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REVIEW

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Systematic review of electrophysiology procedures in patients with obstruction of the inferior vena cava

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Abstract

Aims: The objective of the study was to conduct a systematic review to describe and compare the different approaches for performing cardiac electrophysiology (EP) procedures in patients with interrupted inferior vena cava (IVC) or equivalent entities causing IVC obstruction.

Methods: We conducted a structured search to identify manuscripts reporting EP procedures with interrupted IVC or IVC obstruction of any aetiology published up until August 2020. No restrictions were applied in the search strategy. We also included seven local cases that met inclusion criteria.

Results: The analysis included 142 patients (mean age 48.9 years; 48% female) undergoing 143 procedures. Obstruction of the IVC was not known before the index procedure in 54% of patients. Congenital interruption of IVC was the most frequent cause (80%); and, associated congenital heart disease (CHD) was observed in 43% of patients in this setting. The superior approach for ablation was the most frequently used strategy (52%), followed by inferior approach via the azygos or hemiazygos vein (24%), transhepatic approach (14%), and retroaortic approach (10%). Electroanatomical mapping (58%), use of long sheaths (41%), intracardiac echocardiography (19%), transesophageal echocardiography (15%) and remote controlled magnetic navigation (13%) were used as adjuncts to aid performance. Ablation was successful in 135 of 140 procedures in which outcomes were reported. Major complications were only reported in patients undergoing AF ablation, including two patients with pericardial effusion, one of whom required surgical repair, and another patient who died after inadvertent entry into an undiagnosed atrioesophageal fistula from a previous procedure.

Conclusion: The superior approach is most frequent approach for performing EP procedures in the setting of obstructed IVC. Transhepatic approach is a feasible alternative, and may provide a "familiar approach" for transseptal access when it is

required. Adjunctive use of long sheaths, intravascular echocardiography, electro-anatomical mapping and remote magnetic navigation may be helpful, especially if there is associated complex CHD. With careful planning, EP procedures can usually be successfully performed with a low risk of complications.

KEYWORDS
electrophysiology, inferior vena cava obstruction, interrupted inferior vena cava, superior approach, transhepatic approach

1 | INTRODUCTION

The standard approach for venous access in patients undergoing cardiac electrophysiological (EP) procedures is an inferior approach via the femoral veins and inferior vena cava (IVC). As such, catheters, sheaths and transseptal needles have been designed with this approach in mind. However, in rare cases, an inferior approach may be technically challenging or not possible due to an obstructed IVC, and this is often only discovered de novo during the index procedure. Different approaches may be required depending on the type of obstruction and the nature of the EP procedure.

IVC obstruction may be congenital or acquired. Congenital interruption of the IVC is due to developmental agenesis or non-union. It is a rare anomaly with a prevalence of 0.15% in the general population and 0.6% in patients with congenital heart disease (CHD).[1,2] It is known to be associated with atrial isomerism syndromes and dextrocardia.[3] The IVC is usually interrupted above the level of the renal veins although other anatomical variations exist.[1] Interrupted IVC is often accompanied by an enlarged azygos or hemiazygos system draining into the superior vena cava (SVC). Acquired causes of IVC obstruction include prior surgery (including IVC filters), thrombosis, and trauma. In addition, multiple prior catheterization (especially in patients with complex CHD) may also result in functional obstruction.

Various approaches to EP procedures in this scenario have been described in individual case reports and small case series. The aims of the present study were to systemically review the literature and describe and compare the different approaches to performing EP procedures in patients with IVC obstruction.

2 | METHODS

We searched *Medline*, *PubMed*, *and The Cochrane Library* through to August 2020 without any restrictions for reports of EP procedures on patients with congenital interrupted IVC or IVC obstruction of any aetiology. The search strategy and terms used in the search are detailed in Appendix A. We included cases with IVC filters if the operator did not use the femoral approach because of concerns over catheter entrapment, filter migration or fracture. In addition, references of the included cases were searched for any other relevant cases. Additional strategies included a search of specific electrophysiology journals (*Heart Rhythm*, *Europace*, *Pacing and Clinical Electrophysiology*, *Journal of Cardiovascular Electrophysiology*, *Journal of Interventional Cardiac Electrophysiology*, *Circulation: Arrhythmia and Electrophysiology*, *JACC: Clinical Electrophysiology*) and also reviewing articles citing the cases found on *PubMed*. Reports were considered eligible if patients had interrupted IVC or IVC obstruction of any aetiology and undergoing an EP procedure. We also included seven local and previously unreported cases meeting the inclusion criteria.

Extracted data included demographic information, the cause of obstruction, venous connections, associated CHD, vascular access, catheters, the index arrhythmia, procedural outcome, complications, imaging and previous procedures. In particular, we specifically analysed the use of long sheaths, electro-anatomical mapping (EAM) systems, intracardiac echocardiography (ICE), remote-controlled magnetic navigation (RMN), and transseptal access. We also recorded any specific difficulties and learning points reported by authors.

3 | RESULTS

The literature search strategy identified 1133 potential publications (Figure 1). After thorough screening, 96 publications met our inclusion criteria, reporting on 135 cases and 136 procedures (Appendix B). With the inclusion of 7 local cases, 142 patients and 143 procedures were included in the analysis. Details of additional cases from local institutions are summarized in Table 1.

The mean age of cases was 48.9 years with 67 female patients (47%) (Table 2). In 77 patients (54%), the obstruction was not known before their first procedure. Thirty eight patients (27%) had a previous failed EP procedure.

Most patients (80%) had congenital interruption of the IVC. Other causes of IVC obstruction are summarized in Table 2. Almost all procedures were performed for ablation of a known arrhythmia (99%) with the most frequent arrhythmias being atrial fibrillation (AF), atrioventricular nodal re-entrant tachycardia (AVNRT) and atrial flutter.

Although associated imaging was reported in 80 patients, only 57 patients had imaging performed before the index procedure. computed tomography (CT) scan was the most common modality used (52 patients).

