increases (5.7.10^6/μL to 7.3 × 10^6/μL, and 53.6 ± 18.8 to 56.6 ± 7.1, respectively) were present but not significant ($p = .32$ and .95, respectively).

4 | DISCUSSION

These data suggest that treatment of cIHPSS with PTCE in dogs is associated with a good long-term survival and significant improvement in QoL and clinical signs (CPSS score). Survival time was similar to data previously reported for dogs undergoing open surgery[14] and PTCE, but five-year survival rate compared to that previously identified post-PTCE was slightly lower.[3,8,21] These figures should be compared with caution, as overall survival is dependent on many subjective factors, such as clinician decision making and owner motivation or financial restrictions. Similar to previous studies,[3] our data did not show any difference in survival between dogs affected by left-sided versus central/right sided shunts. Similarly, preprocedure hepatic encephalopathy or seizures was not associated with outcome. Therefore, with the above caveats around factors that are difficult to measure or account for fully, preprocedural neurologic signs should not be considered as a negative prognostic factor for dogs included considered for PTCE.

Although survival and QoL in veterinary patients are often linked by the accessibility of euthanasia, it could be argued that a validated QoL questionnaire provides more accurate and detailed procedure outcome data than mortality rate alone.[28] The use of Hr-QoL questionnaires has become widespread in veterinary medicine, including in the assessment of dogs with extra- and intrahepatic shunts undergoing open surgical treatment.[27] Our study is the first to report Hr-QoL questionnaire long-term outcome data in dogs undergoing PTCE treatment of cIHPSS. The median CPSS following PTCE treatment in this study was 7/110 which compared favorably with a median CPSS of 9/110 and 3/110 for dogs undergoing open surgical treatment of extra- and intrahepatic shunts, respectively.[27] Similarly, the median QoL score following PTCE treatment in this study was 100 (best possible score) which compared favorably with a median QoL score of 96 and 94 for dogs undergoing open surgical treatment of extra- and intrahepatic shunts respectively.[27] It is of note that in this study[27] QoL scores of dogs with shunts to that of healthy dogs were also compared and this control population had a QoL score of 93 which is not the maximum 100 score, indicating there was a slight natural variation and mild overlap between healthy dogs and post-shunt treatment dogs at the excellent end of the QoL scale.

The combined evaluation of Hr-CPSS and Hr-QoL outcomes underscored the complementary nature of objective clinical scoring and owner-reported assessment in the follow-up of treated dogs. Hr-CPSS and HR QoL scores improved significantly over the three time points. Hr-CPSS improvement, even though not reaching significance between the first and second time points, showed graphically a remarkable improvement highlighting the objective positive effect of medical therapy. Conversely, the spread of individual Hr QoL scores following medical therapy demonstrated the limit of owner-reporting assessments especially as some of these scores were acquired retrospectively.

It is likely that a ceiling effect, inherent to clinical scoring-reported outcomes once an acceptable clinical score has been reached, exists. However, although not all dogs could each have medical or dietary measures discontinued, the advantage of PTCE is reinforced by a longer MST compared to studies in which only medical management was performed in which median survival times ranged from 836 days[29] to around the 36 months' time mark,[7,30] which is significantly less than the MST reached in studies on PTCE. In addition, a recent study investigating lifetime survival of dogs with portosystemic vascular anomalies with or without copper -restricted diets, has demonstrated that survival age of surgically treated animals exceeded the one of medically treated ones.[31] Those dogs who continued medical or dietary treatment after PTCE might have done so because of persistent clinical signs when therapy was discontinued, or because of owner factors, such as risk-averseness in reducing drug dose or personal convenience especially related to diet preferences.

