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A Novel Technique of Left Atrial Decompression Using Intracardiac Echocardiography Guidance in 2 Dogs With Advanced Degenerative Mitral Valve Disease

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ABSTRACT

Left atrial decompression (LAD) using transseptal puncture followed by balloon atrial septostomy recently has been described as a palliative minimally invasive procedure in dogs with advanced degenerative mitral valve disease (DMVD). We report herein the first use of intracardiac echocardiography (ICE) guidance combined with 3-dimensional transesophageal echocardiography (3D-TEE) to ensure the safety of the LAD procedure from a caudal approach, as performed in humans, in 2 American College of Veterinary Internal Medicine (ACVIM) stage C and D DMVD dogs (Jack Russell Terrier and Cavalier King Charles Spaniel) with recurrent episodes of acute pulmonary edema. Both LAD procedures were successful, as confirmed by markedly decreased systolic left atrial pressures (17 and 25 mmHg vs. 42 and 80 mmHg before LAD, respectively). Both dogs remained free of left-sided congestive heart failure signs for 8 and 10 months, respectively. The addition of ICE guidance to 3D-TEE is feasible and valuable in medium-sized dogs for safe LAD procedures.

1 | Introduction

Left atrial decompression (LAD) using transseptal puncture (TSP) followed by balloon atrial septostomy has been described as an emerging tool for congestive heart failure (CHF) management in dogs with advanced degenerative mitral valve disease (DMVD) [1, 2]. In these dogs, LAD allows a decrease in left atrial pressure (LAP) by creation of an iatrogenic atrial septal defect (iASD) with left-to-right interatrial shunting. The TSP procedure consists of crossing the interatrial septum (IAS) from the right atrium (RA) to the left atrium (LA) by cardiac catheterization using a transvenous approach. This procedure may be both challenging and dangerous, particularly in small- to medium-sized dogs, with potential life-threatening complications (e.g., pericardial effusion with cardiac tamponade, atrial thrombus formation, aortic root puncture, arrhythmias) [1–4]. Key to the success of TSP is the ability to safely create an iASD at the exact level of the thinnest part of the fibrous IAS, the fossa ovalis (FO), to limit the aforementioned complications and improve long-term iASD patency [1, 2]. Excellent visualization of the IAS anatomy

Abbreviations: 3D, three-dimensional; ACVIM, American College of Veterinary Internal Medicine; CHF, congestive heart failure; DMVD, degenerative mitral valve disease; FO, fossa ovalis; IAS, interatrial septum; iASD, iatrogenic atrial septal defect; ICE, intracardiac echocardiography; LA, left atrium; LA/Ao, left-atrium-to-aorta ratio; LAD, left atrial decompression; LAP, left atrial pressure; RA, right atrium; TEE, transesophageal echocardiography; TRPG, peak tricuspid regurgitation pressure gradient; TSP, transseptal puncture.

and the FO is therefore critical for the safety and success of the procedure. For this purpose, transesophageal echocardiography (TEE) using biplane 2-dimensional and 3-dimensional (3D-TEE) modalities typically is used in dogs and described in human patients [1–3]. Furthermore, high-resolution real-time visualization of the IAS is provided by intracardiac echocardiography (ICE), which has partially replaced TEE in interventional cardiology in humans [5–10]. This unique imaging technology requires a catheter-based steerable ultrasound probe inserted into a vessel, allowing direct visualization of cardiac and vascular structures from inside the cardiovascular system [9–12].

We report here the first use of ICE guidance with 3D-TEE for safe and successful LAD procedures in 2 dogs with advanced DMVD presented for recurrent episodes of left-sided CHF. Additionally, a novel LAD technique is described, using a steerable introducer sheath without any transseptal needle and using a caudal approach.