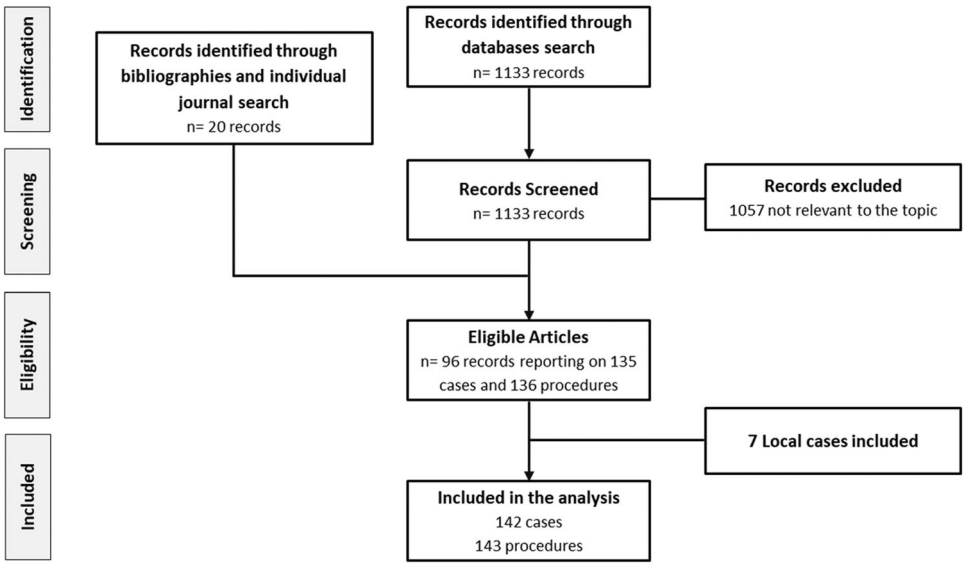

FIGURE 1 PRISMA flow chart: the systemic review procedure

4 | CONGENITALLY INTERRUPTED IVC

Within the subset of 113 patients with congenital interruption of IVC (Table SC.1), 49 patients (43%) had associated CHD and/or lateralization anomalies. Specifically, 38 patients (34%) had lateralization anomalies.

There was significant variability in the arrangement of the systemic venous return. The most frequent arrangement was IVC interruption at the hepatic level with azygos continuation to the SVC. Hemiazygos vein continuation with or without azygos was the second most frequent arrangement. Importantly, there was associated anomalous superior venous return in 21% of cases, with persistent left SVC (PLSVC) or persistent right SVC (in patients with dextrocardia). In 16 of these cases (14%), the inferior venous return system drained to the heart via the PLSVC. There was total absence of IVC or complete interruption without azygos or hemiazygos continuation in 7 patients (6%), thereby eliminating inferior approach as an access option in these cases. On the other hand, there were two cases where direct inferior access to the RA was possible—one case of hypoplastic but uninterrupted IVC with azygos continuation and one case with congenitally interrupted IVC and suprarenal branching to azygos continuation as well as to the hepatic veins.[4,5]

5 | APPROACHES TO ABLATION

Amongst 140 patients undergoing ablation, the superior approach utilizing the SVC was used in 73 patients, inferior approach using the azygos or hemiazygos veins was used in 33 patients, trans-hepatic approach in 20 patients and retrograde trans-aortic approach in 14 patients. These approaches are illustrated in Figures 2–5 and summarized in Figure 6.

The *superior approach* was used in the majority of patients (52%), and it was applicable for all arrhythmic substrates. In particular, the superior approach was the preferred access route (76% of cases) for transseptal access to facilitate left atrial mapping (see later section, *Transseptal access and Ablation of Atrial Fibrillation and Left Atrial Arrhythmias)*. Most operators reported familiarity with catheter manipulation via the superior approach, but radiation exposure for the operator was increased. The main limitation was for patients with additional anomalies of the superior venous return such as a persistent left-sided SVC ± absent right-sided SVC.

The *inferior approach* was the next most frequent approach (24% of cases), typically via the azygos or hemiazygos venous connection into the SVC. The calibre and tortuosity of these venous channels is variable and may limit the number of catheters that can be introduced with an inferior approach. Challenges to catheter manipulation were often reported with this technique because of the longer course and sharp angulation at the entry point of these venous channels into the SVC. As a result, issues with catheter stability and tissue contact were frequently reported, and transseptal access was usually not possible via the inferior route.

Transhepatic approach was utilized in 14% of cases, and it was mainly used to treat AF and atrial flutters (Table SC.2). In a local case, a transhepatic approach was used to treat a midseptal AP (Figure 2). Of 18 cases reporting the mode of sedation/anaesthesia, 15 patients underwent the procedure under general anaesthesia although in 3 of these cases the trans-hepatic access part was obtained under sedation. Chiba needles (18–22 gauge) were reported to have been used in 11 patients (55%). A variety of other long needles (18–22 gauge) were used including 18-gauge trocar needle, 21-gauge Accustick needle and 22-gauge spinal needle. Ultrasound guidance was used in most cases to assist with obtaining transhepatic access (17 patients, 85%). In one case, CT-guidance was used to obtain hepatic vein access. Interventional radiology was often involved to assist with transhepatic access (40%).

