Research in Veterinary Science 103 (2015) 156–163

Contents lists available at ScienceDirect

Research in Veterinary Science

journal homepage: www.elsevier.com/locate/yrvsc

A multimodality imaging approach for guiding a modified endovascular coil embolization of a single intrahepatic portosystemic shunt in dogs

Teja Knapp [a], Iolanda Navalòn [b], Massimo Medda [c], Danitza Pradelli [a,*], Simone Borgonovo [a], Cristina Crosta [a], Claudio Maria Bussadori [a]

[a] Clinica Veterinaria Gran Sasso, Via Donatello 26, 20131 Milan, Italy
[b] Ars Veterinaria, Barcelona, Spain
[c] Istituto Clinico Sant'Ambrogio, Milan, Italy

ARTICLE INFO

Article history:
Received 5 February 2015
Received in revised form 25 September 2015
Accepted 27 September 2015

Keywords:
Intrahepatic portosystemic shunt
Coil embolization
Diagnostic imaging
Transesophageal ultrasonography
Dog

ABSTRACT

Intrahepatic portosystemic shunts (IHPSS) in dogs are aberrant vascular anomalies that connect the portal and the systemic venous vessels. In most of the patients, the surgical approach is unfavourable due to the difficulties in isolating the IHPSS, making the option of a percutaneous transvenous coil embolization (PTCE) one of the safer occlusive procedures. This study describes the treatment of eight dogs with a single IHPSS using a multimodality imaging approach to guide the modified PTCE procedure. This new technique results in a decrease of 71% of the time of the entire procedure with the reduction of 91% in the time required involved the IHPSS identification and in the fluoroscopy exposure time avoiding the need for iodinated contrast agents during the procedure. Moreover, the placement of the catheter before the caval stent ensures its greater stability, enhancing the procedural safety in the phase when the coils are released and avoiding the risk of their dislocation.

1. Introduction

Intrahepatic portosystemic shunts (IHPSSs) are congenital vascular abnormalities caused by an incomplete closure of the ductus venosus, the embryonic vessel that connects the portal vein (PV) with the caudal vena cava (CVC) and ensures the blood flow from the placenta directly to the vital organs, bypassing the hepatic circulation (van Steenbeek et al., 2012). In dogs, its closure occurs 6–9 days after birth (Lamb and Burton, 2004). IHPSS is typically observed in large-breed dogs (Bostwick and Twedt, 1995) and usually presents as a single anomalous vessel within the liver. The types of IHPSS can be classified into the left divisional shunt, central divisional shunt and right divisional shunt (Lamb and White, 1998). The affected dogs may be asymptomatic or may show clinical signs of hepatic encephalopathy. Medical treatment is only palliative, whereas the traditional surgical treatment can be technically difficult.

Previous studies have described the procedure using coils and stents placed in the CVC for the treatment of congenital portosystemic shunt (CPS). (Bussadori et al., 2008; Gonzalo-Orden et al., 2000; Partington et al., 1993) However, those studies revealed several issues, such as the long fluoroscopy exposure time (Rossi et al., 2010), the use of an iodinated contrast agent, the difficulties and the length of the catheter insertion phase through the net of the auto-expandable caval stent and the high complication rate (Weisse et al., 2014).

The objective of this study was to introduce a new imaging approach for guiding a modified percutaneous trans-venous coil embolization (PTCE) in canine IHPSS, providing a reduction in both the length of time required both for the procedure and for the fluoroscopy time, avoiding a portal angiography in the absence of the complications commonly caused by coil migration.

2. Material and methods

Eight consecutive dogs with a diagnosis of IHPSS were included. Three of the dogs were referred to the Clinica Veterinaria Gran Sasso as IHPSS-affected patients, while the other five dogs received the IHPSS diagnosis at our centre based on their clinical history, blood results, and a urine analysis. The pre-operative liver function was tested in all of the IHPSS-affected dogs, included the fasting bile acids and post-prandial bile acids concentrations (Gerritzen-Bruning et al., 2006; Ruland et al., 2010). The diagnostic imaging tools were adopted to confirm the presence of IHPSS and to differentiate it from other portosystemic disorders. The liver was scanned through an intercostal approach, using two ultrasound machines operated by the same experienced sonographer (TK): an Esaote Mylab Class C (Esaote; Genova, Italy) and a Mylab 30 gold (Esaote; Genova, Italy), both of which were

* Corresponding author.
E-mail addresses: tejaknapp@gmail.com (T. Knapp), inavalon@hotmail.com (I. Navalòn), massimomedda@yahoo.it (M. Medda), danitza.pradelli@gmail.com (D. Pradelli), simoneborgonovodvm@gmail.com (S. Borgonovo), mcristinacrosta@yahoo.it (C. Crosta), claudio.bussadori@gmail.com (C.M. Bussadori).

