Received: 4 September 2020 | Accepted: 2 December 2020

DOI: 10.1111/jvim.15999

STANDARD ARTICLE

Journal of Veterinary Internal Medicine Open Access

ACVIM American College of Veterinary Internal Medicine

Transatrial stenting for long-term management of cardiac tumor obstruction of the right atrium in 3 dogs

Chick Weisse[1] | Brian A. Scansen[2] | Allyson C. Berent[1] | Rick E. Cober[2]

[1]Animal Medical Center, New York, New York

[2]Department of Veterinary Clinical Sciences, The Ohio State University, Columbus, Ohio

Correspondence
Chick Weisse, Animal Medical Center, New York, NY.
Email: chick.weisse@amcny.org

Present address
Brian A. Scansen, Department of Clinical Sciences, Colorado State University, Fort Collins, Colorado

Rick E. Cober, CVCA Cardiac Care for Pets, Annapolis, Maryland

Abstract

Background: Venous obstruction in dogs caused by large intracardiac masses can result in severe morbidity with few safe treatments.

Hypothesis/Objectives: Retrospective study to report results after transatrial stent placement in dogs with naturally occurring cardiac masses causing venous obstruction.

Animals: Three client-owned dogs diagnosed with large cardiac masses.

Methods: Retrospective study of patients that received transatrial stents extending from the caudal vena cava, across the right atrium, and into the cranial vena cava (CrVC). Procedures, complications, and outcomes were recorded based upon medical records, referring veterinarians, and client communications.

Results: Two dogs had similar clinical signs suggestive of congestive hepatopathy including marked ascites and lethargy. One dog had clinical signs of CrVC syndrome including head and neck swelling with pitting edema and pleural effusion. After stent placement, venous pressure gradients were decreased and repeat angiography confirmed that vascular patency was reestablished. Resolution of clinical signs was marked in all 3 dogs with only mild complications including tachyarrhythmias and hypertension in 1 dog during the perioperative period. Two dogs that required additional transatrial stent placement for reobstruction 6 and 14 months later improved after the second stent implantation. Survival times poststenting for the dogs were 3, 21, and 37 months, with cause of death related to the cardiac tumor in all dogs.

Conclusions and Clinical Importance: Endovascular transatrial stenting may provide a long-term palliative treatment option for dogs with clinical signs attributable to tumor-induced venous obstruction when more traditional treatments are declined or not indicated.

KEYWORDS

cardiac, cardiac tumor, interventional radiology, oncology, radiology and diagnostic imaging, stent, surgery, transatrial stent

Abbreviations: CdVC, caudal vena cava; CrVC, cranial vena cava; SEMS, self-expanding metallic stent.

1 | INTRODUCTION

A 9-year-old castrated male Petit Basset Griffon Vendeen dog (dog 1) was evaluated at the Ryan Veterinary Hospital of the University of Pennsylvania because of progressive abdominal distension and lethargy of 3 weeks' duration. Physical examination findings included a body weight of 14.7 kg and tachycardia. The dog had severe abdominal distension, a palpable abdominal fluid wave, no jugular distension or jugular pulses, a grade 2 to 3/6 systolic heart murmur, and generalized muscle wasting.

Pertinent clinicopathologic findings included a low serum total protein concentration (4.7 g/dL; reference range, 5.4-7.1 g/dL) and low serum globulin concentration (2.2 g/dL; reference range, 2.4-4.0 g/dL). Prothrombin and partial thromboplastin times were normal with an increase in D-dimer concentration (1.53 μg/mL; reference range, <0.2 μg/mL) and clumped platelets.

Abdominal ultrasonography identified a large volume of anechoic fluid. Evaluation of a sample obtained during removal of 1.1 L of fluid was consistent with a modified transudate. Thoracic radiography identified soft tissue opacities at the heart base and cranial mediastinum. The caudal vena cava (CdVC) was dilated. No evidence of pulmonary metastatic disease was observed.

Echocardiography identified a 5 × 5 cm hypoechoic mass within the right and left atria and spanning the interatrial septum. The mass extended to the level of the tricuspid valve on short axis views of the heart base, but did not appear to invade the right ventricle. Cranial and CdVC blood flow was laminar around the intracardiac mass. Pericardial effusion was not observed. Given the location and extent of the mass, the most common differential diagnoses included hemangiosarcoma, chemodectoma, and ectopic thyroid tissue. Cardiac magnetic resonance imaging confirmed the presence of a large tumor invading the right atrium and a separate but similar-appearing, nonobstructive mass in the cranial mediastinum consistent with thoracic radiographic findings (Figure 1). Multiple hepatic nodules also were identified.

A diagnosis of congestive hepatopathy was made because of suspected CdVC obstruction by the cardiac mass that had resulted in suspected portal hypertension and severe ascites. The dog was discharged from the hospital with furosemide (Salix, Merck) at a dosage of 0.4 mg/kg PO q12h and spironolactone (Amneal Pharmaceuticals) at 1.7 mg/kg PO q12h.

Two weeks later, the dog was reevaluated after no clinical improvement on the prescribed medications. The owners consented to palliative treatment with a stent to relieve venous obstruction and improve the dog's quality of life because surgical removal or debulking was deemed a poor treatment option because of anticipated morbidity.

The dog was anesthetized using standard hospital protocol. Cefoxitin (Fresenius Kabi USA) was administered at a dosage of 30 mg/kg IV once, followed by 15 mg/kg IV q2h during the operative period. The dog was placed in dorsal recumbency with the neck and right hind limb extended to provide access to the left jugular and right femoral veins in the event rotation into right lateral recumbency would be necessary during the procedure. All manipulations of guide wires, catheters, and stents were performed under fluoroscopic guidance. Percutaneous vascular access of the left external jugular vein was followed by placement of a 12-F vascular introducer sheath (Vascular introducer, Infiniti Medical). A 4-F angled catheter (Berenstein catheter, Infiniti Medical) and guide wire (Weasel wire, Infiniti Medical) combination was advanced through the vascular introducer sheath, into the right atrium, and manipulated past the obstruction into the CdVC. The right femoral vein in the proximal portion of the thigh was isolated by surgical cutdown, and a 10-F vascular introducer sheath (Vascular introducer, Infiniti Medical) was placed. A 4-F angled catheter was advanced over a guide wire into the CdVC, and the guide wire then was removed and replaced with a 10-mm gooseneck snare (Amplatz gooseneck snare, ev3 Endovascular). An exchange-length, 0.035-inch guide wire (Basset wire, Infiniti Medical) was advanced through the jugular catheter and CdVC and through the open gooseneck snare. The snare was closed around the jugular guide wire, and the combination was removed through the femoral sheath, which established through-and-through safety guide wire access from the jugular vein to the femoral vein. A 5-F pigtail marker catheter (Pigtail measuring catheter, Infiniti Medical) was advanced through the femoral sheath, adjacent to the through-and-through safety guide wire, and positioned in the CdVC at the level of the diaphragm.