TABLE 1 Summary of the local cases

Arrhythmia	Age/gender	Associated cardiac history	Aetiology of obstruction	Ablation approach	Outcome
Atypical AFL	74/Female	Previous atrial septal defect repair. Previous failed attempt of ablation.	IIVC with azygos continuation	Inferior. EAM was used. Cavo-tricuspid isthmus ablation was performed in addition to an incisional flutter.	Successful No complications
Typical AFL	73/Female	Coronary artery disease, Dual-chamber permanent pacemaker for sinus node disease.	IIVC with hemiazygos continuation	Inferior. EAM and long steerable sheath (Agilis) were used.	Successful No complications
Typical AVNRT	60/Female	Previous failed ablation attempt.	IIVC with azygos continuation	Superior approach via left subclavian vein. EAM was used.	Successful No complications
Diagnostic	52/Male	"Congenital" heart disease surgery aged 5 years. Electrophysiology study was performed to investigate syncope.	IIVC with azygos continuation	No ablation performed. Diagnostic catheters were inserted via femoral vein access.	- No complications
AVRT/WPW	24/Male	Structurally normal heart on echo.	Occluded iliac veins secondary to abdominal surgery as a neonate.	Trans-hepatic. Steerable sheath (Agilis) used. Diagnostic catheters inserted via left IJV and left brachial vein. Cryoablation used for a mid-septal accessory pathway.	Successful No complications
AF Ablation	66/Female	Dilated cardiomyopathy secondary to anthracycline. ICD implant. Poorly controlled AF. Inappropriate ICD therapy due to AF.	Occluded iliac veins from prior abdominal surgery and radiotherapy for abdominal non-Hodgkin's lymphoma aged 40 years.	Superior approach via right IJV. Trans-septal was performed under TEE guidance. EAM and long steerable sheath (Agilis) were used.	Successful No complications
AVN Ablation	59/Male	Non-ischemic dilated cardiomyopathy. Poorly controlled permanent AF. CRT-D in situ. Heterotaxy syndrome with polysplenia and dilated azygos vein on CT.	IIVC with azygos continuation	Successful via trans-aortic approach. Failed inferior and superior approaches attempts due to catheter instability.	Successful No complications

Abbreviations: AFL, atrial flutter; AVN, atrioventricular node; AVNRT, atrioventricular nodal reentry tachycardia; CRT, cardiac resynchronization therapy; CT, computed tomography; EAM, electroanatomic mapping; IIVC, interrupted IVC; IJV, internal jugular vein; TEE, transesophageal echocardiogram.

TABLE 2 Demographic, clinical, and procedure characteristics and imaging performed

N = 142 patients/143 procedures	*N* (%)
Age (years; ±*SD*)	48.9 ± 15.8
Female gender	67 (47%)
Unknown obstruction before procedure	77 (54%)
Prior failed EP procedure	38 (27%)
Causes of IVC Obstruction	
Congenitally Interrupted IVC	113 (80%)
IVC filter	7 (5%)
Unclear/nonspecified cause	7 (5%)
IVC/Bilateral femoral vein thrombosis	6 (4%)
Post abdominal surgery ± radiation	3 (2%)
Surgical ligation	2 (1%)
Hydatid cyst compressing IVC	1 (1%)
Venous obstruction secondary to MVA with pelvic crush injury	1 (1%)
Multiple failed dialysis access points, including bilateral groins	1 (1%)
Cavo-pulmonary derivation for complex CHD and IJV thrombosis	1 (1%)
Ablation approach (*N* = 140)	
Superior approach	73 (52%)
Inferior approach	33 (24%)
Trans-hepatic approach	20 (14%)
Trans-aortic retrograde approach	14 (10%)
Primary arrhythmia/procedure	
Atrial fibrillation	42 (29%)
AVNRT	30 (21%)
Typical atrial flutter	22 (15%)
WPW syndrome/AVRT	17 (12%)
Atypical atrial flutter	11 (8%)
Focal atrial tachycardia	9 (6%)
AV junction ablation	4 (3%)
Ventricular ectopy	3 (2%)
Ventricular tachycardia	3 (2%)
Diagnostic study only	2 (1%)
Available Imaging (*N* = 80)	
Before index study	57
Post index study	23
CT scan	52
MRI scan	15
Not specified	5
Abdominal US scan	4
Combined CT and MRI scans	3
Combined CT and US scans	1
Adjunctive equipment	
3D electroanatomic mapping	83 (58%)
Use of long sheaths	59 (41%)
Deflectable sheaths	34 (58%)
Intracardiac echocardiography	27 (19%)
Transesophageal echocardiography	21 (15%)
Remote controlled magnetic navigation	19 (13%)
Transseptal access (*N* = 42)	
RF guidewire use	17 (40%)
RF needle/RF application to standard needle	8 (19%)
Sharp-tip guidewire	2 (5%)

Abbreviations: AV, atrioventricular; AVNRT, atrioventricular nodal reentry tachycardia; AVRT, atrioventricular reentrant tachycardia; CHD, congenital heart disease; CT, computed tomography; IJV, internal jugular vein; MRI, magnetic resonance imaging; MVA, motor vehicle accident; RF, radiofrequency; US, ultrasound; WPW, Wolff–Parkinson–White syndrome.

Postoperative hemostasis is a unique problem with transhepatic access and various strategies were reported. In 5 patients (25%), vascular embolization coils were used alone to achieve postoperative hemostasis. Gelfoam plugs were inserted to the hepatic tract in 2 patients in addition to manual pressure and right lateral decubitus positioning in one patient. Combined use of Amplatzer Vascular Plug and Gelfoam was employed in 6 patients (30%). In one patient, the transhepatic tract was embolized by an Amplatzer vascular plug followed by several vascular embolization coils. Radiofrequency (RF) energy using endovascular bipolar RF catheter was applied to hepatic tract to achieve hemostasis in one patient. The transhepatic tract was embolized with Avitene collagen plug in another patient. In the local case using transhepatic access, Surgicel Powder (oxidized regenerated cellulose) was introduced into the hepatic tract.

Retrograde transaortic access was used in 10% of cases. The approach provided more limited access; hence, it was primarily used for ablation of left-sided accessory pathways, and occasionally for ablation of the AV node, AV nodal re-entrant tachycardia and peri-nodal atrial tachycardia.