http://dx.doi.org/10.1016/j.rvsc.2015.09.023
0034-5288/

equipped with a micro convex probe CA123 (5–8 MHZ) and a linear probe LA532 (5–10 MHZ) (Esaote; Genova, Italy). To confirm the dimensions and the morphology of the shunt, each dog underwent a CT angiography examination using a GE Light Speed Plus 4 Slice CT (General Electric Healthcare, Milwaukee, WI, USA), with a dual-phase CT angiography study performed by the same experienced radiologist (SB). The protocol provided the acquisition of an abdominal survey helical scan for the orientation, a dynamic scan for timing, and finally, a tri-phase helical scan (the arterial, venal and portal phases). Iopamidol (Iopamiro®, Bracco Imaging Italia Srl; 600 mgI/Kg), the contrast agent, was introduced through a nonselective peripheral venous catheter that was positioned in the cephalic veins. Vitamin K was administered to all of the dogs (Roche SpA; Milano Italy; 0.5 mg/Kg, OS) for 3 days before the procedure, and the dogs received an infusion of plasma (12 ml/Kg) two hours before the interventional procedure (Snow et al., 2010). Thirty minutes before the plasma infusion, the dogs received chlorpheniramine maleate (6 mg/dog SC (Schering-Plough SpA, Milano, Italy). Before the procedure, a double prophylactic antibiotic therapy was administered: metronidazole (Società Prodotti Antibiotici SpA, Milano, Italy; 7.5 mg/Kg EV for 30 min) and amoxicillin–clavulanic acid (Pfizer, Latina, Italy; 20 mg/Kg SC). Each dog was anaesthetized using butorphanol (Intervet, Milan, Italy; 0.2 mg/Kg IM) approximately 15 min before the anaesthetic induction, and propofol was administered (Fresienus Kabi S.r.l. Italy; 2–4 mg/Kg EV) to induce anaesthesia. Then, the dog was intubated, and anaesthesia was maintained with an isoflurane inhalation (1–2%) (Abbott House, UK) and oxygen using an Alpha Delta volumetric ventilator (Siare Engineering International Group SRL, Crespellano, Bologna, Italy) and a semi-closed circuit with respiration. During the procedure, the dog was constantly ECG-monitored. Each dog was placed in dorsal recumbency. The ventral portion of the abdomen and the thigh region were carefully clipped of hair, scrubbed and draped to expose both of the femoral veins. The guide wires, the catheters, the stent and the coils were manipulated using standard sterile techniques. The intra-procedural multimodality imaging approach (MIA) began with the location of the IHPSS's exit using transesophageal ultrasonography (TEU) with a 022 probe (Esaote, Genova Italy). The CT images acquired before the procedure were the reference points for orientating the TEU and visualizing the IHPSS. Based on the CT images, the ultrasound beam was directed clockwise until the IHPSS and its ampulla were bidimensionally imaged. A Doppler analysis was performed to define and confirm the junction shunt flow, placing the sample volume at the connection of the shunt-draining hepatic vein. The combination of a colour Doppler (Fig. 1) and a spectral Doppler (Fig. 2) study was used to define the type and direction of the blood flow, allowing its qualitative analysis before the attenuation. Using this approach, the measurement of the CVC diameter at its IHPSS junction was obtained. Both diameters were then compared with the CT measurements to correctly estimate the dimension and the length of the auto-expandable caval stent. A small skin incision on each thigh of 5 mm facilitated the placement of the vascular introducer. The Seldinger technique was used for the vascular access. In seven of the dogs, two introducers (5–14 Fr) (Cordis Corporation, USA) were positioned in each of the femoral veins: the smaller one for the Simmons catheter (Cordis Corporation, USA) or the Cobra shaped catheter (Cordis Corporation, USA) positioning and, the other was used to release the caval auto-expandable stent. In one dog, after careful evaluation of the diameter of the femoral vein, we were successful in using only one femoral venous access, placing a 13 Fr introducer into which both the Simmons catheter and the release stent system were inserted. In all of the other dogs, a 0.035″ × 150 cm guide wire (Kimal, UK) was positioned through the introducer on the right side and a Simmons catheter or, alternatively, a Cobra-shaped catheter (Cordis Corporation, USA) was advanced percutaneously on that guide until its tip faced into the shunt. The Simmons catheter was selected when the angle between the CVC and IHPSS was less than 90°, while the Cobra-shaped catheter was used when this angle was greater than 90°. Both fluoroscopy and TEU were used to monitor the proper location of the catheter's tip (Fig. 3).

A bubble study confirmed the hook and the introduction of the Simmons or Cobra-shaped catheter inside the shunt. Five millilitres of saline mixed with five millilitres of colloid was agitated back and forth between two syringes connected by a three-way stopcock and then rapidly injected by one of the two syringes directly into the venous catheter. The correct location at the level of the shunt's junction allowed us to clearly confirm the bubble contrast's transit through the anomalous vessel into the caudal vena cava (Fig. 4). The placement of the Simmons

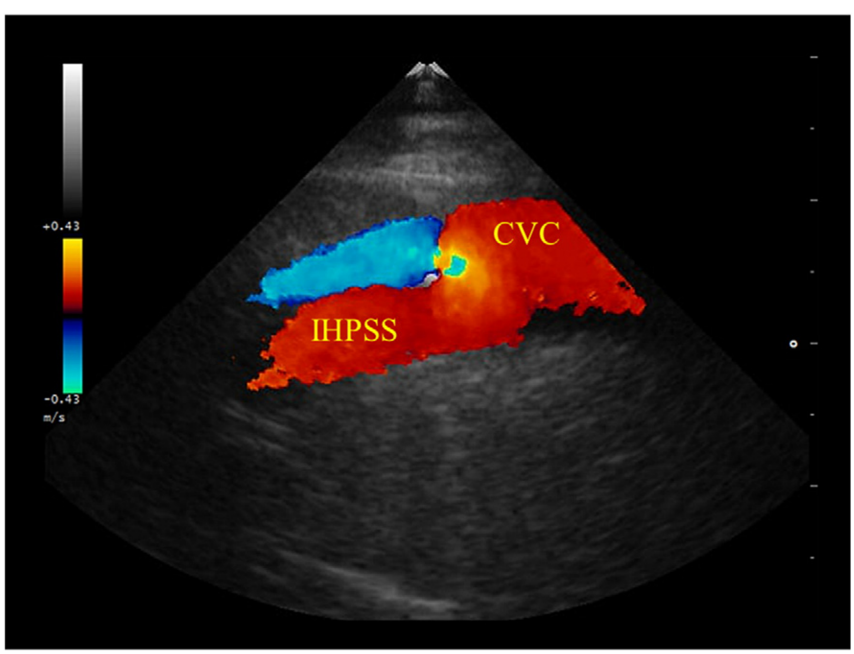

Fig. 1. Transesophageal ultrasonography colour Doppler image: a longitudinal view of the IHPSS's exit. The pre-procedural qualitative analysis of the blood flow from the left tubular type of IHPSS into the caudal vena cava. CVC: caudal vena cava; IHPSS: intrahepatic portosystemic shunt.

