Percutaneous management of lead-related cardiac perforation with limited use of computed tomography and cardiac surgery

Short title: Value of CT in CIED-related cardiac perforation

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Background: Cardiac implantable electronic device (CIED)-related perforation is uncommon but potentially lethal. Management typically includes the use of computed tomography (CT) scanning and often involves cardiac surgery.

Methods: Patients presenting to a single referral centre with CIED-related cardiac perforation between 2013 and 2019 were identified. Demographics, diagnostic modalities, the method of lead revision and 30-day complications were examined.

Results: Forty-six cases were identified; median time from implantation to diagnosis was 14 days (IQR= 4-50). Most were females (29/46, 63%), 9/46 (20%) had cancer,18 patients (39%) used oral anticoagulants and no patients had prior cardiac surgery. Active fixation was involved in 98% of cases; 9% involved an ICD lead. Thirty-seven leads perforated the right ventricle (apex: 24) and 9 punctured the right atrium (lateral wall: 5). Abnormal electrical parameters were noted in 95% of interrogated cases. Perforation was visualized in 41% and 6% of cases with CXR and transthoracic echocardiography, respectively. CXR revealed a perforation, gross lead displacement or left-sided pleural effusion in 74% of cases. Pericardial effusion occurred in 26 patients (57%) of whom 11 (24%) developed tamponade, successfully drained percutaneously. Pre-extraction CT scan was performed in 19 patients but was essential in 4 cases. Transvenous lead revision (TLR) was successfully performed in all cases with original leads repositioned in 6 patients, without recourse to surgery. Thirty-day mortality and complications were low (0% & 26%, respectively).

Conclusion: CT scanning provides incremental diagnostic value in a minority of CIED-related perforations. TLR is a safe and effective strategy.

Keywords: Cardiac perforation; cardiac implantable electronic devices; pacemaker; defibrillator; transvenous lead revision.

1. INTRODUCTION

Cardiac perforation is an uncommon but life-threatening complication associated with implantation of cardiac implantable electronic devices (CIED). Its incidence ranges from 0.1% to 0.8% for pacemakers and from 0.6% to 5.2% for implantable cardioverter defibrillator (ICD) leads.[1]

There is a wide range of presentations, from life-threatening cardiac tamponade to incidental discovery during imaging or device interrogation. Cardiac computed tomography (CT) scanning has been advocated as the imaging modality of choice in the diagnosis of CIED-associated cardiac perforation and planning the management.[2] While management has traditionally involved cardiothoracic surgery as recommended by expert consensus[3], transvenous lead revision has been shown to be safe in limited series.[2,4–6] This study aimed to evaluate the outcomes of transvenous lead revision for cardiac perforation at our centre with cardiothoracic surgery on standby and minimal use of CT scanning.

2. METHODS

2.1 Study population

A prospective database of all cases of lead revision is maintained at St. George's University Hospital (SGH), London, UK. SGH is a major tertiary referral centre for cardiac electrophysiology and CIED extraction in South London.[7] For the purposes of this study, all cases of lead revision were reviewed from 1 January 2013 to 1 September 2019 for the evidence of lead perforation (figure 1).

Cases were identified through a detailed review by 2 independent clinicians. Clinical presentation, chest X-rays (CXR), transthoracic echocardiograms (TTE), CT scans, pacing parameters at device interrogation and the revision procedure report were reviewed. Agreement in the diagnosis of cardiac perforation was reached if perforation was visible on imaging or abnormal pacing indices were noted on interrogation with correlating symptoms. Patient demographics, time to diagnosis,

diagnostic modalities, the method of lead revision and 30-day complications were examined.

The study proposal was approved by the Research Ethics Committee and complies with the principles of the Declaration of Helsinki.

2.2 Definitions

Acute lead perforation was defined as perforation detected during or within 24 hours after implantation. Subacute perforation occurs 24 hours to 29 days after implantation and delayed perforation occurs 30 days or more after implantation. Procedure success and complications were assessed with reference to the definitions outlined in the 2017 Heart Rhythm Society (HRS) consensus document.[8]

2.3 Revision procedures

Revision procedures involving a perforated lead followed a standard protocol. Perforating leads were removed and replaced during the same procedure; repositioning of the culprit lead was purely operator choice. All lead revision procedures were performed in the electrophysiology laboratory with continuous electrocardiographic and arterial blood pressure monitoring with a cardiac surgical team, anesthetic backup, and operating theatre available on standby. The procedure was performed under local or general anesthesia, based on operator discretion and patient's general condition.