6 | ADJUNCTIVE TOOLS FOR ABLATION

Adjunctive strategies included the use of long and/or deflectable sheaths (*n* = 59, 41%) to improve catheter stability and contact. The use of real-time imaging such as transesophageal echocardiography (TEE; *n* = 21;

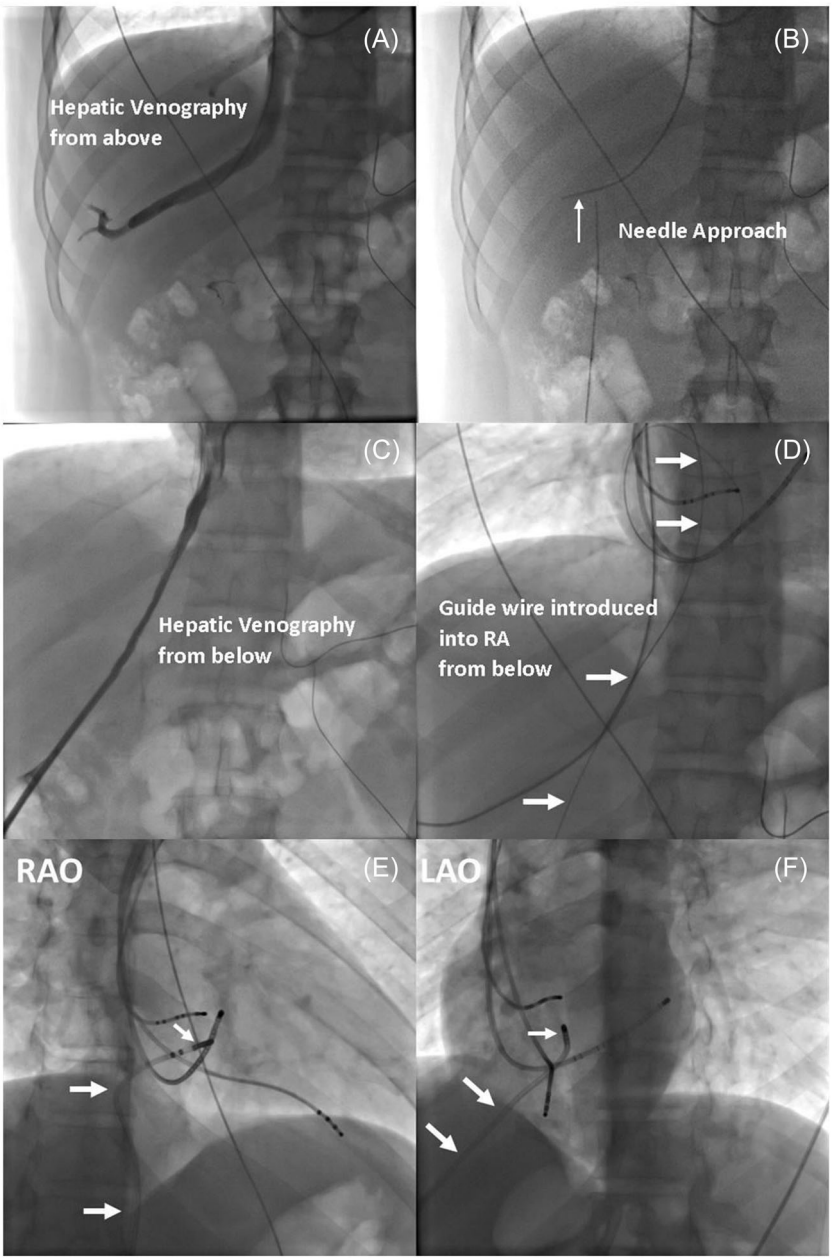

FIGURE 2 Example of transhepatic approach for ablation of right mid-septal accessory pathway in 25-year-old patient with IVC obstruction due to neonatal surgery. (A) Hepatic venogram performed via superior access. (B) Percutaneous needle access into hepatic vein. (C) Hepatic venogram performed. (D) Wire inserted into right atrium. (E) Cryoablation catheter placed in mid-septal position—right anterior oblique (RAO) view. (F) Left anterior oblique (LAO) view. IVC, inferior vena cava

15%) and ICE ($n = 27$, 19%) may assist with catheter navigation and assessing tissue contact. It is noteworthy that an ICE catheter may not cross the azygos-SVC junction from an inferior approach although imaging from the azygos vein provides "TEE-like views".[6] EAM ($n = 83$, 58%) was predominantly used in patients with complex arrhythmia circuits and/or anatomical complexity related to associated CHD.

RMN was used in 19 cases (13%; Table SC.3). Compared to cases performed manually, RMN cases were associated with similar acute procedural success (90% for RMN cases vs. 97% for manual cases; $p = .09$), even though RMN was often used in more complex patients with associated CHD and/or anomalies of lateralization (58% of RMN cases vs. 36% of manual cases; $p = .07$). Consequently, electroanatomic mapping was almost universally used with RMN procedures (95% vs. 54%; $p < .001$). RMN also enabled the use of transaortic retrograde approach for catheter ablation in a higher proportion of patients (26% vs. 7%; $p = .01$).

7 | APPROACHES TO ABLATION OF SPECIFIC ARRHYTHMIAS

7.1 | Ablation of atrioventricular nodal re-entry tachycardia or AV node

This included 30 patients who underwent ablation for AVNRT, and 4 patients who underwent AV node ablation. The superior approach was successfully used in 20 patients (Figure 3), and inferior approach was successfully used in 11 patients. Notably, 2 patients required