Recent evidence exists that diet management of cIHPSS provides significant benefit even on surgically treated animals[7,31,32] and lifelong dietary management are likely needed for such animals. The same statement can likely be applied to some medications for most dogs, making the respective roles of diet/medication and surgery/PTCE in the overall improvement of dogs difficult to tease out. Many dogs presenting with cIHPSS have experienced a fickle appetite and variable fecal quality, and when owners perceive a satisfactory diet has been found as part of medical management, they may be reluctant to change the regime even after PTCE. The proportion of dogs still on medication and/or diet reported in our study was commensurate to other studies reporting long term outcome of PTCE, as Weisse et al. reported that 81% dogs were still on gastroprotectants, and 23% still on lactulose or antibiotics at the time of follow up.[3] Other studies evaluating outcome over a shorter follow-up reported up to 50% of dogs still on medications or diet.[33] Chronic gastrointestinal changes may represent a challenge when treating dogs with cIHPSS long term to the point that some authors have advocated the need for life long medical management after PTCE, in particular, use of proton pump inhibitor (PPI) drugs to manage putative life-long risk of portal hypertension-generated gastrointestinal bleeding and ulcers.[2,3,34] Not all dogs in our study remained on PPI treatment, on the basis that this treatment has been shown to induce changes to the gastrointestinal bacterial microbiota of healthy dogs[35] and that the dysbiosis index is increased after only 2 weeks of continuous treatment with esomeprazole in dogs.[36] Further understanding of the putative long-term benefit to complication ratio using PPI medication in cIHPSS dogs is needed.

As expected, the outcome grade results provided a very different picture to the Hr-QoL and CPSS scores, especially with regard to the worst grade results (27.5% of poor grade in our study). By comparison, Weisse et al.[3] reported a 19% poor grade following PTCE using a grading scheme slightly different than ours but for which the poor category was similarly defined. Other studies reporting outcome of PTCE[8,21,33] did not use this grading system. The difference in poor outcome between our study and that of the Weisse et al. study could be attributable to genuine better results of the procedure reported in their study compared to ours, to owner's fluctuant recollection of infrequent occurrence of clinical signs or to the fact that the Hr-QoL questionnaire allowed to capture more subtle information on signs that could be related to liver dysfunction, which have automatically put the dogs in the "poor" category. From our data, for the seven dogs graded as "poor" with available CPSS and QoL scores, the median QoL score was 80 (range: 10–100) and CPSS score was 23 (range: 4–52) showing that these dogs clearly experienced some clinical signs, but largely their QoL was good. Our data therefore suggest that composite outcome grading may underestimate perceived QoL compared with validated Hr-QoL and CPSS scores, and we recommend that future studies prioritize these more granular instruments when possible.

The rates of major and minor intra- and postoperative complications were commensurate to those reported in previous studies on PTCE,[3,8,21,22] and perioperative death rate much lower than the ones reported for open surgery. Qualitatively the nature of the complications was not too dissimilar (e.g., portal hypertension, stent misplacement) but as the definition of minor and major complications was not standardized between studies it is difficult to draw any meaningful comparison. Furthermore, not all studies recorded the minor and major, intra- and postoperative complications rates separately. The nature and overall rate of the complications in our study also represented the learning curve of four clinicians (ID, EJF, GC surgeons; KB cardiologist) over a period of time in a single institution. All clinicians had undergone suitable training in vascular interventional radiology, but a human interventional radiology consultant did not attend any of the procedures at that center, unlike some studies reporting PTCE outcomes.[3,8] In humans, the learning curve for interventional radiology is reported to be biphasic, with rapid decrease in normalized procedure times in the first 9-months of practice, followed by a less rapid but significant decrease in normalized procedure times between 9-months and 9-years of practice, achieving one career median procedure time within 2–3 years of practice.[37] Quantifying learning curve in our center by similar means was not possible, but the data presented herein represented the learning curve occurring over more than 10 years. Lethal complications, such as caval perforation, did occur in the early phase (<2 years of experience) of the learning curve, and most likely were associated with operator inexperience. Since 2016, very limited similar operator errors were encountered at our institution. Similarly, most other operator's errors such as stent misplacement, inability to catheterize the shunt or coil migration did occur during the early stage of the study period, but not in the later years of experience. Additionally, minor postoperative complications (exclusively surgical site complications) occurred less frequently in the period from 2016 to 2022 (4/44, 9%) compared to the period from 2010 to 2015 (5/17, 29%). In the veterinary field, different specialties do contribute different skill sets, and cooperation should be encouraged to permit more confident decision making and reduce the risk of operator error, as is the case in human interventional radiology.[38]

A majority of right and central division shunt were identified in this study. The proportions of dogs affected by various anatomic shunt classifications differed from prior epidemiological data, reporting an equal distribution of left- and right-divisional shunts,[39] but our data was concordant with that reported in more recent studies on PTCE outcome.[3,8,22] One recent study of dogs with cIHPSS presenting for open surgery[21] did report a majority of left-sided shunts, but this may be a reflection that right- and central-division shunts are less amenable to open surgery, so would present initially as candidates for PTCE. Based on the lack of difference reported in this study regarding survival rates between left-sided and central/right-sided shunts, the authors would recommend that, unless financial restriction dictates a different approach, central/right-sided shunts as well as left-sided shunts are primarily treated by PTCE.