2 | Case Description

Case 1. A 12-year-old 10.2 kg male Jack Russell Terrier was referred for recurrent episodes of left-sided CHF secondary to American College of Veterinary Internal Medicine (ACVIM) stage D DMVD [13] treated PO with torsemide (Upcard, Vetoquinol, Lure, France; 0.29 mg/kg q24h in the morning), furosemide (Libeo, CEVA, Libourne, France; 2.94 mg/kg q24h in the evening), pimobendan (0.37 mg/kg q12h), spironolactone (Prilactone, CEVA, Libourne, France; 2.45 mg/kg q24h), and benazepril (Fortekor, Elanco, Sèvres, France; 0.49 mg/kg q24h). Respiratory examination identified mild tachypnea (respiratory rate of 48 breaths/min) with labored breathing and shorter, rapid and shallow breaths, and inspiratory pulmonary crackles on both hemithoraces. Cardiac auscultation indicated a heart rate of 140 beats/min with regular cardiac rhythm, and a grade 5/6 left apical holosystolic heart murmur. On admission, transthoracic echocardiography (Vivid E9, General Electric medical system, Waukesha, WI, USA) confirmed severe mitral regurgitation (regurgitation fraction, 71%) related to marked remodeling of both mitral valve leaflets with a chordae tendineae rupture on the anterior leaflet. The left ventricle and LA were markedly enlarged (end-systolic left atrium-to-aorta ratio [LA:Ao] and LA volume of 3.3 and 5.8 mL/kg, respectively; cut-off values for defining LA enlargement: ≥ 1.6 and > 1.1 mL/kg, respectively) [13, 14]. Increased peak velocity of early diastolic transmitral flow (E = 2.0 m/s; normal range, < 1.2 m/s) [15] and ratio of E to peak velocity of early diastolic mitral annular motion assessed by pulsed-wave tissue Doppler (E:E′ = 17.5; normal range, < 12) [16] associated with numerous coalescent pulmonary B-lines were consistent with markedly increased LAP and secondary left-sided CHF. The peak tricuspid regurgitation pressure gradient (TRPG) was 63 mmHg and the right ventricle was moderately thickened, which was consistent with a high probability of pulmonary arterial hypertension [17]. Medications were modified as follows: furosemide was replaced with torsemide (0.29 mg/kg q12h), with an increased daily dosage of pimobendane (0.37 mg/kg q8h) and addition of altizide (Aldactazine, Pfizer, Paris, France; 1.47 mg/kg q24h), the remainder of the treatment (spironolactone and benazepril) was unchanged. Two days later, the dog developed dysorexia and vomiting, with normal respiratory function. Azotemia (serum creatinine and urea concentrations of respectively 32.1 mg/L and 2.03 g/L; corresponding reference ranges = 5–18 mg/L and 0.15–0.57 g/L, respectively) and mild hypokalemia were observed, justifying a decrease in torsemide dosage (0.15 mg/kg q12h), benazepril discontinuation, and PO potassium supplementation. Considering the occurrence of cardiorenal syndrome in the context of DMVD refractory to medical treatment, an interventional procedure was considered. The dog was not a candidate for transcatheter edge-to-edge mitral valve repair. A minimally invasive LAD procedure then was offered to the owners and informed consent was obtained.

The dog was premedicated with morphine (0.2 mg/kg IM). Preoxygenation with a mask was performed. Anesthesia was induced using lidocaine (2.0 mg/kg IV), propofol (2.5 mg/kg IV) and midazolam (0.2 mg/kg IV). The trachea was intubated, and mechanical ventilation was initiated. Anesthesia was maintained using an IV anesthesia technique consisting of a variable rate infusion of propofol (0.1–0.3 mg/kg/min) and constant rate infusion of lidocaine (40 μg/kg/min). Electrocardiography, pulse oximetry, end-tidal CO_2 and rectal temperature were monitored and recorded every 5 min throughout the procedure. An arterial catheter was placed in the left auricular artery to monitor blood pressure. The dog was placed in dorsal recumbency. Intracardiac echocardiography was performed by an operator with a high level of ICE experience for guidance of experimental cardiac surgeries (NB), using an intracardiac ultrasound system (Intracardiac ultrasound system ViewMate Z, St Jude Medical, St. Paul, MN, USA) and a 9 Fr intracardiac imaging catheter (Figure 1; ViewFlex Plus catheter, St Jude Medical, St. Paul, MN, USA). Transesophageal echocardiography (EPIC CV, Philips Healthcare, Eindhoven, Netherlands) using a multiplane cardiac phased-array probe (X8-2t Live 3D TEE xMATRIX array transducer, Philips Healthcare, Eindhoven, Netherlands) was performed by a board-certified cardiologist (VC).