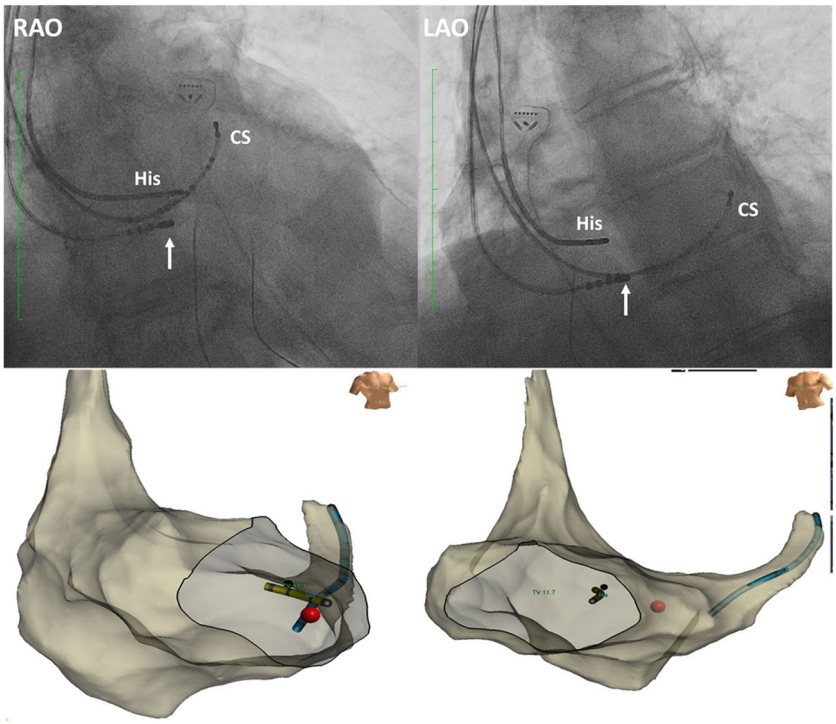

FIGURE 3 Example of superior approach in 60-year-old female patient with AV nodal re-entrant tachycardia and interrupted IVC. Top panels show fluoroscopic views with Ablation catheter (arrow) with His and coronary sinus (CS) catheters. *Top left panel*—right anterior oblique (RAO) view; *Top right panel*—Left anterior oblique (LAO) view. Bottom panels show corresponding electro-anatomical images with ablation site (red dot) and His and CS catheters. *Bottom left panel*—RAO view; *Bottom right panel*—LAO view. IVC, inferior vena cava

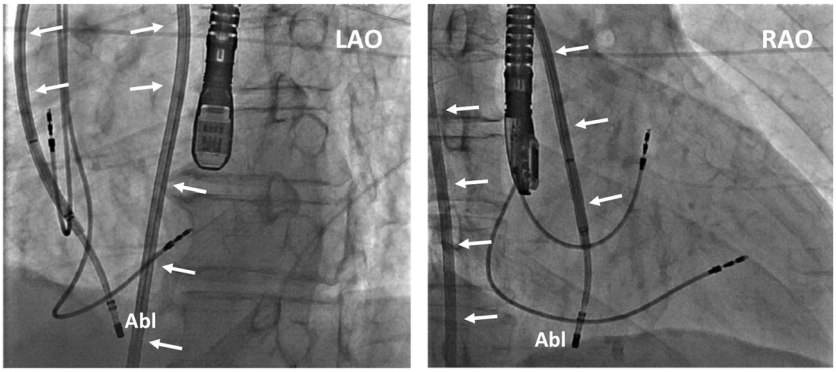

FIGURE 4 Example of inferior approach for ablation of typical right atrial flutter with the aid of a steerable sheath (arrows) inserted via azygous vein. Left panel—left anterior oblique (LAO). Right panel—right anterior oblique (RAO) views

ablation via a retrograde transaortic approach after failed superior approach due to inadequate catheter stability. In one patient, the slow pathway was ablated via transhepatic approach. No complications were reported for ablation procedures related to these types of arrhythmias.

7.2 | Ablation of accessory pathways

Sixteen out of seventeen patients with accessory pathways (APs) underwent successful ablation. Retrograde transaortic approach was attempted in six cases to ablate left-sided APs and was successful in five cases. In one patient, a left-sided AP was ablated successfully using superior approach and transseptal access. Amongst the seven patients with right-sided APs, superior approach was used in three patients and inferior approach in three patients. However, catheter manipulation was noted to be challenging and time-consuming with an inferior approach.[7,8] One local patient with a mid-septal AP and occluded iliac veins underwent the EP procedure with diagnostic catheters inserted via a superior approach, and ablation catheter introduced via a transhepatic approach, at the discretion of the operator (Figure 2). The transhepatic approach was also utilized to ablate a nodoventricular AP in the presence of twin AV nodes in a pediatric patient with CHD. Finally, there were two cases of AVRT via twin AV nodes in association with complex CHD. One was successfully ablated with superior approach and second one retrogradely with aid of RMN. No complications were reported for ablation procedures related to these types of arrhythmias.

7.3 | Ablation of typical atrial flutter

Amongst 22 patients undergoing ablation of the cavo-tricuspid isthmus (CTI), superior approach was utilized in 9 patients,