Pericardiocentesis was performed before lead manipulation in patients with large or hemodynamically significant pericardial effusion. In these cases, the pericardiocentesis catheter remained in position until after the perforating lead had been revised. Perforating leads were explanted in a stepwise manner: Simple traction was initially attempted (after retraction of the screw in cases of active fixation leads); where this was unsuccessful, a Liberator Locking Stylet (Cook Medical, Bloomington, Indiana, USA) was used, with reapplication of traction.

Venous access was preserved methodically in all cases. After withdrawal of the fixation helix, the lead was cut close to the IS-1 connector, and then a sheath slightly larger than the lead was advanced over it to enter the implant vein. The sheath used was a standard peripheral vascular sheath (St Jude), modified by removal of the hub and

associated valve. The lead was withdrawn through this sheath, then one or more guidewires were advanced through the sheath. The sheath was removed, and a peel-away sheath was advanced over the guidewire and used to implant the new lead. In all lead replacement cases, the new lead was an active-fixation model implanted at a different cardiac site to the one that had been removed.

2.4 Post-procedure follow-up

During hospital stay, daily clinical and echocardiographic assessment were carried out to rule out new-onset or worsening pericardial effusion. In patients in whom pericardiocentesis was performed, the catheter was removed once the daily fluid drainage was <40 mL. CXR and device interrogation were performed before discharge. Patients were regularly followed afterwards at SGH device clinic, or at their local hospitals according to patient preference.

2.5 Statistical analysis

Categorical variables were displayed as counts and percentages and continuous variables were reported as mean ± standard deviation (SD) if normally distributed and as median and interquartile range (IQR) if not normally distributed. The distribution of continuous variables was assessed for normality with Shapiro-Wilk test. Statistical analysis was performed using SPSS statistical software, version 26 (IBM Corp., Chicago, IL, USA).

3. RESULTS

Over the study period, 15709 devices were implanted at SGH or in the centres that routinely refer complicated cases to this tertiary centre, and 584 device revisions were performed for various indications. A total of 46 lead perforation cases were managed at SGH, with an incidence of 0.29%; the majority (27/46; 59%) were originally implanted at this institute. All patients were managed without cardiac surgical intervention.

In this series, most cases with perforation were female (29/46, 63%) aged 77 ± 12 years with a high body mass index (27.2 ± 6.4 kg/m^2) and a left ventricular ejection

fraction of 52 ± 11%. Hypertension (61%), coronary artery disease (30%), atrial fibrillation (28%) and cancer (20%) were the most common co-morbidities; no patients had a prior history of cardiac surgery. A high proportion (39%) used oral anticoagulants, whilst 24% required an anti-platelet agent (table 1).

3.1 Implantation characteristics

In our study, most of the leads causing perforation were pacing leads (42/46, 92%), of an active fixation mechanism (45/46, 98%) (table 2). Most culprit leads were positioned in the right ventricle (37/46, 80%), predominantly at the apex (24/37, 65%). Of the 9 right atrial perforation cases, the majority were positioned at the lateral wall (5/9, 56%) despite the infrequent use of this site (table 3). Out of the five perforations associated with ICD implantation, four were caused by the right ventricular (RV) high-voltage lead and one was caused by the right atrial pacing lead. The implantation procedures were carried out by experienced operators in 29/45 cases (64%) and trainees in 16/45 cases (36%), the implantation procedural details could not be retrieved for one case implanted outside SGH.

3.2 Clinical presentation

The median time from implant to initial presentation raising clinical suspicion of perforation was 14 days (IQR= 4 - 50 days). Seven patients (15%) presented with acute perforation, 23 patients (50%) with subacute perforation and 16 patients (35%) with delayed perforation (table 3).