Contrast angiography was performed by simultaneous injection through the pigtail marker catheter and jugular sheath to determine

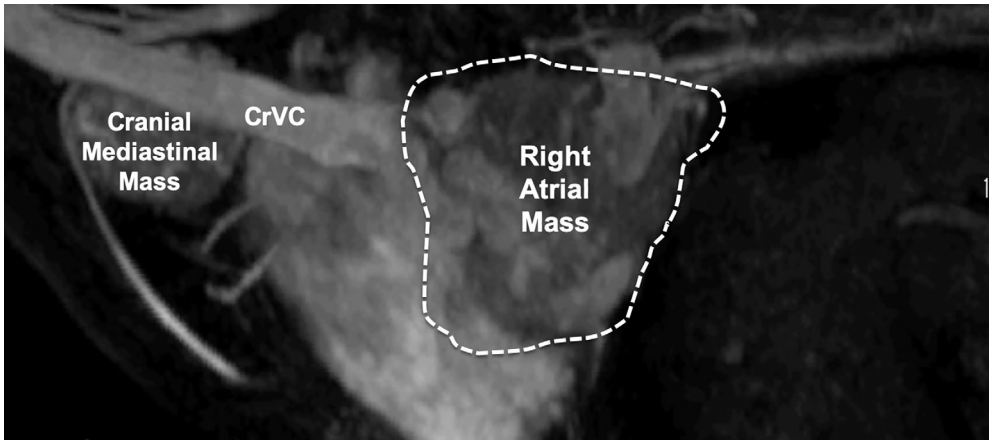

FIGURE 1 Lateral thoracic magnetic resonance angiogram from case 1demonstrating large right atrial mass (white dashed outline) and cranial mediastinal mass. Note the contrast filling of the cranial vena cava (CrVC); however, the venous obstruction of the CdVC has prevented contrast filling of this vessel

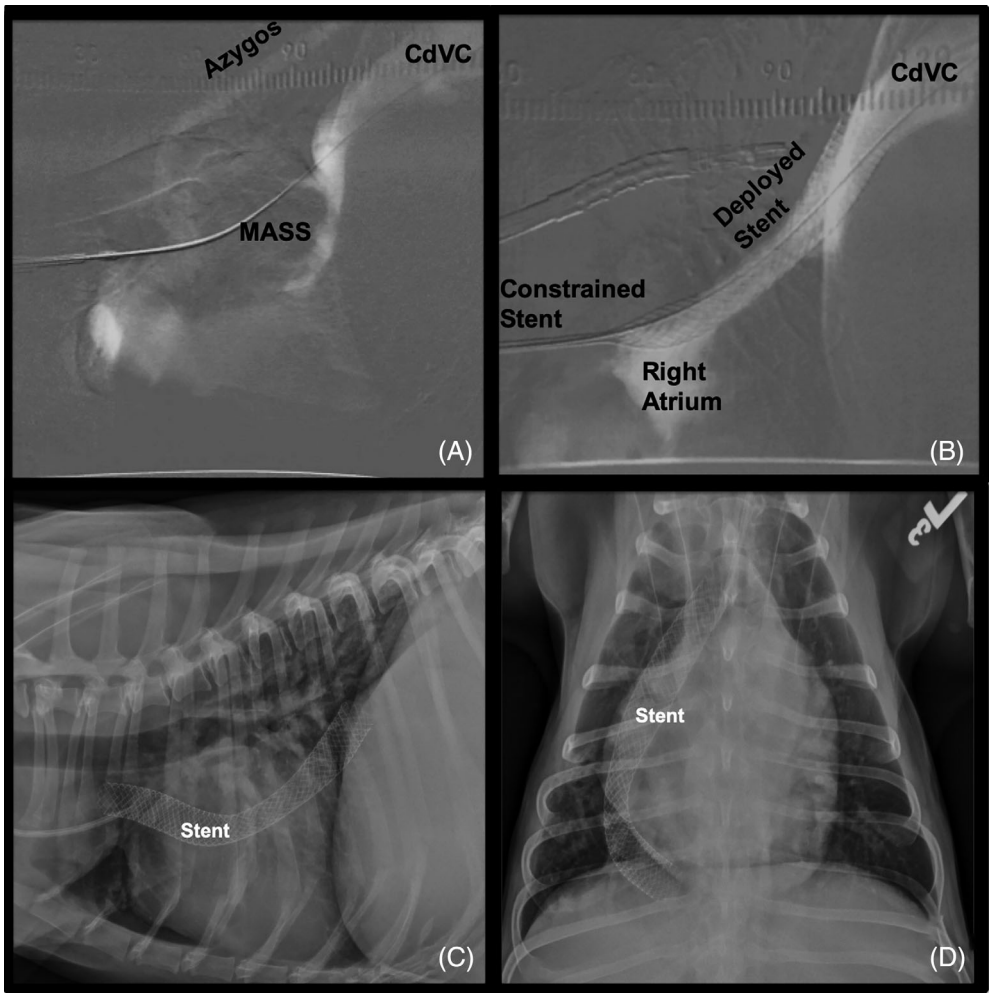

FIGURE 2 Lateral digital subtraction thoracic caudal vena cava (CdVC) venograms (A,B) and lateral (C) and ventrodorsal (D) thoracic radiographs from case 1. A, CdVC venogram demonstrating the right atrial mass (MASS) filling defect extending to the CdVC and right atrium junction. Note the azygous vein providing some decompression of the partially obstructed CdVC. B, CdVC venogram performed after partial deployment of the transatrial stent. The deployed stent has restored venous return with contrast entering the right atrium and the azygous vein is no longer filling with contrast as the obstruction has been relieved. C,D, Post-transatrial stent placement thoracic radiographs demonstrating stent extension from the cranial vena cava, through the right atrium, to the CdVC

the precise location and extent of the cardiac mass in the right atrium. Caudal vena cava contrast drainage was delayed when compared to cranial vena cava (CrVC) drainage. In addition, the CdVC was distended and contrast drained via collaterals into the vertebral venous plexus and subsequently the azygos vein to return blood of the right atrium, cranial to the tumor obstruction (Figure 2A). The pigtail catheter and jugular sheath then were used to measure a venous pressure gradient of 6 mm Hg (8 cmH_2O) between the CrVC and the obstructed CdVC confirming severe venous obstruction.

Diameters of the CrVC and CdVC were extrapolated from angiograms obtained with the marker catheter in place. Stent diameter was selected to be approximately 110% to 120% of the diameter of the measured vessels. Stent length was determined such that the cranial aspect of the stent would fall caudal to the brachiocephalic venous confluence within the CrVC and the caudal aspect of the stent would fall between the right atrium and the diaphragm. A 10-F delivery system containing a 14 mm × 100 mm self-expanding mesh nitinol stent (Vet-Stent trachea, Infiniti Medical) was advanced over the exchange-length safety guide wire and through the jugular vascular sheath until it was in position across the right atrium and the venous obstruction. Positioning of the delivery system was confirmed by repeat angiography. A transesophageal echocardiography system was used to monitor stent position and tumor displacement during deployment. Assisted respiration was temporarily ceased during deployment of the stent and monitored by use of constant fluoroscopic and transesophageal echocardiographic guidance. During stent deployment across the mass, the dog developed atrial fibrillation, tachyarrhythmias, and hypertension that responded to an IV esmolol (Mylan Institutional) bolus (dose not reported) followed by a constant rate infusion. After approximately 75% stent deployment, a repeat contrast venogram via the femoral sheath confirmed restored blood flow and drainage through the decompressed CdVC and stent interstices into the right atrium and ventricle (Figure 2B). Collateral CdVC decompression via the vertebral venous plexus and azygos vein was no longer observed (Figure 2B-D). Stent deployment then was completed, and the delivery system removed over the guide wire. Repeat, poststenting central venous pressures were obtained through the pigtail catheter and jugular sheath and indicated nearly complete resolution of the CrVC and CdVC pressure gradient (actual values not reported in patient record) and near complete resolution of the previous venous obstruction based on repeat angiography.