Both femoral veins were isolated using a cutdown procedure for the introduction of the ICE probe and an 11.5-Fr steerable sheath (AgilisTM NxT steerable introducer, Abbott, St. Paul, MN, USA) into 10- and 12-Fr vascular access sheaths respectively, inserted in the left and right femoral veins, which were further passed via the caudal vena cava to the RA. Under both ICE and 3D-TEE guidance, the steerable sheath was advanced onto a 0.032″ J-tip stiff guidewire (Figure 2A) and the IAS was tented with the assembly at the level of the FO. The TSP then was performed by exchanging the 0.032″ guidewire for a 190-cm 0.014″ straight-tip guidewire (Abbott, St. Paul, MN, USA), using the stiff end previously precut to facilitate the puncture (Figure 2B). The dilator of the sheath then was advanced gently into the LA. The 0.014″ guidewire was exchanged for the 0.032″ guidewire for additional support, using the J-tip side to avoid inadvertent puncture of the LA wall or aortic root. The entire steerable sheath then was advanced into the LA with gentle manipulation under both ICE (Figure 3A) and 3D-TEE (Figure 3B) guidance. The dilator was slowly removed to avoid air suction into the sheath and life-threatening air embolism. Heparin was administered (50 UI/kg IV). The 0.032″ guidewire was exchanged for a 150-cm 0.035″ J-tip stiff guidewire (SP Medical, Karise, Denmark), the steerable sheath then was vented and withdrawn into the RA with the 0.035″ guidewire

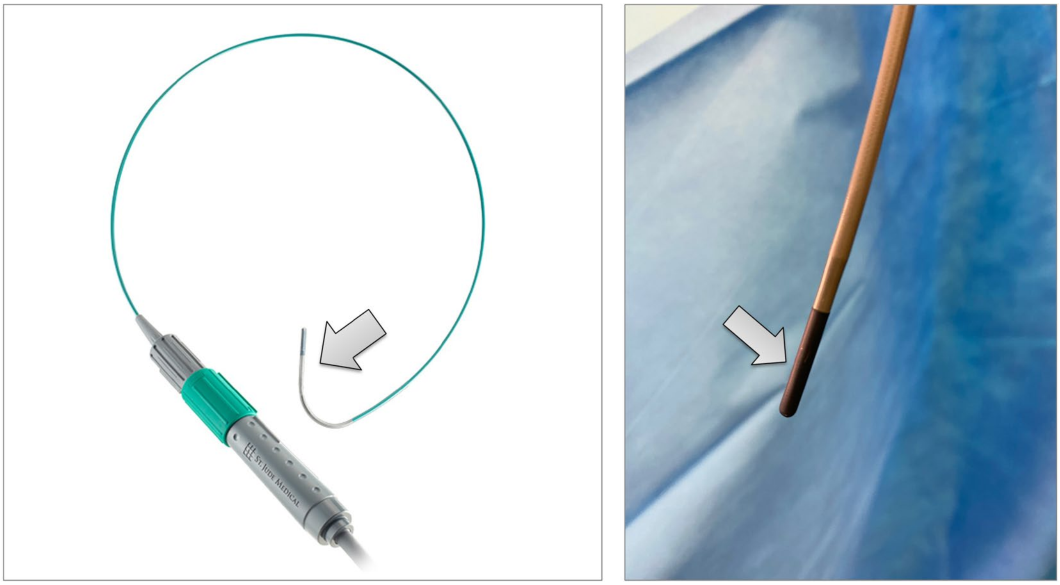

FIGURE 1 | The ViewFlex Plus catheter and its phased-array transducer (arrows) used for intracardiac echocardiography guidance in both dogs. *Source:* https://www.cardiovascuLar.abbott/us/en/hcp/products/electrophysiology/imaging-diagnostic-systems/viewmate-ultrasound-console-and-viewflex-catheter.html (access 20th January 2025).