Symptoms suggestive of cardiac perforation were reported in 30 patients (65%), while the suspicion in the remaining cases was raised by device interrogation parameters. The most common symptoms were chest pain, present in 20 patients (44%); dyspnea, present in 15 patients (33%) and presyncope in 6 patients (13%). Chest pain was more common in patients presenting with subacute perforation (15 of 23, 65%) than delayed perforation (3 of 16, 19%), p= 0.004. Eleven patients (24%) presented with symptoms and clinical features consistent with cardiac tamponade and underwent urgent pericardiocentesis; 3 of these had acute, 4 had subacute and 4 had

delayed perforation. Four patients presented with hemothorax, requiring intercostal tube drainage. Blood transfusion was required in 5 patients, 4 of whom had cardiac tamponade and one had hemothorax.

3.3 Device interrogation

While high capture threshold was the principal abnormality bringing CIED-related perforation to medical attention in 16 patients (35%) (table 3), pre-revision device interrogation revealed abnormal pacing parameters in 41 of 43 patients (95%). The most frequent abnormality was high capture threshold, noted in 32 patients, while loss of capture was documented in 9 cases. Absence of sensing and abnormal lead impedance were noted in 3 and 4 patients respectively.

3.4 Chest radiography

CXR was performed in all patients before lead revision (figure 2). A clear perforation, with the lead tip outside the cardiac silhouette, was identified in 19 cases (sensitivity= 41%). Either a perforation, gross lead displacement or left-sided pleural effusion could be detected in 34 cases (sensitivity= 74%).

3.5 Transthoracic echocardiography

TTE was performed in all patients. CIED-related perforation was visualized in 6 cases (13%) (figure 3), while 26 cases (57%) had pericardial effusion. Twenty-nine cases (64%) had one of the following: visualized perforation, pericardial effusion or pleural effusion.

3.6 Computed tomography

CT was performed in 19 patients (41%), for various indications (table 3). Most of these scans were requested in the acute setting by emergency physicians in the investigation of chest pain, often interpreted as suggestive of pulmonary embolism or aortic dissection. CT imaging was deemed essential for the diagnosis of perforation in only 4 cases (figure 4), all of whom had minor, non-diagnostic abnormalities on device interrogation and no clear evidence on echocardiography or chest radiograph. In one

case, CT demonstrated cardiac perforation in a patient with a known chronic pericardial effusion before pacemaker implantation. In a separate case, the fact that the lead exited the heart was obscured in the chest radiograph by the presence of hemothorax. In two other patients, CT helped exclude clinically suspected competing causes of chest pain, namely pulmonary embolism or aortic dissection. Other than confirming the diagnosis of perforation, the CT did not contribute to planning the management in any case.

3.7 Management of perforation

Transvenous lead revision was performed in all confirmed cases of CIED-related cardiac perforation, with the decision to replace or reposition the culprit lead at the operator's discretion. Pericardiocentesis was carried out prior to lead revision in 14 patients (30%); eleven of whom had cardiac tamponade. Eleven procedures (24%) were performed under general anesthesia with transesophageal echocardiographic monitoring.

In line with our institute practice, the culprit leads were removed completely without testing their integrity in forty cases (87%), while the leads were tested and repositioned in 6 cases (13%). Simple traction with standard stylets was sufficient in 45 (98%) patients while a Liberator Locking Stylet (Cook Medical Inc.) was required in one patient. New leads were successfully implanted at new locations with adequate parameters during intra-procedure interrogation.

3.8 Follow-up

After lead revision, the symptoms resolved in all patients; clinically and echocardiographically there was no indication of pericardial effusion. Twelve patients (26%) suffered procedure-related complications, the most frequent of which was hospital-acquired pneumonia (6/46, 13%). Esophageal perforation related to transesophageal echocardiography probe occurred in one patient, who was managed conservatively and made a good recovery despite a prolonged hospital stay.[9] Two patients (4%) developed acute kidney injury, with one attributed to pneumonia driven sepsis. Two patients (4%) experienced heart failure decompensation, one case (2%) was complicated with pocket infection and another (2%) was complicated by infection of a prosthetic hip joint. There was no difference in the incidence of complications

between revisions conducted under local anesthesia (8/35, 22.8%) and general anesthesia (4/11, 36.4%, p=0.37). The median length of stay was 7 days (IQR= 3– 10 days), following which 37 patients (82%) were discharged home and the others transferred to local hospitals; there was no procedural or 30-day mortality.