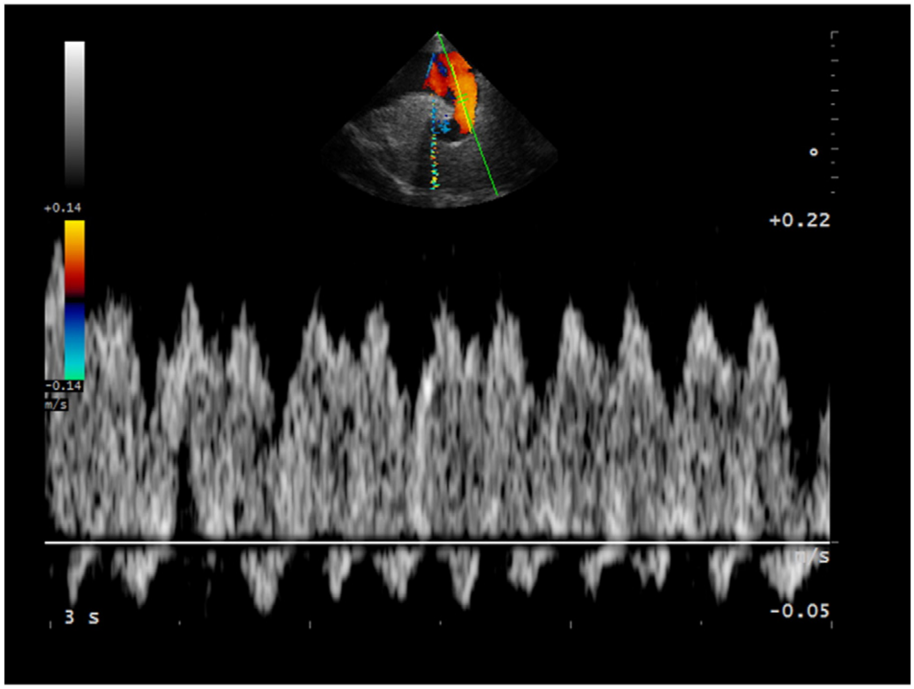

Fig. 2. Transesophageal ultrasonography PW Doppler: the waveform of the pre-procedural blood flow from the right ampullar IHPSS to the CVC at the shunt's exit. CVC: caudal vena cava; PW: pulsed wave; IHPSS: intrahepatic portosystemic shunt.

or Cobra catheter was maintained using a 0.014″ × 150 cm guide (Abbott Vascular, Santa Clara, CA 95054-2807 USA).

The auto-expandable stent (from 18 to 24 mm × 6 cm depending on the CVC diameter measured on the CT) (Cordis corporation, USA) was then implanted inside the CVC. The release of the auto-expandable stent system occurred under monitoring with both transesophageal ultrasonography (Video 1) and fluoroscopy. The 0.014″ × 150 cm guide (Abbott Vascular, USA) was then removed. The release of the coils (Cook, Denmark) was performed through the catheter under monitoring by both fluoroscopy and TEU (Figs. 5 and 6) (Video 2). A Doppler TEU measured the residual blood flow through the partially occluded IHPSS (Fig. 7), and the number of coils required for each dog was properly assessed. A second bubble study evaluated the attenuation of the post-PTCE IHPSS flow (Video 3).

The process was considered to be concluded when a flow reduction of 50% (based on the colour Doppler) was obtained and the coils filled

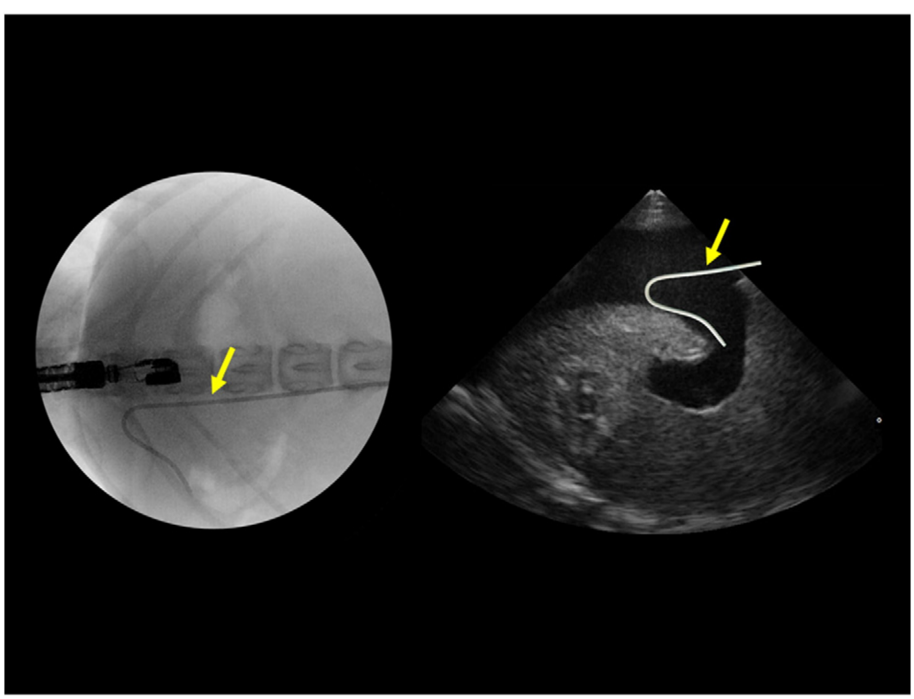

Fig. 3. Multi-imaging approach: the left side of the fluoroscopy image and the right side of transesophageal sonogram with a superimposed drawing of the same Simmons catheter (yellow arrow) into the shunt's exit.