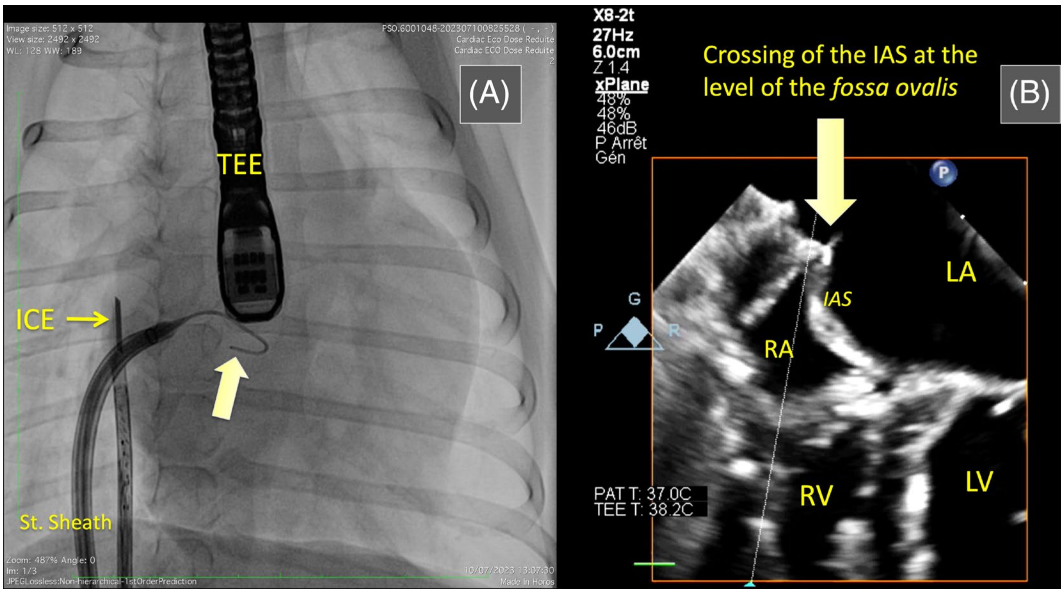

FIGURE 2 | (A and B) Imaging guidance for interatrial septal puncture (Case 1). (A) Ventrodorsal angiographic image showing the double echocardiographic guidance used for the procedure with both ICE and TEE probes. Note also the steerable sheath (St. Sheath) over the 0.032″ J-tip stiff guidewire (large arrow). (B) Two-dimensional TEE view showing the stiff end of the 190-cm 0.014″ straight-tip guidewire crossing the interatrial septum (IAS). ICE: intracardiac echocardiography; LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle; TEE: transesophageal echocardiography.

maintained in the LA, and a NuMed Tyshak veterinary low-pressure balloon catheter (diameter = 8 mm, length = 4 cm, rated burst pressure = 5.0 ATM) was advanced onto the 0.035″ guidewire into the steerable sheath and placed across the IAS under ICE guidance, and was inflated 3 times for approximately 15 s each time (Figure 4). A patent iASD with left-to-right interatrial shunting was created and confirmed by 2D-color ICE and 3D-color TEE. The balloon catheter then was removed, and the steerable sheath was readvanced into the LA. Invasive systolic V-wave LAP was markedly decreased after atrial septostomy (17 mmHg vs. 42 mmHg before), and the procedure therefore was deemed successful. Clopidogrel was added to the medical treatment for 1 month. Transthoracic echocardiography performed the day after procedure confirmed a patent iASD with 7.3 mm diameter left-to-right interatrial shunting associated with a decrease in LA size (end-systolic LA:Ao = 2.6 and LA volume = 4.3 mL/kg) and pressure (E = 1.5 m/s and E:E′ = 11.9). The torsemide and altizide dosages then were decreased, and the serum creatinine concentration normalized a few days after procedure