The femoral vascular sheath was removed, and the femoral vein ligated. The jugular vascular sheath was replaced with a 7-F triple lumen catheter that was secured in place. The dog recovered without

complications, the esmolol was tapered and discontinued overnight, and atenolol (Mylan Pharmaceutical) was administered at 0.4 mg/kg PO q24h, phenoxybenzamine (API Solutions) at 0.17 mg/kg PO q24h, and amoxicillin/clavulanic acid (Clavamox, Zoetis) at 16.7 mg/kg PO q12h for 10 days at discharge 2 days later. Diuretics were discontinued.

Dog 1 was reexamined approximately 7 weeks after stent placement. The owners reported improved appetite, resolution of abdominal distension, and occasional cough. Body weight of 13 kg reflected a loss of 1.4 kg since the procedure, likely a combination of ascites resolution and improving body condition after increased appetite. Repeat laboratory testing indicated resolution of hypoproteinemia (from 4.7 to 6.0 g/dL; reference range, 5.4-7.1 g/dL), hypoglobulinemia (from 2.2 to 2.7 g/dL; reference range, 2.4-4.0 g/dL), and hypoalbuminemia (from 2.5 to 3.3 g/dL; reference range, 2.5-3.7 g/dL). The dog had no clinical signs for approximately 14 months. At that time, the dog was examined for abdominal distension suggestive of tumor ingrowth into (or beyond) the stent, vascular thrombosis, or worsening heart failure. Repeat catheterization confirmed tumor ingrowth, vascular obstruction, and an increased venous pressure gradient (values not recorded). Restenting (within the first stent) using another 14 mm × 100 mm self-expanding, mesh nitinol stent placed through the jugular sheath again relieved the obstruction. The dog recovered uneventfully, and ascites resolved.

Approximately 7 months later (21 months after the first stent procedure), the dog was euthanized for progressive lethargy, anorexia, and coughing. Necropsy was performed and disclosed large volume abdominal, pleural and pericardial effusions, a large cardiac mass for which histological and immunohistochemical evaluations were inconclusive for neuroendocrine tumor, multifocal cranial mediastinal carcinoma metastases with histomorphological features suggestive of

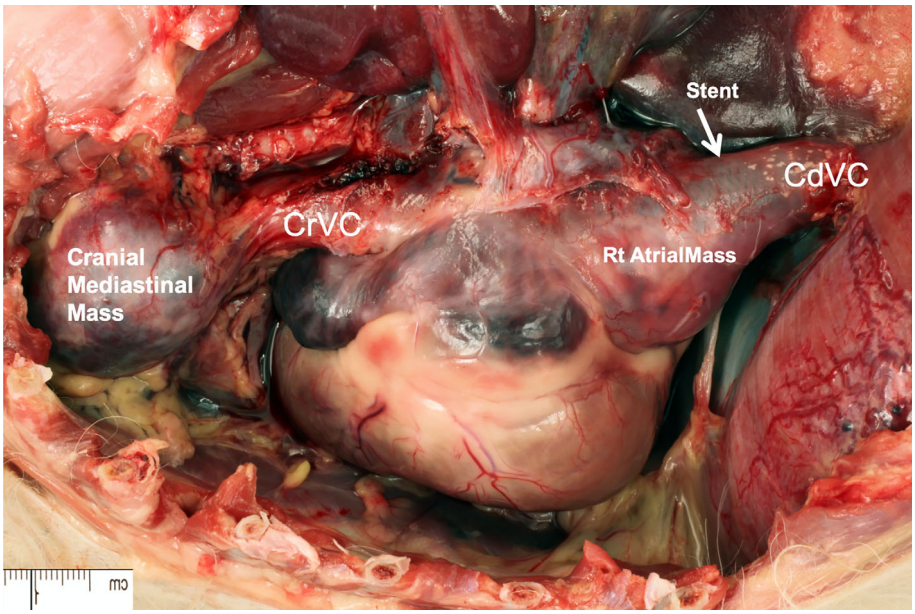

FIGURE 3 Autopsy image from case 1 approximately 21 months after initial stent placement in a left lateral thoracic perspective demonstrating the 2 masses as well as a stent visible in situ within the caudal vena cava (CdVC)

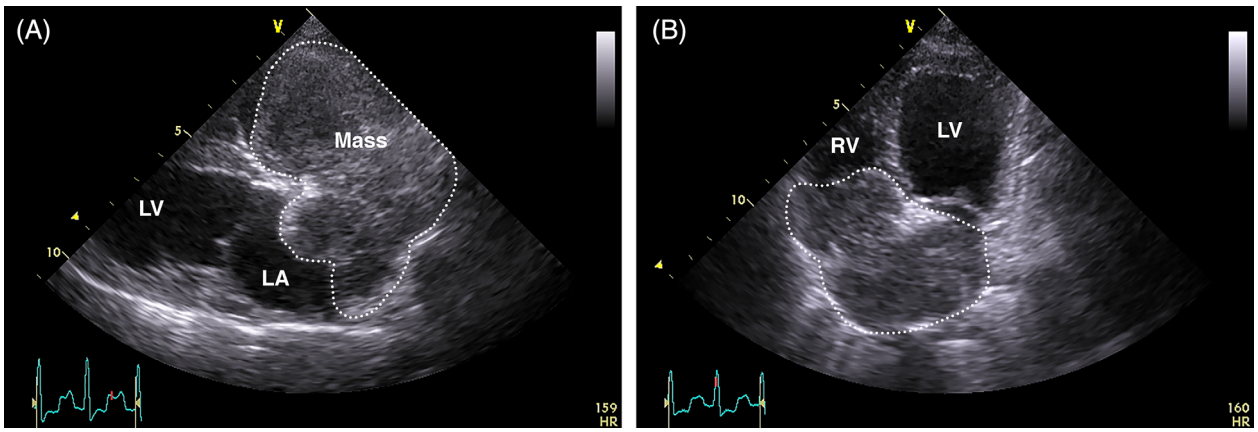

FIGURE 4 Transthoracic echocardiographic images from case 2. Imaging from a right parasternal 4-chamber (A) and apical 4-chamber (B) view demonstrated a large, echogenic mass (dotted outline) filling nearly the entire right atrial chamber with deviation of the interatrial septum and likely extension of the mass to the left atrium (LA). LV, left ventricle; RV, right ventricle

ectopic thyroid carcinoma (positive staining for thyroid markers), and no other evidence of distant metastases. Although the histopathology and special stains were inconclusive, the tachyarrhythmias and hypertension experienced during manipulation of the tumor while deploying the stent were suggestive of a functional paraganglioma. Tumor ingrowth into the stent had occurred and a catheter could not easily be passed through the lumen, suggesting recurrent malignant vascular obstruction (Figure 3).