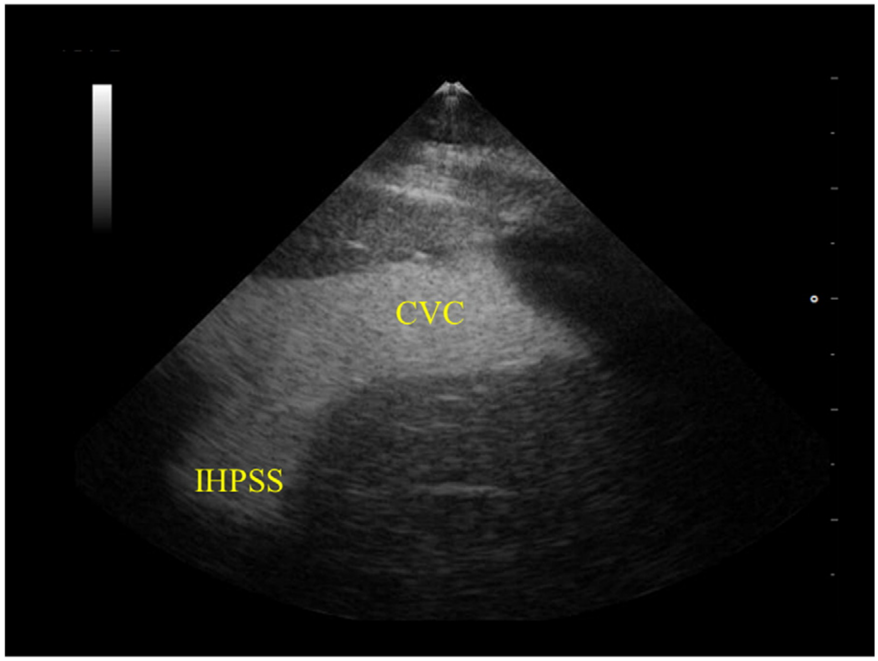

Fig. 4. Transesophageal bubble study. A longitudinal view at the shunt's exit. The contrast study confirmed the introduction of the catheter into the tubular intrahepatic portosystemic shunt and showed the direction of the blood flow from the IHPSS into the caudal vena cava.

more than 75% of the IHPSS's diameter (Weisse et al., 2014). Due to the great risk of the onset of portal hypertension, the reduction in the IHPSS blood flow should not be more than 75% of the blood flow before the attenuation (Buob et al., 2011; Kummeling et al., 2004; Sereda and Adin, 2005). A spectral Doppler analysis was used to provide additional information, and a higher peak blood flow velocity (CW Doppler) that was inversely proportional to the stenotic ductal area generated by the released coils was detected. Finally, the catheter and the introducer were removed before proceeding with a conservative suture of both the femoral veins, and the dogs recovered from the anaesthesia.

The post-operative care included close monitoring of the dogs for signs of portal hypertension and an abdominal ultrasound examination before discharge. We recommended monthly abdominal ultrasound examinations until the closure of the IHPSS was certain. A low-protein diet was maintained until the liver function showed significant improvement. The post-operative follow-up included the monitoring of the serum bile acid levels, the blood cell counts, a serum biochemistry analysis and a complete urine analysis at 3 months and 6 months after the procedure. The follow-up data were collected by telephone contact with the referring veterinarian or owner. One year after the procedure,

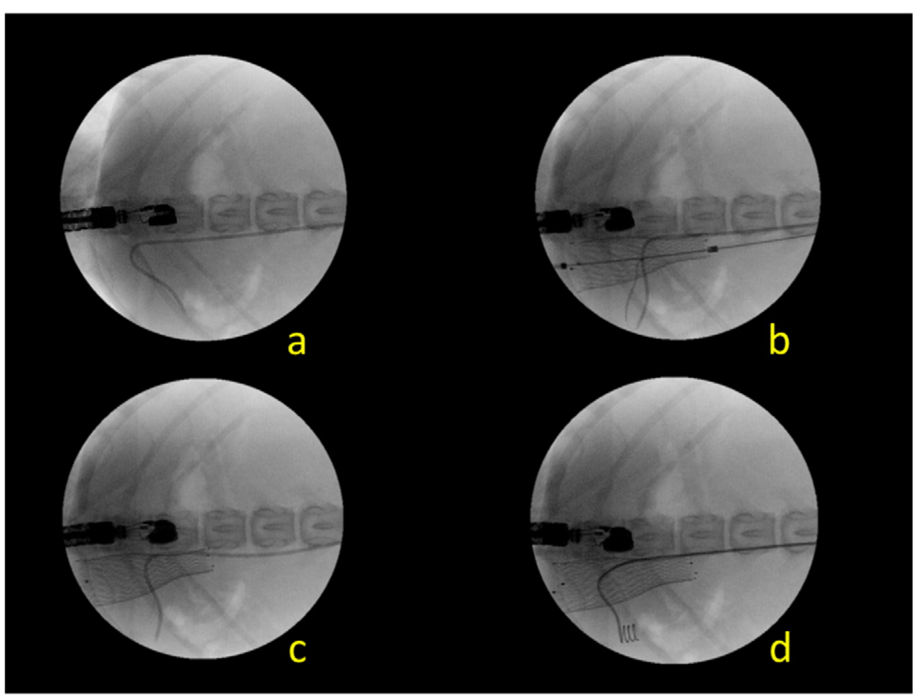

Fig. 5. Sequential fluoroscopic images of a right ampullar IHPSS at different times during the modified PTCE (ventro-dorsal view). The transesophageal probe appears on the left of each image, monitoring the operative field. a: The Simmons' catheter is inserted into the shunt; b: the placement of the stent; c: the Simmons' catheter and stent are properly located at the exit of the shunt; d: the release of the coil inside the IHPSS. IHPSS: intrahepatic portosystemic shunt; PTCE: percutaneous transvenous coil embolization.