4. DISCUSSION

Lead perforation is a potentially life-threatening complication of CIED implantation. Our cohort shows that 85% of cases were diagnosed > 24 hours after implantation and 35% > 30 days after implantation, similar to other recent series.[6] As in previous series, our data showed that clinical presentation with CIED-related perforation can vary widely.[2,4,10] While 24% of patients in our series presented with cardiac tamponade, 35% of patients in our series had no symptoms and were brought to attention because of abnormal device interrogation parameters.

Clinical characteristics of CIED-related cardiac perforation

In concordance with previous literature, a greater proportion of the patients in this series were female. As expected, given the population's age, there was a substantial burden of cardiac and extracardiac comorbidities, while the absence of cardiothoracic surgery may hint at a protective effect. It is possible that the intra-thoracic adhesions following cardiac surgery encapsulate the heart and apply a 'reinforcing' effect on the myocardium to potentially prevent perforation. Thirty-nine percent of patients were receiving an oral anticoagulant, and while it is unlikely that anticoagulants caused a perforation, they may have augmented the clinical significance of a minor perforation.

Our data showed that the overwhelming majority of CIED-related perforation involved active fixation leads, which is consistent with several previously published studies.[2,10] This has been attributed to the helical screwing fixation mechanism, which can penetrate through the myocardium. A population-based cohort study, however, failed to confirm this observation.[11] This suggests that the relationship between active fixation mechanism and cardiac perforation may not be causal. Rather, the higher prevalence of active leads in the overall population translates into a higher likelihood of

perforations involving active fixation leads. As such the fact that most perforations in this study involved active fixation leads does not prove a higher risk of perforations with this fixation mechanism.

Most of the culprit leads were Medtronic 5076 pacing leads (64.4%), but this was the most frequently implanted lead in our region during the study period. This fact, together with the good safety record of this lead model, suggests that there is no excess of risk of perforation with the 5076. According to Medtronic's product performance reports, which monitor lead implant numbers and complications during the first 30 days after implantation across the United States, there were 1,212 reported cases of cardiac perforation out of 2,777,413 Medtronic 5076 leads registered as of July 31, 2020 (0.04%).[13]

While ventricular perforation accounted for 80% of our cohort, CT scans in asymptomatic patients suggest that atrial perforation may be more frequent, which is mechanistically plausible given its thinner myocardium.[14] The difference may be due to ventricular perforations tending to be more symptomatic and easier to recognize with lead migration, than atrial perforations; this merits consideration in larger studies. In 11 cases, cardiac perforation occurred despite the operators' intention to place the RV lead in the interventricular septum. This may highlight the limitations of fluoroscopic imaging to identify septal lead position in the setting of challenging patient anatomy.

Incremental value of CT scanning in diagnosis

It has been suggested that CT scanning is essential in managing lead perforations, both to confirm the diagnosis and to define the position of the perforated lead to plan a management strategy. Although it is a sensitive imaging modality in this setting,[2] it comes with extra cost and higher radiation exposure than other modalities. Our data showed the diagnosis of CIED-related perforation could be made in 91% of patients without the need for CT. In our experience, the majority of CT scans (63%) were requested by non-cardiologists in the very acute setting for non-cardiac differentials. A combination of abnormal CXR/TTE and pacing parameters in these cases would have led to the correct diagnosis without necessitating a CT, other than in a small proportion (9%) where other evidence was equivocal. Our experience indicates that the

greatest utility of CT occurs acutely to exclude life-threatening causes of chest pain, and also when other radiographic abnormalities hamper the interpretation of CXR or TTE. The true value of CT usage can be limited to cases where diagnostic uncertainty persists despite the clinical assessment, device interrogation, CXR and TTE (Figure 5). Management can subsequently follow the same streamlined steps in cases with a variety of extracardiac lead-tip positions irrespective of the imaging modality.