A 7-year-old, 29.6 kg male castrated Australian Shepherd dog (dog 2) presented to the Internal Medicine Service of The Ohio State University Veterinary Medical Center for refractory ascites. The ascites had been present for 2 months and was reported to be nonresponsive to diuretic treatment. Physical examination identified marked abdominal distension with a palpable fluid wave and mild jugular pulsation at the thoracic inlet. Results of a CBC and serum biochemical profile were unremarkable. Abdominal ultrasonography identified severe ascites with CdVC and hepatic venous dilatation. Fluid analysis of the abdominal effusion was compatible with a modified transudate. Echocardiography (Figure 4) disclosed a mixed echogenic mass occluding the right atrial lumen and displacing the atrial septum to the left. Acquired tricuspid stenosis was observed and the parietal tricuspid valve leaflet appeared thickened consistent with either thrombus or extension of the atrial mass. Medical treatment was initiated with furosemide at a dosage of 1.7 mg/kg PO q12h, spironolactone at 0.83 mg/kg PO q12h, and enalapril (Oceanside Pharmaceuticals) at 0.3 mg/kg PO q12h.

Venotomy of the right external jugular vein was performed and a 7-Fr biopsy forceps (Cup biopsy forceps, Cook Medical) advanced under fluoroscopic guidance and used to obtain a biopsy specimen of the luminal right atrial mass. Well-differentiated cardiac myocytes and adipose tissue with small quantities of fibrous connective tissue were observed on histopathology and interpreted as nondiagnostic with no evidence of neoplasia. At the time of biopsy, venography was performed to estimate caval diameters, with the CrVC measured at approximately 14 mm and the CdVC at approximately 18 mm. The length required to span the atrium was estimated at 120 mm. Over the next 2 months, weekly abdominocentesis (approximately 5 L per visit) was required to control abdominal fluid accumulation. Two months after initial presentation, transatrial stenting was performed in a manner similar to that described for dog 1. The venous pressure gradient was 7 mm Hg (4 mm Hg in the CrVC, 11 mm Hg in the CdVC). Venography identified a large filling defect in the right atrium, obstructing CdVC return. A custom-made woven nitinol stent (Vetstent-Trachea, Infiniti Medical) measuring 20 mm × 113 mm was advanced from the left jugular vein access site and deployed from the CdVC, through the right atrial lumen, and into the CrVC. Follow-up venography showed improved CdVC return. The dog was discharged 2 days postoperatively after an uneventful recovery. Home treatment consisted of the previous furosemide, spironolactone, and enalapril; additionally administered medications included tramadol (Sun Pharmaceuticals) at a dosage of 1.7 mg/kg PO q12h and amoxicillin/clavulanic acid at 12.5 mg/kg PO qh12.

The dog was reexamined 5 days after the stent procedure for vomiting, lethargy, panting, and inappetence. Physical examination disclosed a regular heart rate of 180/min, body temperature of 103.3 F, and severe peritoneal effusion. A CBC disclosed a left shift with band neutrophils of 2.4×10^3/L (27%), and toxic changes in leukocyte morphology. Cytology of the effusion showed 67% neutrophils, 32% monocytes, and 1% lymphocytes, consistent with moderate mixed inflammation. Bacterial culture of the abdominal

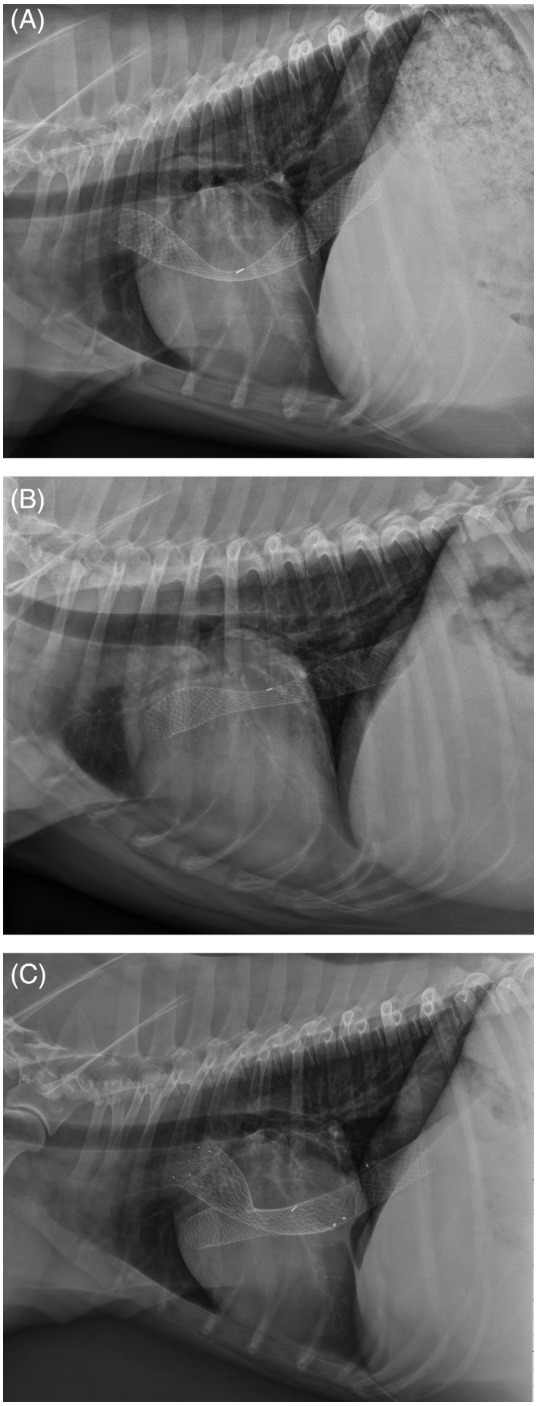

FIGURE 5 Thoracic radiographs from case 2 at 1 day post stent implantation (A), 4 months post stent implantation showing migration of the cranial aspect of the stent into the right auricle (B), and 13 months after initial stenting (7 months after the second stent implantation) showing position of the second stent

effusion was negative. Sterile peritonitis was suspected and enrofloxacin (Baytril, Bayer Animal Health) was administered prophylactically at a dosage of 8.3 mg/kg IV q24h, cerenia (Zoetis) at 0.83 mg/kg SQ q24h, and IV fluids. Tachycardia persisted throughout hospitalization and was interpreted as a focal atrial tachycardia. Digoxin (Hikma Pharmaceuticals) at a dosage of 0.004 mg/kg PO q12h and diltiazem (Hikma Pharmaceuticals) at 1 mg/kg PO q8h were administered for the atrial arrhythmia. The dog was discharged 2 days after presentation on furosemide 2.7 mg/kg PO q8h, spironolactone 0.83 mg/kg PO q12h, enalapril 0.33 mg/kg PO q12h, amoxicillin/clavulanic acid 12.5 mg/kg PO q12h, enrofloxacin 4.5 mg/kg PO q24h, diltiazem 1 mg/kg, PO q8h, and digoxin 0.004 mg/kg PO q12h.