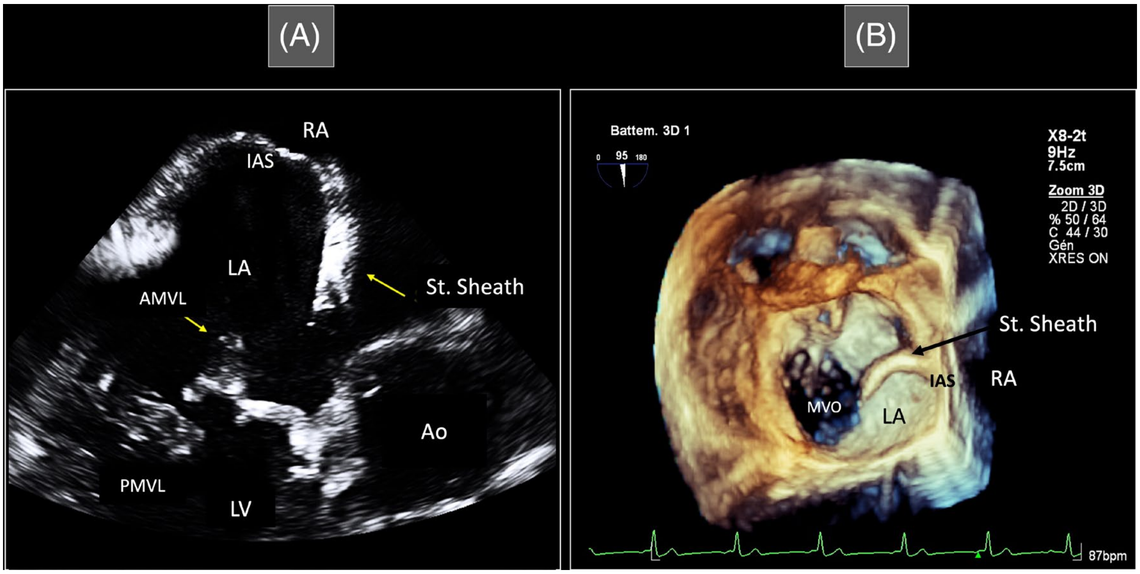

FIGURE 3 | (A and B) Combined intracardiac (A) and three-dimensional transesophageal echocardiography (B) for guiding the steerable sheath (St. Sheath) across the interatrial septum (IAS), allowing access to the left atrium (LA; Case 1). (A) This 2D intracardiac echocardiographic image obtained with the ViewFlex Plus catheter placed in the right atrium (RA) near to the IAS shows the precise positioning of the St. Sheath into the enlarged LA after transseptal puncture. Note the markedly thickened anterior (AMVL) and posterior (PMVL) mitral valve leaflets associated with severe prolapse of the former within the LA cavity. (B) This three-dimensional transesophageal echocardiographic image from the LA roof shows the correct positioning of the St. Sheath into the LA after crossing the IAS at the level of the fossa ovalis. Ao: aorta; LV: left ventricle; MVO: mitral valve orifice.