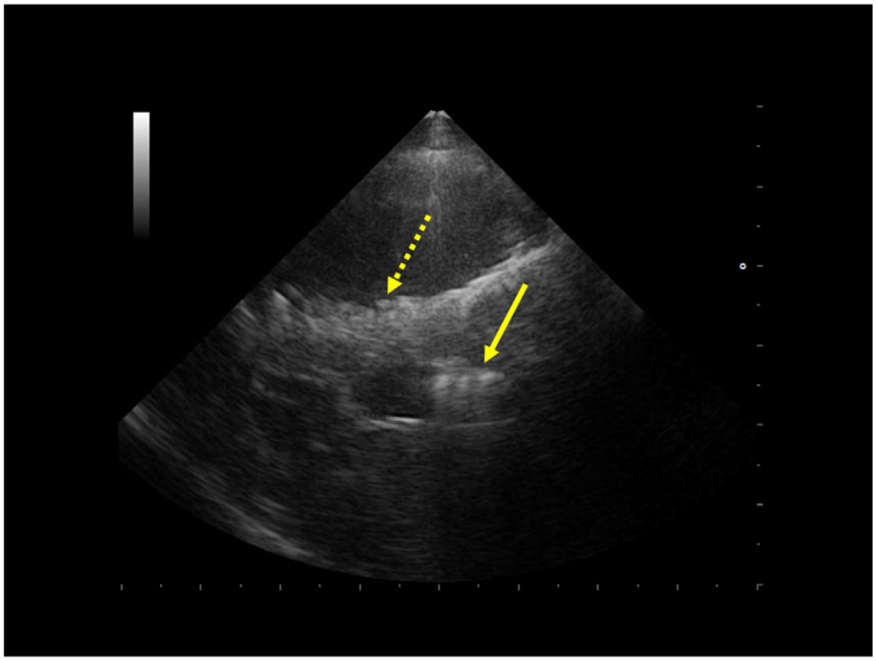

Fig. 6. Bidimensional transesophageal ultrasonography: a longitudinal view of the shunt's exit. The dotted arrow indicates the stent, while the continuous arrow is directed at the proper location of the coil.

the CT angiography examination was suggested to confirm the persistency of the correct positioning of the stent and the coils. (Figs. 8 and 9).

3. Results

Eight dogs, five males and three females, underwent endovascular coil embolizations for IHPSS guided by a multimodality imaging approach. The dogs were included in this study with the owners' consent for the procedure. The mean age was 13 months (range from 6 months to 36 months). The mean body surface area (BSA) was 0.78 (range from 0.52 to 1.07). The mean weight was 21.9 kg (range from 12 to 35 kg). A second PTCE was required in two of the dogs. The mean time of the MIA procedure (from the introduction of the guiding catheter until its removal) was 23 min (range from 15 to 30 min). Compared with the standard technique previously used in our clinic, the MIA-guided embolization of the IHPSS resulted in a reduction of 71% of the time for the entire procedure. In particular, the greatest reduction in the time required involved the identification phase of the IHPSS (a reduction of 91% of the time compared with the standard technique) because of the easy and rapid TEU viewing of the IHPSS and the absence of portal

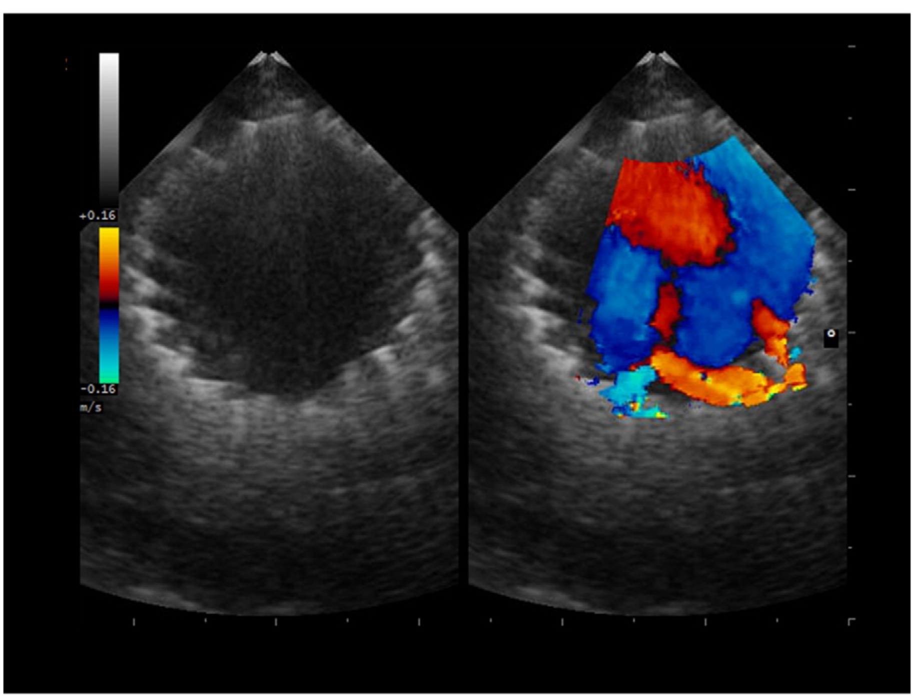

Fig. 7. Dual transesophageal ultrasonography. On the left, the bidimensional transesophageal sonogram in the transversal view shows the cross-section of the stent inside the caudal vena cava. On the right side of the figure, the post-PTCE residual turbulent blood flow through the net of the stent after the partial occlusion is shown. PTCE: percutaneous transvenous coil embolization.