At reevaluation 2 weeks after stent implantation, ascites was completely resolved, the CBC was normal, and the heart was in normal sinus rhythm with first degree atrioventricular block and rare premature atrial complexes. Furosemide was gradually tapered and discontinued 1 month after stent implantation. Follow-up examinations over the next 5 months were unremarkable, but 5.5 months after stent implantation ascites began to reaccumulate. Radiographs at that time identified migration of the cranial aspect of the stent into the right auricle (Figure 5). Six months after stent implantation, cardiac catheterization again was performed in a manner comparable to the first procedure; CdVC venography showed narrowing of the contrast through the prior stent with compressed stent diameter measured at 8 mm and a pressure gradient was identified from the cranial right atrium (10 mm Hg) to the CdVC (13 mm Hg). Balloon dilatation of the compressed region of the original stent was attempted using an 18 mm × 4 cm balloon dilatation catheter (Tyshak balloon dilatation catheter, Numed), but the stent lumen returned to 8 mm diameter after balloon dilatation. Percutaneous access to the right jugular vein then was obtained using an 11-Fr sheath (Pinnacle, Terumo) and a second stent (a laser-cut, self-expanding nitinol stent [Vet stent-Cava, Infiniti Medical] measuring 26 mm diameter by 80 mm length) was implanted from the jugular access site over a guidewire directed through the interstices of the first stent to recapture position within the CrVC because the cranial aspect of the original stent could not be catheterized because of migration into the right auricle.

A mild decrease in ascites accumulation was noted after the second stent procedure, but intermittent abdominocentesis was required. Adjustments in diuretic treatment were made on a monthly to bimonthly basis over the next 2.5 years, with abdominocentesis required every 2 to 4 months. The dog's quality of life remained good with progressive increases in the dose of diuretic required to control abdominal fluid accumulation. Atrial fibrillation developed 15 months after the second stent implantation. The dog was euthanized 37 months after initial presentation because of lethargy and inappetence. On necropsy, the right atrial lumen was distended by a tan, nodular mass comprising >90% of the atrial volume (Figure 6). The mass obstructed the tricuspid orifice and caval entrances and displaced the atrial septum to the left, compromising left atrial volume. The stents were unchanged in position with a patent lumen and open interstices at the cranial aspect of the right atrium and CrVC junction. Areas of endothelialization were observed around the stent, particularly at contact points among the atrium, mass and vein, which may have partially impaired flow through the stent interstices. Histologically, the mass was compatible with a paraganglioma, staining positive for synaptophysin and chromogranin A.

A 9-year-old castrated male Beagle (dog 3) was examined at the Animal Medical Center Interventional Radiology service for head and neck swelling and edema. The dog had a previous history of well-controlled diabetes mellitus managed with 0.65 U/kg Humulin insulin (Novolin H, Novo Nordisk) SC q12h. Physical examination findings included body weight of 10 kg, head and neck swelling with pitting edema, decreased lung sounds, tachypnea (40 breaths per minute), and a grade 2/6 systolic heart murmur.

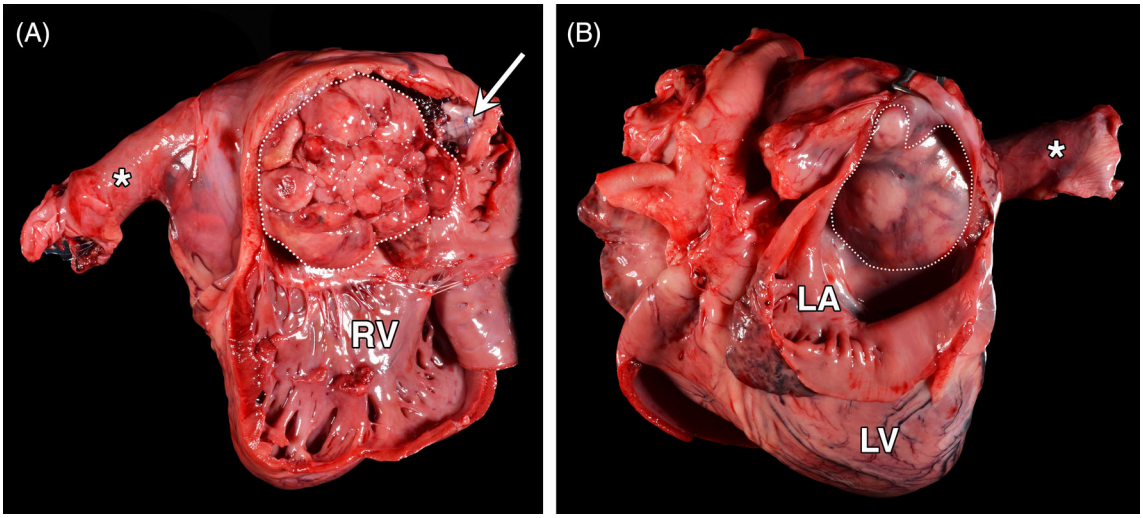

FIGURE 6 Necropsy images from case 2. The opened right atrial perspective (A) shows a large, expansile mass (dotted outline) filling the right atrial lumen and obstructing the tricuspid valve orifice. The wireframe of the stent can be seen at the CdVC (*) and also at the right auricle (arrow). From the left atrial perspective (B), the mass (dotted outline) can be seen deviating the interatrial septum but was not invasive to the left atrium (LA). LV, left ventricle; RV, right ventricle

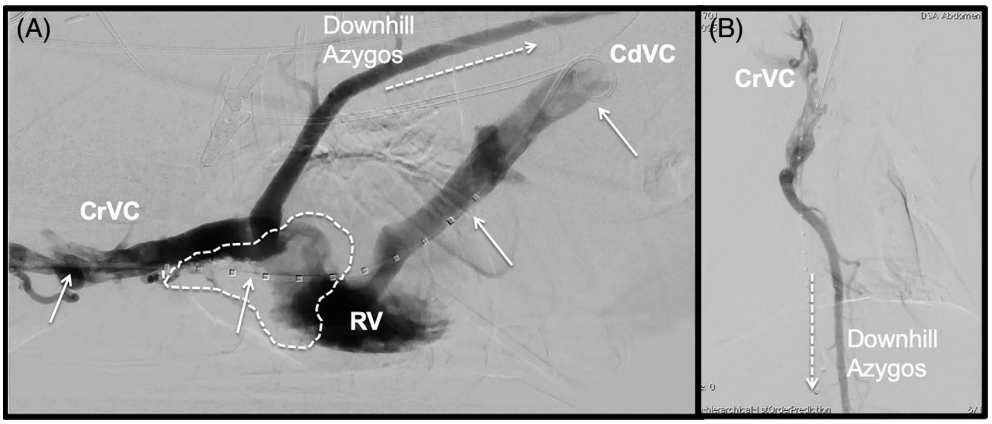

FIGURE 7 A, Lateral and, B, ventrodorsal digital subtraction thoracic venograms before transatrial stent placement from case 3. A, Dual caudal vena cava (CdVC) and cranial vena cava (CrVC) venograms through a marker catheter (white arrows) and the jugular sheath (not visualized) demonstrating a filling defect from the tumor (white dashed outline) in the right atrium. The CdVC is patent, however, the CrVC is distended with collateral vessel reflux as well as reverse flow down the azygous vein ("Downhill azygous vein"). B, Ventrodorsal digital subtraction CrVC venogram demonstrating downhill azygous vein flow because of the CrVC tumor obstruction at the level of the CrVC and right atrial junction

Echocardiography identified a mass obstructing the CrVC and right atrium. Thoracic radiography disclosed no obvious pulmonary metastases, moderate pleural effusion, and elevation of the trachea at the level of the cranial mediastinum. Thoracocentesis of 225 mL modified transudate fluid improved tachypnea and had a triglyceride concentration of 30 mg/dL, with no evidence of neoplastic cells on cytology. Thoracic computed tomography identified a large heart base mass (6 × 5.5 × 5.3 cm) with strong contrast enhancement, displacing the CrVC to the right and causing severe compression at the level of the right atrium. A moderate volume of fluid was detected in the dependent portion of the thorax and several small (approximately 3 mm) soft tissue nodules were present throughout the lungs. Fine-needle aspiration of the cardiac mass yielded epithelial cells with minimal atypia consistent with a chemodectoma.