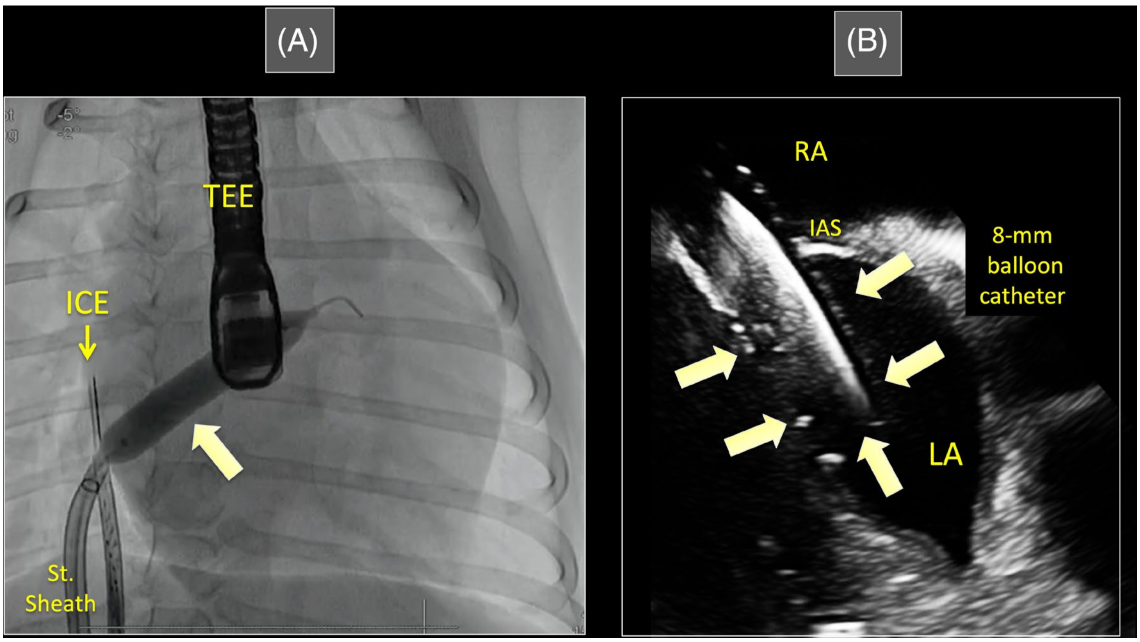

FIGURE 4 | (A and B) These ventrodorsal angiographic view (A) and two-dimensional intracardiac echocardiography image obtained with the ViewFlex Plus catheter placed in the right atrium (RA) near to the interatrial septum (IAS; B) show the atrial septostomy after transseptal puncture, using an 8-mm NuMed Tyshak low-pressure balloon catheter (Infinity Medical, Redwood, CA, USA; arrows) inflated to the rated pressure for 15 s (Case 1). ICE: intracardiac echocardiography; LA: left atrium; St. Sheath: steerable sheath; TEE: transesophageal echocardiography.

(16.0 mg/L). Two months after the procedure, the echocardiographic improvements persisted. The owners reported mild abdominal distension 6 months after procedure with good overall condition. Repeated transthoracic echocardiography showed a 7 mm-diameter patent iASD with an increased TRPG (76 mmHg), and the presence of mild right-sided CHF confirmed by dilatation and decreased distensibility of the caudal vena cava, dilated hepatic veins, and a mild amount of anechoic ascites, of which cytological examination was consistent with a modified transudate. The morning dosage of torsemide was increased slightly. The dog remained free of clinical signs of left-sided CHF for 8 months after the procedure, with a monitored at-home respiratory rate < 30 breaths/min. Sudden death occurred after an acute syncopal episode during a walk. The owners declined necropsy.