Transvenous vs Surgical Revision

In accordance with the 2017 HRS expert consensus statement, transvenous lead revision in our series successfully removed all culprit leads which caused symptoms, hemodynamic compromise or had abnormal electrical parameters.[7] Only one case involved a recently implanted asymptomatic lead. While a consensus statement endorsed by the American Heart Association favors surgical management,[3] several limited case series endorse the approach we adopted, with procedure success rate ranging from 92% to 96%.[2,4,6,10] The safety of this method has been attributed to a sealing effect of the surrounding myocardium or the newly formed fibrous tissue combined with the low pressure in the right heart.[6]

The tip of the perforating lead in 11 patients (24%) of our series was located outside the pericardial space, the removal of which was uneventful, other than an esophageal injury due to the precautionary use of transesophageal echocardiography. While surgical management has been traditionally advised in similar instances,[15] recent case series demonstrated the safety of a percutaneous approach.[16]

Having performed transvenous revision in 46 consecutive patients without mortality or need for emergency surgical intervention, we must dispute the wisdom of routine surgical intervention in this cohort. The patients are typically frail, and we would have anticipated an even higher rate of serious complications if all 46 had undergone surgical repair via a sternotomy or thoracotomy. The availability of standby surgical assistance is very reassuring during these procedures, but as we have not had to activate this service suggests that these revisions could be considered in a non-surgical centre for patients in whom transfer to a surgical centre might exacerbate risk.

The majority of revision procedures (76%) were performed under local anesthesia with cardiac surgery on standby in operating rooms adjacent to the electrophysiology labs. Prior experience from other procedures in our centre suggests that we can achieve an interval of less than 15 minutes or less from surgical decision to skin incision with this arrangement when the need arises. General anesthesia was used in the 11 cases where the anticipated likelihood of recourse to surgery seemed higher, with no significant difference in the rate of complications compared to local anesthesia.

Transvenous lead revision was performed in all confirmed cases of CIED-related cardiac perforation, with the decision to replace or reposition the culprit lead at the operator's discretion. It is our institutional practice to replace the culprit lead, partly from concern that the perforation may have arisen from a defect in the initial lead, partly from concern that the steroid that is normally eluted from the lead tip may have become depleted by the time it is revised, leaving it vulnerable to adverse inflammation at the tissue interface. In the 6 cases where the leads were tested, they were found to be intact and were subsequently repositioned, suggesting this is also an acceptable option.

4.1 Limitations

This is a retrospective single-centre data set. High voltage leads were not well represented in this series and our findings may not be applicable to these.

Due to the low incidence of CIED-related cardiac perforation (0.29%), together with the absence of an ideal method for selecting control patients, identifying independent predictors is extremely challenging and probably requires pooling data from multiple tertiary centres.

5. CONCLUSION

Transvenous lead revision is a safe and effective first-line management strategy in cardiac perforation associated with CIED leads. CT imaging provides incremental diagnostic value in only a minority of CIED-related perforations.

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Figure legends:

Figure 1: Summary of the study findings- Insets: (A) Fluoroscopy of the needle accessing the pericardial space during pericardiocentesis. (B) CXR showing the ventricular lead outside the cardiac silhouette (arrow). (C) TTE showing the atrial lead in the pericardial space (arrow). (D) CT scan showing an extracardiac ventricular lead (arrow). (E) Fluoroscopy of transvenous lead revision. CIED= cardiac implantable electronic device; CT= computed tomography; CXR= chest radiograph; TTE= transthoracic echocardiography.