The patient was anesthetized and placed in dorsal recumbency. Percutaneous right jugular vascular access was obtained and a 12-Fr vascular introducer sheath placed. Serial angiography of the CrVC showed slow contrast drainage, a filling defect at the level of the cranial aspect of the right atrium, reverse blood flow in the azygos vein, and multiple small venous collateral vessels decompressing the distended CrVC (Figure 7). The CdVC had normal venous drainage. A transatrial 14 mm × 85 mm self-expanding metallic stent (SEMS) (Vetstent-Trachea, Infiniti Medical) was placed without complications based upon calibrated measurements made during angiography and was followed by bradycardia (heart rate not recorded in record). The venous pressure gradient obtained before stent placement (gradient, 6 mm Hg; CrVC, 13 mm Hg; CdVC, 7 mm Hg) was decreased immediately after stent placement (gradient, 1 mm Hg; CrVC, 11 mm Hg; CdVC, 10 mm Hg). Repeat angiography identified resolution of the CrVC obstruction, improved venous drainage, and return of normal (caudal to cranial) azygos vein blood flow (Figure 8). The introducer sheath was exchanged for a triple-lumen catheter and the patient recovered with only mild bleeding from the vascular sheath site. Procedure time was 90 minutes. The patient was discharged 2 days later

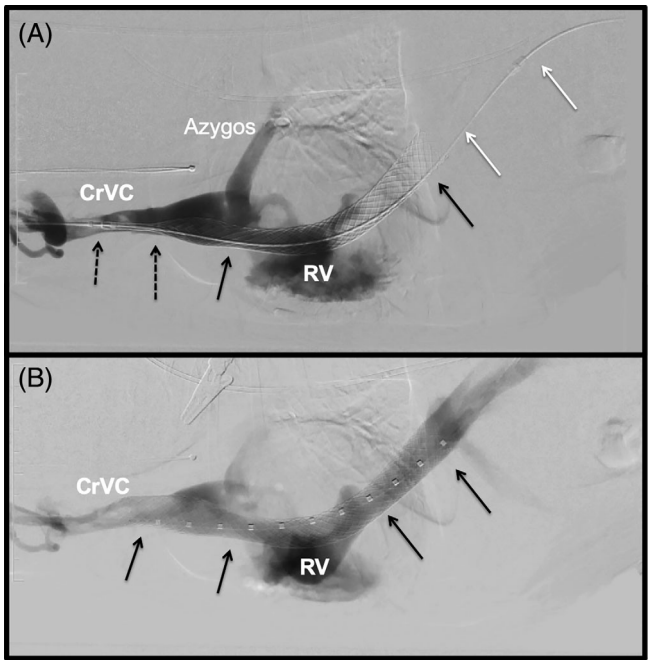

FIGURE 8 Lateral thoracic digital subtraction venograms pre (A) and post (B) transatrial stent placement from case 3. A, Cranial vena cava (CrVC) venogram after partial transatrial stent deployment over a guidewire (white arrows). The deployed stent (black arrows) has restored CrVC patency as demonstrated by the contrast flow into the right atrium and ventricle (RV) with only minimal reflux in the azygous vein. The proximal end of the stent is still constrained (black dashed arrows) within the delivery system. B, Dual CrVC and CdVC venograms after complete stent (black arrows) deployment demonstrating accurate stent placement and restored CrVC patency

on amoxicillin/clavulanic acid at a dosage of 12.5 mg/kg PO q12h for 14 days and instructions to continue previous insulin treatment.

Head and neck swelling resolved over the next few days. Examination 6 days postoperatively showed that the head and neck swelling

and pleural effusion had resolved. The dog weighed 7.8 kg, which was 2.2 kg less than before transatrial stenting. Toceranib (Palladia, Zoetis) at a dosage of 2.5 mg/kg PO q48h, cerenia at 2 mg/kg as needed, metronidazole (Covetrus) at 16 mg/kg PO q12h as needed, and famotidine (Pepcid AC, Fresenius Kabi USA) at 1.3 mg/kg PO q24h were prescribed.

The dog was presented dead-on-arrival to the emergency service 169 days after stenting. The dog had collapsed and had what appeared to be a convulsion according to the owner. No ascites or head swelling was present at the time of death and the stent was patent upon on necropsy examination. Marked hepatomegaly suggestive of right-sided heart failure was present as well as tumor infiltration into the right and left atria, the right ventricle, the epicardial surface, and pericardial space, resulting in a mass effect and pericardial hemorrhage.

2 | DISCUSSION

Three dogs were presented with large, nonresectable intracardiac masses obstructing venous return to the right atrium. Venous return to the heart was severely decreased, leading to congestion and subsequent ascites (dogs 1 and 2) or head swelling and pleural effusion (dog 3). Central venous obstruction can have marked systemic effects because of decreased cardiac output and venous congestion. In the first 2 cases, marked ascites and lack of identifiable intra-abdominal disease suggested congestive hepatopathy or other type of hepatic venous outflow obstruction.[1] Budd-Chiari Syndrome, as originally described, refers to primary obstruction of the hepatic veins, but some degree of CdVC obstruction typically is present.[2-4] The other 2 components of hepatic venous outflow obstructions include veno-occlusive disease characterized by obstruction at the level of the sinusoids and terminal venules, and congestive hepatopathy, defined as venous obstruction at the level of the heart.[3,4] In dogs 1 and 2, obstruction of CdVC blood flow at the level of the right atrium resulted in hepatic congestion, portal hypertension, and subsequent ascites and thus would be consistent with congestive hepatopathy. Hind limb edema was not apparent in these 2 dogs because the canine CdVC seems to easily develop systemic venous collateral circulation when obstruction is chronic. The canine portal system does not establish collateral circulation as readily, and intrahepatic venous hypertension leads to increased hydrostatic pressure and development of a modified transudative abdominal effusion. Although the azygos vein permits decompression of the obstructed CdVC via lumbar veins and the vertebral venous plexus, the size of this vessel often is insufficient to provide complete relief of venous congestion. The location of the venous obstruction also leads to increased CdVC pressures, which may explain the lack of acquired portosystemic shunts that presumably would develop to relieve chronically increased portal venous pressure. Because CdVC pressures are increased in addition to portal venous pressure, there does not seem to be an increasing pressure gradient that would favor collaterals to develop. This situation has occurred in other dogs with Budd-Chiari syndrome.[1]