Case 2. An 8-year-old 10.5 kg male Cavalier King Charles Spaniel was referred for advanced ACVIM Stage C DMVD with recurrent acute left-sided CHF episodes, treated PO with furosemide (1.3 mg/kg q8h), pimobendan (0.24 mg/kg q12h), spironolactone (1.42 mg/kg q24h), and benazepril (0.47 mg/kg q24h), and was receiving PO supplementation of taurine and omega-3 fatty acids. Physical examination at presentation identified mild dyspnea and tachypnea associated with persistent pulmonary edema, with a grade 5/6 left apical holosystolic heart murmur. Transthoracic echocardiography confirmed a double chordae tendineae rupture on both mitral valve leaflets with severe mitral regurgitation (regurgitation fraction = 74%). The left ventricle and LA were markedly enlarged (end-systolic LA:Ao = 2.6 and LA volume = 5.2 mL/kg), and LAP was markedly increased, as suggested by the increased value of the mitral E wave (1.80 m/s). The combination of a high TRPG (58 mmHg) with dilatation of both the right ventricular outflow tract and pulmonary trunk was consistent with a high probability of pulmonary arterial hypertension [17]. The owners requested an interventional procedure that could lower the frequency of left-sided CHF episodes and improve quality of life. A LAD therefore was planned. The patient was anesthetized and monitored as in the previous case. The steerable sheath was advanced to the RA onto the 0.032″ J-tip stiff guidewire, and then was steered in a ventromedial direction until the dilator was tenting the IAS at the level of the FO. The TSP and atrial septostomy were performed using the same techniques as described above, with successful creation of a 6.3 × 4.3-mm^2 diameter patent iASD (Figure 5) allowing a subsequent substantial decrease in invasive systolic V-wave LAP (25 mmHg versus 80 mmHg before). Post-operative transthoracic echocardiography indicated decreases in both LA size (end-systolic LA:Ao = 2.1 and LA volume = 4.2 mL/kg) and pressure (E = 1.5 m/s). A small thrombus was visualized within the RA near the iASD and the dog became mildly dyspneic. Enoxaparin (100 UI/kg q8h IV), clopidogrel (1.79 mg/kg q24h PO), and sildenafil (1.19 mg/kg q12h PO) were prescribed to treat suspected pulmonary thromboembolism. The dyspnea resolved and the intracardiac thrombus disappeared within 48 h, and the dog was discharged from the hospital. Transthoracic echocardiography performed 2 months after the procedure showed stable improvement in LA size and pressure variables with decreased TRPG (35 mmHg), improvements that persisted 6 months after procedure. The dog remained free of left-sided CHF clinical signs for 10 months after the procedure until it died suddenly during sleep. The owners declined necropsy.

3 | Discussion

Balloon atrial septostomy was first described in a dog as a palliative treatment of a severe congenital pulmonary hypertension by creation of right-to-left interatrial shunting [18]. Treatment of dogs with end-stage DMVD is challenging [13] and LAD has been reported recently, allowing immediate and substantial LAP decrease with a median survival time of 195 days after the procedure [1, 2], and subsequent quality of life improvement as noted for our 2 cases with no