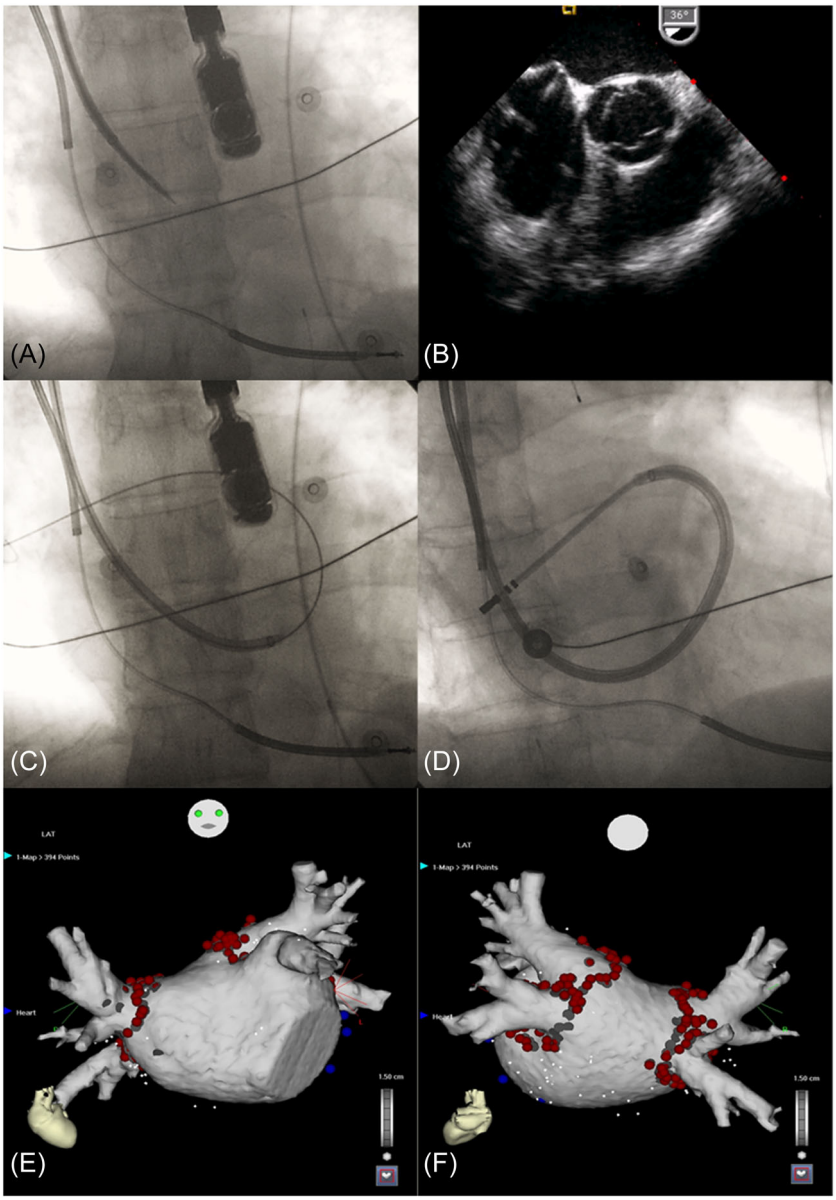

FIGURE 5 Example of transseptal access via superior approach in 66-year-old female patient with atrial fibrillation, dilated cardiomyopathy and occluded iliac veins due to prior surgery. (A) SL0 sheath and Transseptal needle (BRK-1; bent to 150°) introduced via right internal jugular vein. (B) TEE guidance of transseptal puncture. (C) Guidewire passed into left atrium and pulmonary vein. (D) Ablation performed with aid of steerable sheath. (E) Lesion set for pulmonary vein isolation projected on merged CT—anterior view. (F) posterior view. CT, computerized tomography; TEE, transesophageal echocardiography

inferior approach in 8 patients (Figure 4), trans-hepatic approach in 4 patients, and the case was abandoned in 1 patient. Achieving adequate contact was frequently cited as an issue regardless of whether a superior or inferior approach was used,[9–11] although the acute angle at the azygous-SVC junction made catheter manipulation a challenge with the inferior approach.[9] Specific catheter manoeuvres may also improve catheter contact and stability. For example, Malavasi et al.[10] reported that catheter inversion technique provided improved stability when using superior approach. Kynast et al.[12] reported success with ablation in two stages; initially by retracting catheter tip from the ventricular end and then re-starting a line from the IVC end angulated against the CTI and connecting it to the original line. No complications were associated with ablation of typical flutter. In addition, CTI ablation was also performed in 13 of the patients who underwent ablation for AF.

7.4 | Ablation of focal atrial tachycardia and atypical macro-reentrant atrial flutter in right atrium

This included 9 patients with focal atrial tachycardia and 11 patients with atypical macro-reentrant atrial flutter. The latter occurred exclusively in patients with associated CHD, the flutter circuit was often related to prior surgery, although concomitant CTI-dependent atrial flutter and/or focal tachycardias were frequently present as well. Superior approach (7 patients), inferior approach (6 patients), trans-hepatic (4 patients), and transaortic (3 patients) were used, and depended on the site of the arrhythmia circuit. EAM was frequently used (18 of 20 patients), highlighting the potential complexity of arrhythmia circuits in these patients. Atypical sites for arrhythmia have also been described in this cohort including one case of focal atrial tachycardia from the hepatic segment of the IVC, and another case of atypical lower loop re-entry around the suprahepatic veins.[13,14] Two unsuccessful cases were