Dog 3 presented with head and neck swelling and pleural effusion, consistent with CrVC syndrome.[5-7] Cranial vena cava syndrome results from obstruction of blood flow secondary to extrinsic compression or intrinsic occlusion from tumors, thrombosis, or heartworms.[5] The severity of clinical signs depends upon the completeness and duration of the obstruction and the adequacy of collateral venous drainage; chronic obstructions provide more time for collateral circulation to develop and relieve venous hypertension. Occlusion of the superior vena cava in humans necessitates collateral venous drainage to develop, likely through some combination of communications among the internal mammary, lateral thoracic, vertebral, and esophageal veins with the azygos vein or inferior vena cava; similar collaterals likely develop in dogs.[8-10] Experimentally, ligation of the CrVC cranial to the azygos vein in dogs leads to chylothorax in approximately 50% to 70% of cases.[6,7] It is unclear why some dogs have the ability to tolerate this obstruction and others do not; the difference likely is explained by available collateral circulation. Interestingly, dog 3 experienced at least partial relief of venous congestion by reverse blood flow through the azygos vein (so-called "downhill azygos vein") into the vertebral venous plexus and lumbar veins and then into the CdVC. After ligation of the superior vena cava in humans, the azygos vein has been shown to reverse blood flow direction.[8] Reverse azygos blood flow observed in dog 3 has not been reported previously in dogs. Although the azygos vein routinely is sacrificed during thoracic surgery in humans thoracic surgery[8] and occasionally in dogs, consideration should be given before sacrificing this vessel, especially if venous drainage from the head, neck or forelimbs may be of concern in the future. En bloc ligation of the thoracic duct (including the azygos vein) has been considered for surgical management of idiopathic chylothorax in dogs.[11] Because the azygos vein can provide decompression of obstructed lymphatics, ligation of this vessel may have beneficial or deleterious effects in different cases and should be studied more carefully before routinely being ligated. We were surprised by the partial decompression of CdVC obstruction provided by the azygos vein, as well as the reverse ("downhill") drainage by the azygos vein to decompress CrVC obstructions, in these 3 dogs.

Cardiac tumors ultimately were the cause of the obstructions in all 3 dogs. The most common cardiac tumors in dogs are hemangiosarcoma, chemodectoma, and ectopic thyroid tissue.[12,13] The tachyarrhythmias and hypertension experienced in dog 1 were suggestive of a possible nonadrenal pheochromocytoma or paraganglioma. Paraganglion cells are located in the atrium, and these tumors affecting these cells have been described previously in dogs.[14,15] When functional, these tumors are called nonadrenal pheochromocytomas or chromaffin (positive) paragangliomas (in the region of the atria). When the tumors are nonfunctional, chromaffin-negative, and located in the region of the aortic body, they are referred to as chemodectomas.[14] Although the histopathology and special staining of the cardiac tumor in dog 1 was inconclusive, the tachyarrhythmias and hypertension experienced during manipulation of the tumor while deploying the stent were suggestive of a functional paraganglioma. Dog 1 also had a concurrent cranial mediastinal ectopic thyroid carcinoma. It was unclear if this was a second primary tumor or related to the heart-based mass. Because of the often slow-growing nature of neuroendocrine tumors, these patients can have prolonged survival with palliative treatments such as venous stenting. Understanding the potentially functional

nature of these tumors should alert the clinician to provide preoperative alpha blockade in these patients, which has been shown to decrease morbidity and mortality rates in both humans and animals with similar tumors.[16,17]

Palliative stenting of malignant vascular obstructions of the CdVC was first described in humans in 1992.[18] Since that time, numerous reports of endovascular stenting for both benign and malignant vascular obstructions in humans followed.[19,20] Concerns about the cardiac location and proximity of these obstructions to the tricuspid valve have raised concerns about potential stent migration or malpositioning, as well as development of intractable arrhythmias. Other potential concerns include impaired cardiac venous return through the stent interstices, cardiac perforation,[21] aorta-right atrium fistula formation,[22] or hemolysis.[23] Successful transatrial stent placement in 2 humans with extension of cardiac tumor thrombus from hepatocellular carcinoma was reported in 2003.[24] Both human patients presented with Budd-Chiari Syndrome characterized by ascites and extensive lower extremity edema; both received transatrial stents among other treatments, and clinical signs improved until death 1 and 3 months later. It was concluded that transatrial stent placement was well tolerated and successful at improving the clinical signs associated with venous obstruction during the short-term follow-up in these 2 patients. The success reported in human patients led us to offer this procedure to the owner of dog 1 when more traditional treatment options were declined because of associated risk and invasiveness. Successful endovascular stenting for Budd-Chiari syndrome in 3 dogs has also been reported, which further supported stenting as a potentially viable palliation in these patients.[1]

In general, endovascular stents should be oversized by approximately 0% to 20% of the maximal diameter of the native human vessels being stented so as to provide sufficient apposition and minimize migration.[20,25,26] Transatrial stents are less likely to migrate because of positioning across the atrium with blood flow in 2 opposing directions. There is no place for the stent to migrate as long as it remains above the tricuspid valve and does not fall into the ventricle. One stent in dog 2 did migrate into the right atrial appendage, likely because of insufficient contact with the CrVC. We avoided this issue in subsequent cases by interlocking 2 or 3 stents in series from CdVC to CrVC, if necessary.[27,28] This experience reinforces the idea that sufficient stent length within both the CrVC and CdVC is necessary to provide stability. Substantial contact with the CrVC and CdVC should be the goal to prevent migration into the atrium because stent expansion often is difficult to anticipate during stent deployment. We recommend as much stent-to-vessel wall contact as possible without extending into either brachiocephalic vein. Extension of the stent across hepatic veins does not seem to cause any morbidity. Recent reports of endovascular stents in this location suggest they are well tolerated in dogs over the long term.[1,29]

The large SEMS chosen in these dogs had relatively wide interstices to permit sufficient blood flow and not impair venous return. Although cardiac output was not challenged in any of these patients, resolution of the ascites and edema and return to normal prestenting functional activity suggests that reasonable venous return and cardiac output were maintained in 2 patients and improved in the other dog that still required periodic abdominocentesis. These concerns were further challenged when 2 of the dogs required additional stents to be placed within the first transatrial stent. Clinical signs improved in both patients after placement of the second stents, suggesting sufficient blood flow still was maintained. In the transatrial stent placement cited previously in a human, overlapping stents were used initially, further supporting that 2 layers of stents permit adequate cardiac venous return.[24] Pressure gradients decreased after placement of additional stents, suggesting sufficient flow through stents as well. Neointimal formation across the stent interstices was apparent on necropsy, but was observed to be minimal and primarily associated with contact points. Potential restenting should be discussed with clients before the initial procedure.

Thrombosis or tumor embolism was not a substantial problem in any of these cases. Perioperative and postoperative anticoagulation were not used in these dogs although it is routinely recommended in humans undergoing endovascular stenting, particularly for venous obstructions complicated by associated thrombosis.[30] Because endovascular stent placement has not been associated subsequent thrombosis in our experience, anticoagulation was not carried out.