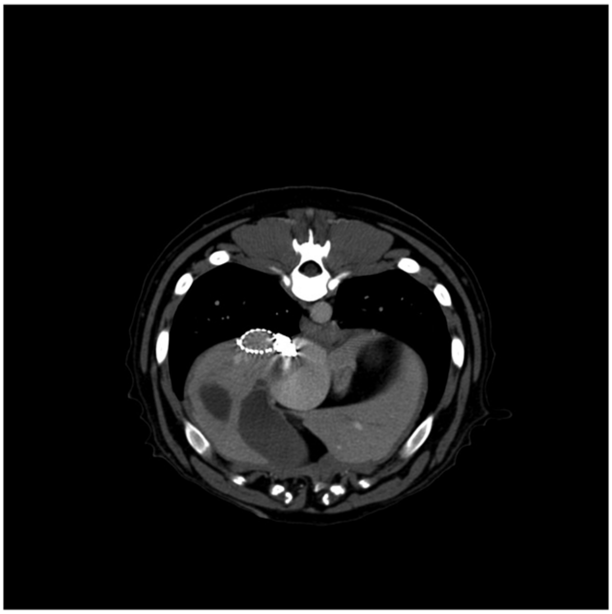

Fig. 8. Post-contrast CT scan, transverse section at T11 level from a Bernese dog with left divisional intrahepatic shunt showing the correct location of the caudal vena cava stent and coils.

venography. The mean times of the embolization procedures reported in the veterinary literature are approximately 90 min (range from 30 to 340 min) (Weisse et al., 2014) and 59 min (range from 30 to 120 min) (Bussadori et al., 2008).

As described above, the percutaneous access was performed using both femoral veins, except in one dog (Abruzzese Shepherd, 2 years old, weight: 21 kg) in which the left femoral vein as a single vascular access was used. A dual-phase CT angiography revealed a single left divisional IHPSS in five of the dogs and a right divisional IHPSS in three of the dogs. Moreover, this technique allowed better visualization of the IHPSS morphology: seven dogs showed a ductal ampulla and one dog had a tubular IHPSS.

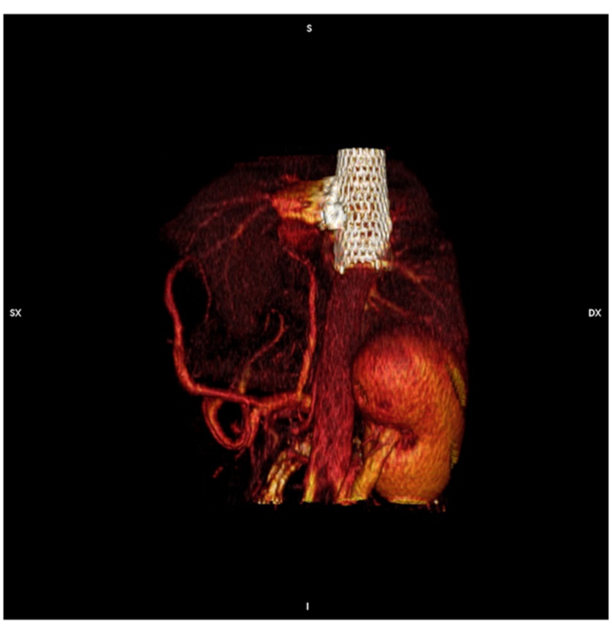

Fig. 9. Tri-dimensional CT scan reconstruction, on the dorsal view from a Bernese dog one year after the PTCE-procedure. The caudal vena cava stent (CVC stent) and the coils are in the correct location.

The selection of which catheter to use depends on the shape of the IHPSS and on its angle within the CVC. We used the Cobra catheter in two dogs due to the shape of the vessels and the Simmons catheter in all of the other cases. The embolic coils were released through the same catheter to partially reduce the shunt flow while concurrently monitoring the portal pressure. The mean pre-PTCE portal vein pressure was 9.9 mm Hg (range: 7.9 mm Hg to 11.8 mm Hg) and the mean post-PTCE portal vein pressure was 14.2 mm Hg (range: 11.7 mm Hg to 16.0 mm Hg).

Six dogs underwent a single MIA-guided procedure, whereas the PTCE did not achieve a sufficient partial attenuation of shunt blood flow in two dogs, and a second endovascular coil release was required. In those cases, the left jugular vein was used for the percutaneous access. The size of the coils was IMVCE-35-10-8 (8 mm), IMVCE-35-10-5 (5 mm), and IMVCE-35-10-10. The dogs received a different number of coils, from a minimum of two to a maximum of seven coils. The stents' dimensions ranged from 18 × 60 mm to 22 × 60 mm. No intraoperative complications occurred in the dogs included in the study. Most of the dogs showed an excellent post-operative outcome at the three months follow-up control: no residual flow, significantly improvement of the serum biochemical and CBC abnormalities in the absence of clinical signs, without dietary or medical management. In two dogs, the residual shunt flow required additional coils released six months after the PTCE procedure.

The CT angiography examination after the procedure confirmed the correct location of the devices in the two scanned dogs. For the other dogs included in the study, the owners declined the consent for the sedation (4 dogs) or the procedure was too recent (still not one year after the procedure) in the other two dogs. All of the data are summarized in Table 1.