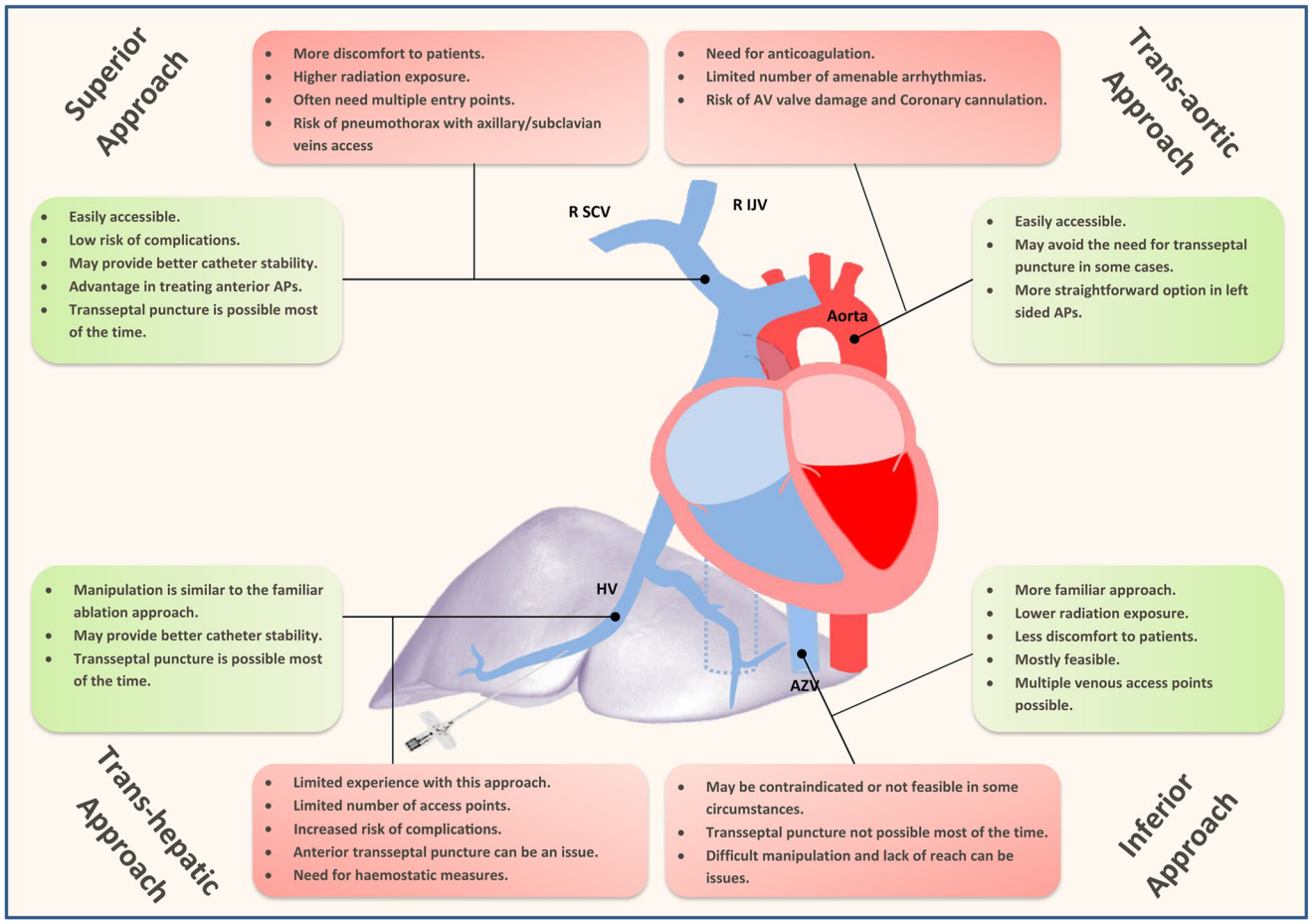

FIGURE 6 Advantages and disadvantages of different approaches used in the setting of inferior vena cava obstruction (IVC). Note: the absence of hepatic IVC in the diagram. AZV, azygos vein; HV, hepatic vein; IJV, internal jugular vein; SCV, subclavian vein

reported; one case used an inferior approach and the second case used RMN via transaortic approach and failure was due to non-sustained nature of atrial arrhythmia. No complications were reported for ablation procedures related to these types of arrhythmias.

7.5 | Transseptal access and ablation of atrial fibrillation and left atrial arrhythmias

Amongst 42 cases of transseptal access, it was usually performed via superior approach (32 patients), or transhepatic approach (9 cases). There was one exceptional case using an inferior approach because the patient had an anatomical variant of interrupted IVC with branches into the hepatic vein allowing direct access into the RA.[5] TEE was used to guide transseptal access in 17 cases and ICE in 24 cases.

Transseptal access from a superior approach was usually performed via the right internal jugular vein (IJV, 69%). Lim et al.[15] was first to report the feasibility and safety of superior approach use for AF ablation in 3 patients using right IJV access. In 7 cases double transseptal access was obtained using the left axillary veins for the second transseptal puncture.[16] Stiffer angulated sheaths such as Mullins sheath, SL3 sheath were felt to provide better guide support and help advancement into the left atrium.[15,17,18] Early reports described manual modifications to the standard transseptal equipment to achieve access. For example, the Brockenbrough needle was often manually bent to 120–150° to provide greater reach and similar angle of entry across the inter-atrial septum (IAS).[15,17–21]

A significant proportion of the contemporary data regarding the efficacy and safety of AF ablation in patients with obstruction of the IVC come from a single observational series that described specific techniques that are worthy of attention.[16] First, ICE was used to identify the optimal site for transseptal access, and a more superior and anterior transseptal access point appeared to improve mapping and ablation of the septal segments of the right pulmonary veins. Second, steerable sheaths were routinely used to directly engage the fossa ovalis. Finally, RF needles or wires were used to facilitate transseptal access.

EAM-guided RF ablation for AF was the most common technique (34 patients), although 6 cases of cryoballoon ablation were reported. In one cryoablation procedure, difficulty was encountered in advancing the 15F steerable sheath across the IAS and this was overcome by the use of 6.0 × 29 mm Armada angioplasty catheter to dilate the puncture site.[20] Once left atrial access is achieved,

exchanging to a steerable sheath helped to overcome the tendency of the catheter being directed towards the mitral valve with the superior approach.[17,18] There was one case where the transseptal puncture was performed across prosthetic material (Dacron) following an atrial septal defect repair.[21]

Transseptal access using the transhepatic approach had the inherent advantage of providing a familiar angle of approach to the IAS. SL1 sheath was utilized in five patients and steerable sheath in three patients to perform transseptal punctures. RF needle, RF application to standard needle or RF guidewire were utilized in four patients. Owing to the more posterior RA access point from the hepatic vein, transseptal puncture tended to be more anterior and ablation of the right pulmonary veins was reported to be more challenging.[22] Investigators reported that it was possible to continue conventional anticoagulation algorithms for left atrial ablation following transhepatic access without excess bleeding. There was one case using cryoablation technique for AF ablation using the transhepatic approach.[23] Trans-aortic retrograde approach, with the aid of RMN, was used for AF ablation in two patients.[24]

8 | OUTCOMES AND COMPLICATIONS

Ablation was successful in 135 of 140 procedures in which outcomes were reported. There were no repeat procedures performed in the local cases after their index procedures. In previously reported cases, one patient underwent a repeat procedure for ablation of typical atrial flutter after having had prior ablation for AVNRT. Both procedures were performed successfully using an inferior approach.

In the *superior approach* group, one patient experienced left atrial perforation during attempted transseptal puncture with superior approach and it required thoracotomy and left atrial repair.[22] Haemoptysis was reported in another patient undergoing cryoballoon ablation but it was attributed to irritation from the TEE probe.[19] A patient undergoing AF ablation died 11 days following the procedure after inadvertent entry into an undiagnosed atrioesophageal fistula from a prior convergent epicardial ablation performed 3 weeks before. This complication was thought to be unrelated to the superior approach of access.[16]

In the *transhepatic approach* group, one patient undergoing RF PVI developed a small pericardial effusion that did not require intervention.[22] One patient developed reactive arthritis 16 days following cryoballoon ablation, and it was possibly related to the hemostatic plug.[23] Self-limited scrotal tenderness developed in one patient a day after PVI and a small amount of blood in the pelvis was noted on CT. Anticoagulation was restarted the following day.[25]

In the *transaortic* approach group, one patient developed a groin haematoma associated with pseudoaneurysm requiring thrombin injection following AF and atrial tachycardia ablation using RMN.[24] There were no complications reported in the inferior approach group.