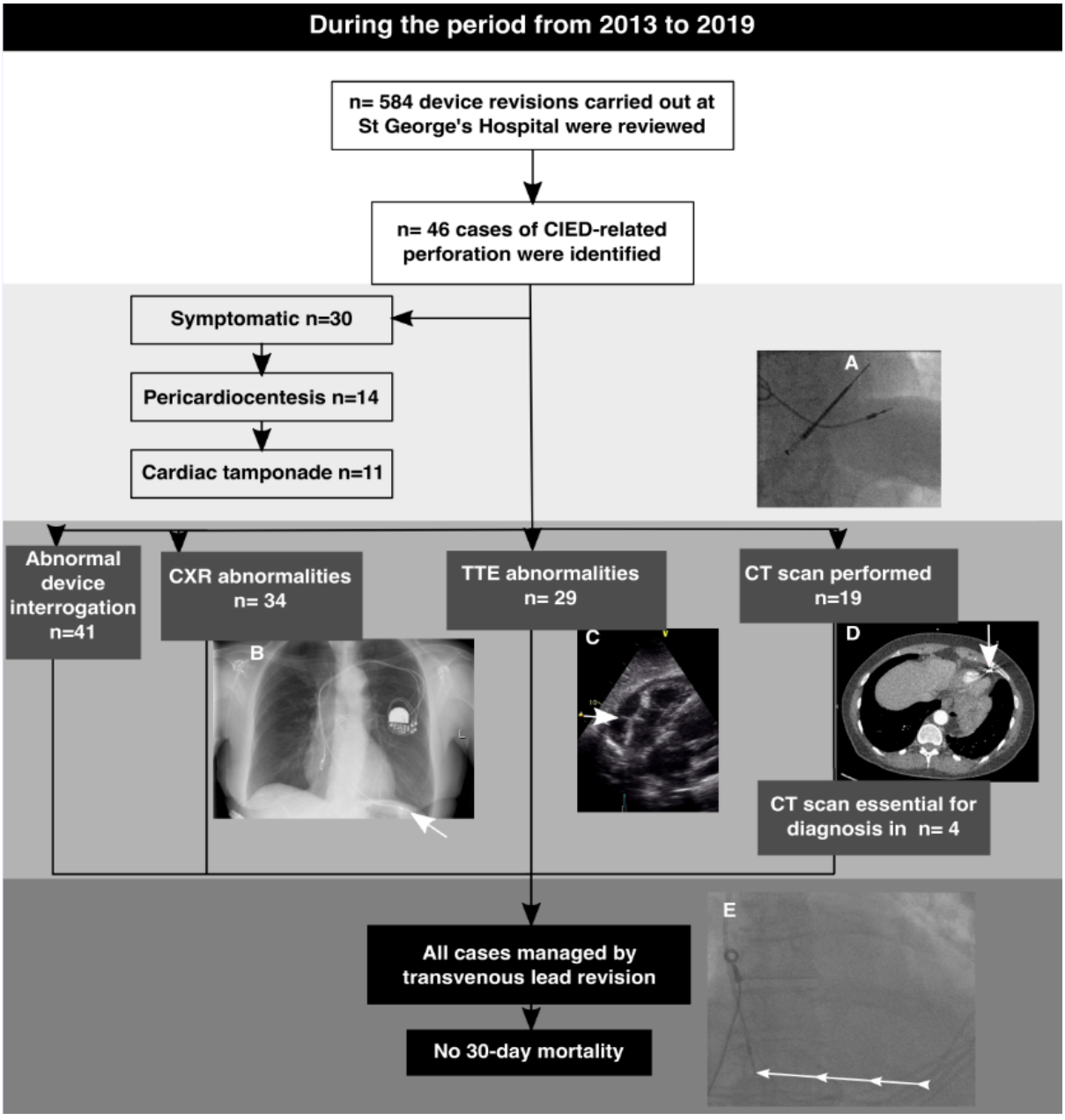

Figure 2: Radiographic characteristics of lead perforation- The relation of the right ventricular (RV) lead tip (white arrow) is demonstrated relative to the cardiac silhouette (white dotted line). (A) Posteroanterior (PA) chest radiograph (CXR) post implantation showing the tip of the RV lead in the right hemithorax (B) Lateral CXR in the same patient as A showing that the lead tip is posteriorly directed. (C) PA CXR showing RV lead tip outside the cardiac shadow. (D) Lateral CXR in the same patient as C showing the lead tip to be anteriorly directed. (E) PA CXR showing abnormal RV lead position. (F) Lateral CXR in the same patient as E, with the RV lead tip outside the free wall of the RV outflow tract.