We evaluated 3 cases of venous obstruction in dogs associated with large cardiac masses. In all cases, stent placement was successful and resolution of ascites or head swelling and pleural effusion was achieved. Two dogs required additional stent placement for partial stent occlusion. In both cases, restenting resulted in ascites resolution or substantial reduction, suggesting overlapping of open stents did not prevent blood flow through the interstices. Transatrial stents may be a safer alternative to leaving stent free ends within the atrium and may prevent stent migration into the ventricle. Transatrial stenting may be considered for similar patients when traditional treatment options are declined or are deemed to be associated with excessive morbidity or mortality, but careful monitoring is necessary to evaluate for stent occlusion. Relatively long-term palliation (>3 months) was possible using this technique.

ACKNOWLEDGMENT

No funding was received for this study.

CONFLICT OF INTEREST DECLARATION

Drs Weisse and Berent are consultants (and Dr Weisse is a minority shareholder) for Infiniti Medical, a veterinary medical device company that makes interventional radiology equipment for veterinary patients. None of the techniques described in the manuscript are unique to Infiniti Medical products.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

ORCID

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

Brian A. Scansen https://orcid.org/0000-0001-7427-2402

REFERENCES

1. Schlicksup MD, Weisse C, Berent A, et al. Use of endovascular stents in three dogs with Budd-Chiari syndrome. *J Am Vet Med Assoc*. 2009; 235:544-550.
2. Aydinli M, Bayraktar Y. Budd-Chiari syndrome: etiology, pathogenesis and diagnosis. *World J Gastroenterol*. 2007;13:2693-2696.
3. Okuda K, Kage M, Shrestha SM. Proposal of a new nomenclature for Budd-Chiari syndrome: hepatic vein thrombosis versus thrombosis of the inferior vena cava at its hepatic portion. *Hepatology*. 1998;28: 1191-1198.
4. Bayraktar UD, Seren S, Bayraktar Y. Hepatic venous outflow obstruction: three similar syndromes. *World J Gastroenterol*. 2007;13:1912-1927.
5. Nicastro A, Cote E. Cranial vena cava syndrome. *Compend Contin Educ Pract Vet*. 2002;24:701-710.
6. Fossum TW, Birchard SJ. Lymphangiographic evaluation of experimentally induced chylothorax after ligation of the cranial vena cava in dogs. *Am J Vet Res*. 1986;47:967-971.
7. Blalock A, Cunningham RS, Robinson CS. Experimental production of chylothorax by occlusion of the superior vena cava. *Ann Surg*. 1936; 104:359-364.
8. Sukigara M, Takamoto S, Omoto R. Downhill azygos vein secondary to occlusion of the superior vena cava in Behcet's disease. *Chest*. 1988;94:1308-1309.
9. Johnson LS, Kinner DG, Brown RA, et al. Downhill esophageal varices. *Arch Surg*. 1978;113:1463-1464.
10. Felson B, Lessure AP. Downhill varices of the esophagus. *Dis Chest*. 1964;46:740-746.
11. Macdonald NJ, Noble PM, Burrow RD. Efficacy of en bloc ligation of the thoracic duct: descriptive study in 14 dogs. *Vet Surg*. 2008;37: 696-701.
12. Treggiari E, Pedro B, Dukes-McEwan J, Gelzer AR, Blackwood L. A descriptive review of cardiac tumours in dogs and cats. *Vet Comp Oncol*. 2017;15(2):273-288.
13. Rajagopalan V, Jesty SA, Craig LE, Gompf R. Comparison of presumptive echocardiographic and definitive diagnoses of cardiac tumors in dogs. *J Vet Intern Med*. 2013;27(5):1092-1096.
14. Way AC, Moore FM. Right atrial chromaffin paraganglioma in a dog. *J Vet Cardiol*. 2012;14:459-464.
15. Buchanan JW, Boggs S, Dewan S, et al. Left atrial paraganglioma in a dog: echocardiography, surgery, and scintigraphy. *J Vet Int Med*. 1998;12(2):109-115.
16. Lebuffe G, Dosseh ED, Tek G, et al. The effect of calcium channel blockers on outcome following the surgical treatment of phaeochromocytomas and paragangliomas. *Anaesthesia*. 2005;60: 439-444.
17. Herrera MA, Mehl ML, Kass PH, Pascoe PJ, Feldman EC, Nelson RW. Predictive factors and the effect of phenoxybenzamine on outcome in dogs undergoing adrenalectomy for pheochromocytoma. *J Vet Intern Med*. 2008;22:1333-1339.
18. Irving JD, Dondelinger RF, Reidy JF, et al. Gianturco self-expanding stents: clinical experience in the vena cava and large veins. *Cardiovasc Intervent Radiol*. 1992;15:328-333.
19. Brewster DC, Athanasoulis CA, Darling RC. Leiomyosarcoma of the inferior vena cava. *Arch Surg*. 1976;111:1081-1085.
20. Oudkerk M, Heystraten FM, Stoter G. Stenting in malignant vena caval obstruction. *Cancer*. 1993;71:142-146.
21. Prahlow JA, O'Bryant TJ, Barnard JJ. Cardiac perforation due to Wallstent embolization: a fatal complication of the transjugular intrahepatic portosystemic shunt procedure. *Radiology*. 1997;205: 170-172.
22. Sehgal M, Brown DB, Picus D. Aortoatrial fistula complicating transjugular intrahepatic portosystemic shunt by protrusion of a stent into the right atrium: radiologic/pathologic correlation. *J Vasc Interv Radiol*. 2002;13(4):409-412.
23. Van Israel N, French AT, Wotton PR, et al. Hemolysis associated with patent ductus arteriosus coil embolization in a dog. *J Vet Intern Med*. 2001;15:153-156.
24. Wallace MJ. Transatrial stent placement for treatment of inferior vena cava obstruction secondary to extension of intracardiac tumor thrombus from hepatocellular carcinoma. *J Vasc Interv Radiol*. 2003; 14:1339-1343.
25. Brountzos EN, Binkert CA, Panagiotou IE, Petersen BD, Timmermans H, Lakin PC. Clinical outcome after intrahepatic venous stent placement for malignant inferior vena cava syndrome. *Cardiovasc Intervent Radiol*. 2004;27:129-136.
26. Raju S, Hollis K, Neglen P. Obstructive lesions of the inferior vena cava: clinical features and endovenous treatment. *J Vasc Surg*. 2006; 44:820-827.
27. Scansen BA. Interventional cardiology: what's new? *Vet Clin North Am Small Anim Pract*. 2017;47(5):1021-1040.
28. Dunn M, Scansen BA. Interventional radiology management of vascular obstruction. *Vet Clin North Am Small Anim Pract*. 2018;48(5):819-841.
29. Weisse C, Berent A, Todd K, et al. Endovascular evaluation and treatment of intrahepatic portosystemic shunts in dogs: 100 cases (2001-2011). *J Am Vet Med Assoc*. 2014;244:78-94.
30. Klein AS. Management of Budd-Chiari syndrome. *Liver Transpl*. 2006; 12(suppl 2):23-28.

How to cite this article: Weisse C, Scansen BA, Berent AC, Cober RE. Transatrial stenting for long-term management of cardiac tumor obstruction of the right atrium in 3 dogs. *J Vet Intern Med*. 2021;35:120–129. https://doi.org/10.1111/jvim.15999