4. Discussion

The use of an abdominal ultrasonography after the presumptive clinical diagnosis based on the blood analysis (D. Paepe et al., 2007) was determined to be a highly accurate and sensible diagnostic method for the diagnosis of congenital IHPSS (D'Anjou et al., 2004; Holt et al., 1995; Lamb, 1996; Szatmari et al., 2004a; Szatmari et al., 2004b). From the right intercostal approach, a large tortuous vessel is apparent inside the liver, draining blood from the portal vein to the caudal vena cava. A left divisional IHPSS bends to the left, moving away from the probe (D'Anjou, 2007; D'Anjou et al., 2004) and typically has an ampulla located near the shunt's junction with the CVC (White and Burton, 2000), while the right divisional IHPSS bends in the direction of the probe (D'Anjou, 2007). The central divisional shunts are more difficult to visualize, especially in large breed dogs (D'Anjou et al., 2004). The CT angiographic examination yielded information that was complementary to the abdominal ultrasound results that allowed a better assessment of the morphology, the dimension, and the location of the anomalous vessel and its relationships with the other organs (Henseler et al., 2001; Zwingenberger, 2009; Zwingenberger et al., 2005).

MIA is a technique that combines pre-PTCE computed tomography (CT) images with intra-PTCE constant monitoring by TEU and the spot use of fluoroscopy during the procedure, leading to a good intraoperative control for guiding the PTCE procedure. In particular, TEU allows the quick identification and measurement of the shunt and the measurement of the caval diameter.

All of these data are essential to the selection of the appropriate auto-expandable caval stent and the number of the coils that are going to be released. The higher diagnostic accuracy of TEU, compared with the exclusive use of fluoroscopy, is ensured by the constant real-time views of the region of interest from different angles inside the operative field. Moreover, the combination of the constant TEU and the spot fluoroscopy yielded an accurate evaluation of the flow through the shunt before the embolization, the correct positioning of

Table 1
summarize the treatment of canine portosystemic shunts by transvenous coil embolisation in eight dogs: breed, weight, BSA, IHPSS location and type, stent dimensions, type of catheters and coils, number of coils released in the first and, eventually in the second procedure, and CT scan one year after the PTCE-procedure are reported.

Breed	Weight (Kg)	BSA	CT IHPSS location	IHPSS type	Type of catheter	Stent dimensions (mm)	Type of coils	N° of coils 1[rst] PTCE	N° of coils 2nd PTCE	CT-scan post-PTCE
Bernese shepherd	35	1.07	Left divisional	Ampulla	Cobra; 4Fr	24 × 60	IMVCE-35-10-8	3	2	Done one year after the procedure
Labrador retriever	22	0.79	Right divisional	Ampulla	Simmons; 5Fr	18 × 60	IMVCE-35-10-8	4	–	The owner declined the consent for the sedation
Weimaraner	26	0.88	Right divisional	Ampulla	Simmons; 5Fr	22 × 60	IMVCE-35-10-8	2	2	PTCE procedure too recent
Abruzzese shepherd	21	0.76	Left divisional	Ampulla	Simmons; 5Fr	22 × 60	IMVCE-35-10-8 IMVCE-35-10-5	4	–	The owner declined the consent for the sedation
German shepherd	18	0.69	Right divisional	Tubular	Cobra; 5Fr	16 × 60	IMVCE-35-10-8 IMVCE-35-10-5 IMVCE-35-10-10	7	–	The owner declined the consent for the sedation
Shar-pei	12	0.52	Left divisional	Ampulla	Simmons; 5Fr	18 × 60	IMVCE-35-10-8 IMVCE-35-10-5 IMVCE-35-10-10	4	–	PTCE procedure too recent
Labrador retriever	18	0.69	Left divisional	Ampulla	Simmon; 5Fr	20 × 60	IMVCE-35-10-8 IMVCE-35-10-5 IMVCE-35-10-10	5	–	The owner declined the consent for the sedation
German shepherd	23	0.81	Left divisional	Ampulla	Simmons; 5Fr	22 × 60	IMVCE-35-10-8	2	–	Done one year after the procedure

the delivery catheter, the caval stent release phase and its position and stability inside the vessel, the release phase of the coils and their position inside the vascular abnormality and the residual flow through the shunt.

One of the most important added values of the MIA guide in a PTCE procedure is the great reduction in the fluoroscopy exposure time, using a bubble study to confirm the catheter position inside the IHPSS (Saponaro et al., 2012) instead of portography, thereby ruling out the potential side effects of iodinated contrast agents. The catheter positioning before the release of the caval stent allowed us to avoid the difficult passage through the net of the stent, making the procedure faster due to the easy hook to the junction with the shunt. The stability of the catheter was enhanced by the use of a 0.014″ × 150 cm guide that reduced the catheter's pressure on the stent and the risk of its dislocation.

Placing the catheter before the auto-expandable caval stent dramatically decreases the complication rate by avoiding the serious risk of the coils being released inside the caudal vena cava, and therefore, the potential risk of the coils' migration into the right ventricle and ultimately to the pulmonary artery. An additional value of the herewith study was the introduction of the post-procedure angiography CT as a complementary part of the long-term follow-up that has allowed to document the current status of the liver and the stability of the implanted devices.

The main limitation in this study is the small number of treated dogs and the lack in the long-term follow-up that, at present, prevents the encouraging results obtained in the eight consecutive dogs from inferring that this procedure is preferable to other techniques.

5. Conclusions

The results of the present study strongly suggest that the combination of imaging methods may be a highly advantageous intraoperative guide for a percutaneous coil embolization and the release of stents. The modified PTCE procedure may reduce the risk of a potential complication due to coil migration. Other strengths of this study are the reduction of the fluoroscopy time and the non-use of iodinated contrast agents during the procedure. Based on these advantages, the authors now use this method as their treatment of choice in IHPSS occlusions. Although further studies are required, the MIA-guided modified PTCE has proven to be a promising technique in the interventional IHPSS occlusion procedure.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.rvsc.2015.09.023.

References

Bostwick, D.R., Twedt, D.C., 1995. Intrahepatic and extrahepatic portal venous anomalies in dogs: 52 cases. J. Am. Vet. Med. Assoc. 206, 1181–1185.