9 | DISCUSSION

This systematic review summarizes the findings of the published literature regarding different approaches for EP procedures in the setting of IVC obstruction.

Congenital interruption of the IVC accounted for 80% of cases of IVC obstruction in the present study, and it has a known prevalence of 0.15% in the general population.[1] Obstruction of the IVC was not known to the operator before their first procedure in 54% of cases in the series because the condition is usually clinically silent and often uncovered *de novo* during interventional procedures.[26] Hence, it is useful for cardiac electrophysiologists to have an understanding of potential pitfalls and solutions for achieving cardiac access when presented with this clinical scenario.

First, CHD and lateralization anomalies are often present in patients with congenitally interrupted IVC,[3] being found in 43% of patients with in this series. This compounds the procedural complexity beyond simple access to the heart. Postponement of the index procedure may be warranted to allow for additional imaging.[27] Adjunctive tools such as TEE, ICE, EAM, long sheaths or RMN are also frequently required in this setting. In terms of acquired IVC anomalies, IVC filters are an emerging issue. Early reports highlighted potential issues with catheter entrapment, filter migration or fracture[28] prompting the use of alternative access approaches in this scenario.[29] However, subsequent reports suggested that IVC filters were not an absolute contraindication to an inferior approach for EP procedures.[30] More recently, a large single centre series has reported on the feasibility of complex transfemoral EP procedures in the majority of patients with IVC filters.[31] A systematic review by Shah et al.,[32] has also demonstrated safety and feasibility of transfemoral access, and hence a standard inferior approach may still be first-line in such patients.

When one considers the conventional inferior approach, it is noteworthy that significant variability exists in the venous system and approximately 6% of patients with congenital IVC obstruction do not have any usable conduits to RA. Conversely, direct access to RA is occasionally possible via anomalous branching from the IVC into hepatic venous system, and this was observed in 2% of patients in this study. However, the usual passage is via azygos or hemiazygos venous connection into the SVC. Catheter manipulation is often challenging although it may be partially overcome by the use of long and/or steerable sheaths. Hence, issues with catheter stability and tissue contact were frequently reported with ablation via the inferior approach, even for relatively simple arrhythmias such as typical right atrial flutter. Transseptal access is generally not feasible via an inferior approach. More recently, novel percutaneous approaches have been described to re-establish access through occluded iliocaval systems.[33–35]

Retrograde transaortic access is familiar to electrophysiologists but provides limited access. It is the most straightforward approach for ablation of left-sided accessory pathways, but otherwise has limited utility for other arrhythmic substrates.

The superior approach is the most frequently used route for performing EP procedures in the setting of IVC obstruction. However,

one should be also aware that additional anomalies of the superior venous return may be present, and ideally this should be excluded by preprocedural imaging. Although it is potentially feasible to place multiple sheaths in IJV,[29] multiple access sites may be required and there is a risk of pneumothorax. Patients have also reported more discomfort with the superior approach. Increased radiation exposure for the operator is also a consideration, and this may be mitigated with the use of EAM and RMN. Transseptal access via the superior approach has been reported. One of the inherent challenges of transseptal access via a superior approach is the displacement of the transseptal apparatus as forward pressure is applied. This may be partially overcome with additional bending of the standard transseptal needle to 120–150°. Moreover, Santangeli and colleagues[16,36] have recently described an elegant technique for overcoming this issue with the use of real-time ICE imaging to identify the optimal site (ideally aiming for the antero-superior aspect of the fossa), deflectable sheath to engage the fossa, and RF needle/wire to cross the fossa.

Transhepatic access is a novel access strategy in patients with obstructed IVC. Transhepatic access has been used in other areas of medicine including for vascular access for dialysis or total parenteral nutrition. It has also been used as an access point for cardiac procedures in the children.[37,38] From an EP perspective, inherent advantages include familiar catheter manipulation, and enhanced stability (because of fewer curves). Moreover, transseptal puncture is feasible although the entry point of the hepatic veins to the RA is more posterior than usual, and this results in a more anterior transseptal puncture.[22] An obvious disadvantage is the limited experience with this approach, and assistance from interventional radiology colleagues is recommended. Hence, it is not a viable "ad hoc bail out" strategy. Complications include bleeding, infection, hepatitis, pancreatitis, pneumothorax, gallbladder perforation and hepatic vein thrombosis. Different methods have been used to achieve post-procedural haemostasis including bipolar RF cauterization, intrahepatic coils, Avitene collagen plug, Gelfoam, placing patients in right lateral decubitus position or simply applying manual pressure.[23,37] Another consideration is the ability to re-access the transhepatic approach for repeat procedures. While this not been specifically reported in the EP literature, cases of repeat transhepatic approach for dialysis access has been described. This may be facilitated by the use of a temporary embolization agent (Gelfoam) to seal the tract in the index procedure, to preserve this access for future use.[39]

There are several potential limitations in this study. Despite a systematic search strategy, it is possible that relevant reports may have been missed. The level of descriptive details was variable, resulting in some missing data. Publications bias should also be considered when considering the apparent high success rate and low number of reported complications.

This systematic review demonstrates that cardiac electrophysiology studies are generally feasible in the setting of IVC obstruction. The superior approach is the most frequently utilized strategy and it provides sufficient access in most cases with a low risk of complications. In cases where transseptal access is required, transhepatic access should be considered as an alternative to superior access if local expertize is available. Careful planning with preprocedural imaging, and the availability of adjunctive equipment such as long sheaths, TEE, ICE, EAM, RMN and/or RF assisted transseptal adjuncts are likely to improve success, especially if there is associated CHD beyond IVC obstruction.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

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

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