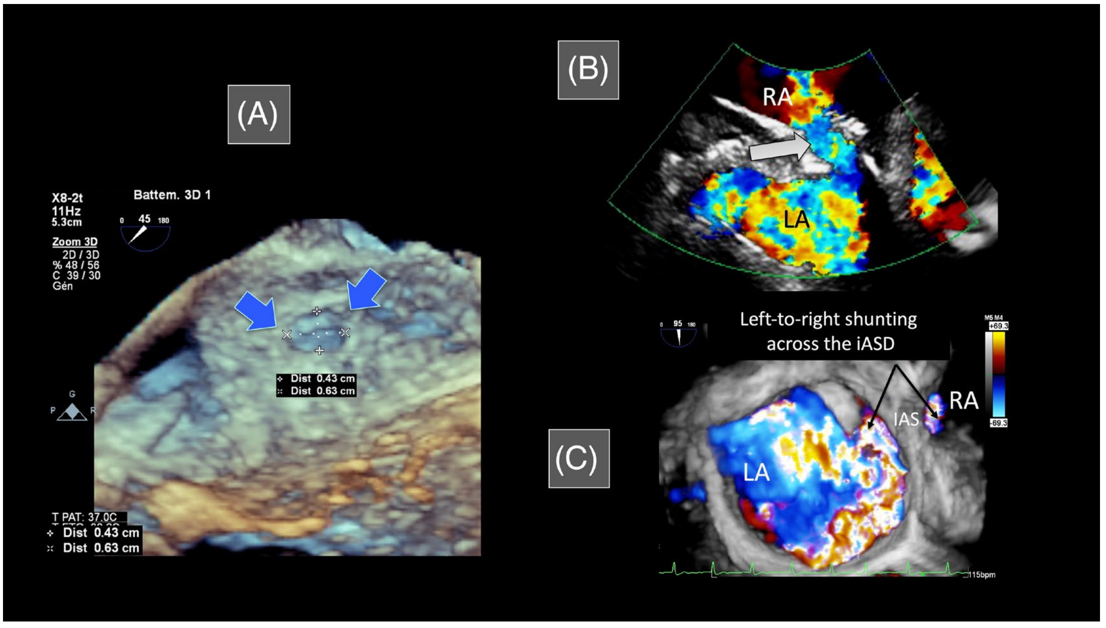

FIGURE 5 | (A–C) Combined imaging guidance confirming the creation of a patent iatrogenic atrial septal defect (iASD) in Case 2. (A) Three-dimensional (3D) transesophageal echocardiographic (TEE) *en face* view of the interatrial septum from the left atrium (LA), showing the 6.3 × 4.3 mm^2 iASD (blue arrows). (B) This two-dimensional intracardiac echocardiographic image using color-flow Doppler mode with the ViewFlex Plus catheter placed in the right atrium (RA) near to the interatrial septum (IAS) confirms the patency of the iASD by visualization of a turbulent left-to-right interatrial shunting (gray arrow). (C) This 3D-TEE image using color-flow Doppler mode from the LA roof shows the patency of the iASD with a turbulent left-to-right interatrial shunting.

recurrence of left-sided CHF episodes 8 and 10 months after the procedure.

In interventional cardiology in humans, ICE is currently replacing TEE for the guidance of various procedures (e.g., atrial septostomy, atrial septal defect closure, LA appendage occlusion, ablation of arrythmias, several transcatheter valve repair techniques) [9–12]. One of the major benefits of ICE over TEE in human patients is the lack of need for general anesthesia, which is not of value in dogs. Another benefit is that the interventionalist also can control the imaging, whereas a separate imager is required for TEE guidance.

The use of ICE was first reported in a dog by our group during a challenging patent ductus arteriosus transcatheter occlusion [19]. The procedure provides several benefits well described in human patients undergoing TSP procedure, including direct visualization of the endocardium, precise positioning of the guidewire and sheath in contact with the FO, early detection of procedure-related complications as well as shorter procedure duration and fluoroscopy exposure [5–8]. Potential limitations of ICE in veterinary cardiology include its cost, the lack of currently available standardization of echocardiographic views and the need for specific training in this modality [10, 12].

Regarding the TSP procedure, a slightly different technique than that described previously [2] was performed in our 2 dogs, using a femoral approach as performed in interventional cardiology in humans, and using a steerable sheath. The latter has proven to be more efficient for the treatment of atrial fibrillation using TSP in humans [20], allowing a convenient contact force to optimize tenting of the FO. The steerability of the AgilisTM NxT provides a marked advantage over non-steerable sheaths because it can adapt to most anatomical variations. An 11.5 Fr (outer diameter) steerable sheath is compatible with most small to medium-sized dogs, but must be manipulated with care once positioned inside the heart, guided by the most precise imaging possible. Use of a small 0.014″ wire is more delicate, more penetrating and less risky than using a transseptal needle. Less force is needed to perforate the septum, with less risk of perforating the LA or the aortic root.

In humans suffering from heart failure with preserved ejection fraction, LAD decreases pulmonary capillary wedge pressure leading to clinical improvement and may improve survival when using an IAS device [21–23]. The latter prevents iASD closure, seen in approximately 30% of LAD cases without device implantation [24]. The creation of an 8-mm left-to-right interatrial shunt has been shown to be optimal to effectively decrease LAP without a clinically relevant increase in right atrial pressure [25]. Several months after the procedure, Dog 1 showed worsening of pulmonary hypertension which was thought to be related to left-to-right interatrial shunting (group 1 pulmonary hypertension) [17], considering the postoperative decrease in LA size and pressure. Although the optimal iASD diameter is unknown in dogs, it is possible that some will not tolerate the long-term effects of an 8-mm atrial septostomy, with potential complication of right-sided CHF. Prospective studies are needed to determine the optimal iASD diameter in dogs for effectively decreasing LAP without substantially increasing pulmonary arterial pressure, according to the animal's body weight or surface area, or to cardiac dimensions.

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Disclosure

Authors declare no off-label use of antimicrobials.

Ethics Statement

Authors declare no Institutional Animal Care and Use Committee (IACUC) or other approval was needed. Authors declare human ethics approval was not needed.

Conflicts of Interest

The authors declare no conflicts of interest.

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