Complete shunt closure was reported in a majority of dogs and in almost all dogs available for follow-up, flow was markedly reduced (40/43; 93%); however, this was assessed using imaging methods that could lead to false negative results, and in the absence of repeated portovenography (only done in 7 cases) to clearly visualize flow, these results should be interpreted with caution. Portovenography is a very reliable and objective modality to document residual portal flow[40,41] but it is invasive. The use of intraoperative transesophageal echocardiography has been suggested as a non-invasive and relatively objective way of measuring occlusion,[42] and represents a potentially more reliable, non-invasive method to visualize coil deployment as well as postoperative shunt flow.

Exploration of changes to blood work reported in this study has been limited to selected parameters. This was a secondary goal, as changes to biochemical values following shunt attenuation do not necessarily correlate with clinical changes.[24] In the selected parameters reported here, improvement was noted but normalization did not occur. Complete normalization of blood work is likely to be a positive finding but should not drive primary clinician decision making. Furthermore, we believe that in dogs with good QoL and low CPSS scores, persistent mild biochemical abnormalities alone should not be interpreted as treatment failure.

The limitations of this study include those known to be associated with use of questionnaires. For dogs retrospectively recruited, some scoring relied on owner recall and therefore may be biased. In particular, dramatic post treatment improvement, as well as the passage of time, may lead to owners being more generous with QoL scores. Conversely, there is also the potential for attention bias where owners remember abnormal behavior more easily than normal behavior which may lead to relatively increased CPSS scores. However, the number of retrospectively recruited dogs was lower than the number of prospectively enrolled, so this bias was minimized. The approach to intraoperative decision making (e.g., catheter position, coil-type and size used, and when to finish the procedure) was subjective and operator dependent. This meant that procedure technique was difficult to standardize. Similarly, decision to reintervene was likely to be clinician- and case-dependent, and objective criteria for when to deploy more coils were lacking. The number of dogs that underwent reintervention in this study was limited, but it is possible that some dogs who remained on medical or dietary management at last follow-up would have benefited from a repeat procedure. However, it is equally possible that these dogs' shunts were meaningfully closed, and that liver dysfunction remained. Further studies focusing on objective assessment of shunt closure are critically needed.

In conclusion, the results of this study demonstrated that a sustained long-term improvement in both QoL and CPSS scores was achieved in dogs undergoing PTCE treatment of their shunt beyond what can be expected with medical management alone even of the latter produced significant increase in QoL and CPSS scores compared to premedical treatment. Furthermore, these improved scores were above that achieved by medical management preprocedure alone and comparable to scores post open surgical treatment of both extra- and intrahepatic shunts. Further studies to determine optimal planning around discontinuation of medical and dietary management or the decision to perform reintervention are required.

AUTHOR CONTRIBUTIONS

Chanoit GP, DEDV, PhD, DipACVS, DipECVS, FRCVS: Substantial contributions to the conception or design of the work and interpretation of data for the work; drafting the work or revising it critically for important intellectual content; final approval of the version to be published; 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. Scott P, BVSc: Contribution to data acquisition, analysis, and interpretation, drafting and revision of work, and final approval of the manuscript. Borgeat K, BSc, BVSc, MVetMed, CertVC, FHEA, DipACVIM, DipECVIM (Companion Animals), FRCVS: Contribution to data acquisition, revision of work, and final approval of the manuscript. Doran I, BVSc, CertSAS, DSAS, FHEA, MRCVS: Contribution to the conception and design of the study, enrolment of surgical cases, data acquisition, revision of work, and final approval of the manuscript. Lipscomb V, MA, VetMB, FHEA, DipECVS: Contribution to design of study with particular original

input on questionnaire design and analysis, revision of work, and final approval of the manuscript. Friend EJ, BVetMed, CertSAS, DipECVS: Contribution to the conception and design of the study, enrolment of surgical cases, data acquisition, revision of work, and final approval of the manuscript.

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CONFLICT OF INTEREST STATEMENT

KB is a paid consultant for Infiniti Medical, but no third parties have had any input into the design of this study or the manuscript preparation. All other co-authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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