Buob, S., Johnston, A.N., Webster, C.R., 2011. Portal hypertension: pathophysiology, diagnosis, and treatment. J. Vet. Intern. Med. 25, 169–186.

Bussadori, R., Bussadori, C., Millan, L., Costilla, S., Rodriguez-Altonaga, J.A., Orden, M.A., Gonzalo-Orden, J.M., 2008. Transvenous coil embolisation for the treatment of single congenital portosystemic shunts in six dogs. Vet. J. 176, 221–226.

D'Anjou, M.A., 2007. The sonographic search for portosystemic shunts. Clin. Tech. Small Anim. Pract. 22, 104–114.

D'Anjou, M.A., Penninck, D., Cornejo, L., Pibarot, P., 2004. Ultrasonographic diagnosis of portosystemic shunting in dogs and cats. Vet. Radiol. Ultrasound 45, 424–437.

Gerritzen-Bruning, M.J., van den Ingh, T.S., Rothuizen, J., 2006. Diagnostic value of fasting plasma ammonia and bile acid concentrations in the identification of portosystemic shunting in dogs. J. Vet. Intern. Med. 20, 13–19.

Gonzalo-Orden, J.M., Altonaga, J.R., Costilla, S., Gonzalo Cordero, J.M., Millan, L., Recio, A.O., 2000. Transvenous coil embolization of an intrahepatic portosystemic shunt in a dog. Vet. Radiol. Ultrasound 41, 516–518.

Henseler, K.P., Pozniak, M.A., Lee Jr., F.T., Winter III, T.C., 2001. Three-dimensional CT angiography of spontaneous portosystemic shunts. Radiographics 21, 691–704.

Holt, D.E., Schelling, C.G., Saunders, H.M., Orsher, R.J., 1995. 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. 207, 1190–1193.

Kummeling, A., Van Sluijs, F.J., Rothuizen, J., 2004. Prognostic implications of the degree of shunt narrowing and of the portal vein diameter in dogs with congenital portosystemic shunts. Vet. Surg. 33, 17–24.

Lamb, C.R., 1996. Ultrasonographic diagnosis of congenital portosystemic shunts in dogs: results in prospective study. Vet. Radiol. Ultrasound 37, 281–288.

Lamb, C.R., Burton, C.A., 2004. Doppler ultrasonographic assessment of closure of the ductus venosus in neonatal Irish wolfhounds. Vet. Rec. 155, 699–701.
Lamb, C.R., White, R.N., 1998. Morphology of congenital intrahepatic portacaval shunts in dogs and cats. Vet. Rec. 142, 55–60.
Paepe, D., Haers, H., Vermote, K., Saunders, J., Risselada, M., Daminet, S., 2007. Portosystemic Shunts in Dogs and Cats: Laboratory Diagnosis of Congenital Portosystemic Shunts Vlaams Diergeneeskundig Tijdschrift 76, 241–248.
Partington, B.P., Partington, C.R., Biller, D.S., Toshach, K., 1993. Transvenous coil embolization for treatment of patent ductus venosus in a dog. J. Am. Vet. Med. Assoc. 202, 281–284.
Rossi, F., Domenech, O., Bussadori, R., Bussadori, C., 2010. Role of multi-modality imaging to guide procedures of transvenous coil embolisation for the treatment of canine intrahepatic porto-systemic shunt. Vet. Radiol. Ultrasound 51, 198-198.
Ruland, K., Fischer, A., Hartmann, K., 2010. Sensitivity and specificity of fasting ammonia and serum bile acids in the diagnosis of portosystemic shunts in dogs and cats. Vet. Clin. Pathol. 39, 57–64.
Saponaro, V., Lacitignola, L., Staffieri, F., Crovace, A., 2012. Intraoperative contrast echocardiography to verify the surgical occlusion of a single extrahepatic portosystemic shunt in a dog. Res. Vet. Sci. 93, 463–465.
Sereda, C.W., Adin, C.A., 2005. Methods of gradual vascular occlusion and their applications in treatment of congenital portosystemic shunts in dogs: a review. Vet. Surg. 34, 83–91.
Snow, S.J., Ari Jutkowitz, L., Brown, A.J., 2010. Trends in plasma transfusion at a veterinary teaching hospital: 308 patients (1996–1998 and 2006–2008). J. Vet. Emerg. Crit. Care 441–445.
van Steenbeek, F.G., van den Bossche, L., Leegwater, P.A., Rothuizen, J., 2012. Inherited liver shunts in dogs elucidate pathways regulating embryonic development and clinical disorders of the portal vein. Mamm. Genome 23, 76–84.
Szatmari, V., Rothuizen, J., van den Ingh, T.S., van Sluijs, F.J., Voorhout, G., 2004a. Ultrasonographic findings in dogs with hyperammonemia: 90 cases (2000–2002). J. Am. Vet. Med. Assoc. 224, 717–727.
Szatmari, V., Rothuizen, J., van Sluijs, F.J., van den Ingh, T.S., Voorhout, G., 2004b. Ultrasonographic evaluation of partially attenuated congenital extrahepatic. Vet. Rec. 155, 448–456.
Weisse, C., Berent, A.C., Todd, K., Solomon, J.A., Cope, C., 2014. Endovascular evaluation and treatment of intrahepatic portosystemic shunts in dogs: 100 cases (2001–2011). J. Am. Vet. Med. Assoc. 244, 78–94.
White, R.N., Burton, C.A., 2000. Anatomy of the patent ductus venosus in the dog. Vet. Rec. 146, 425–429.
Zwingenberger, A., 2009. CT diagnosis of portosystemic shunts. Vet. Clin. N. Am. Small Anim. Pract. 39, 783–792.
Zwingenberger, A.L., Schwarz, T., Saunders, H.M., 2005. Helical computed tomographic angiography of canine portosystemic shunts. Vet. Radiol. Ultrasound 46, 27–32.