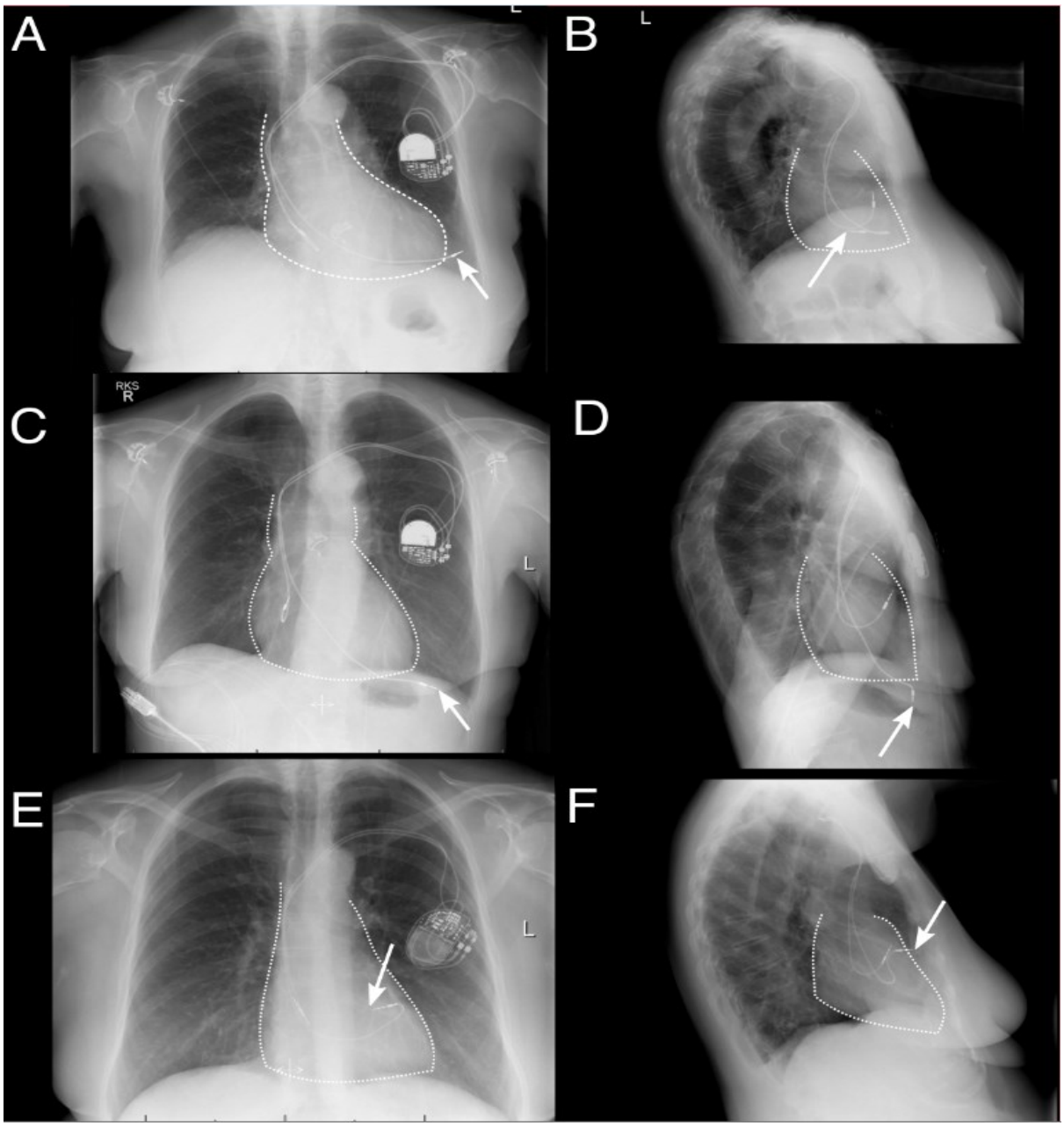

Figure 3: Echocardiographic characteristics of lead perforation- (A)Transthoracic echocardiogram, subcostal view demonstrating right atrial lead perforation with the lead tip in the pericardial space (white arrow). (B) Transthoracic echocardiogram, apical view demonstrating right ventricular apical lead perforation, where the lead is visualized in the pericardial space anterior to the left ventricular apex (black arrow). LA= left atrium; LV=left ventricle; RA= right atrium; RV= right ventricle.

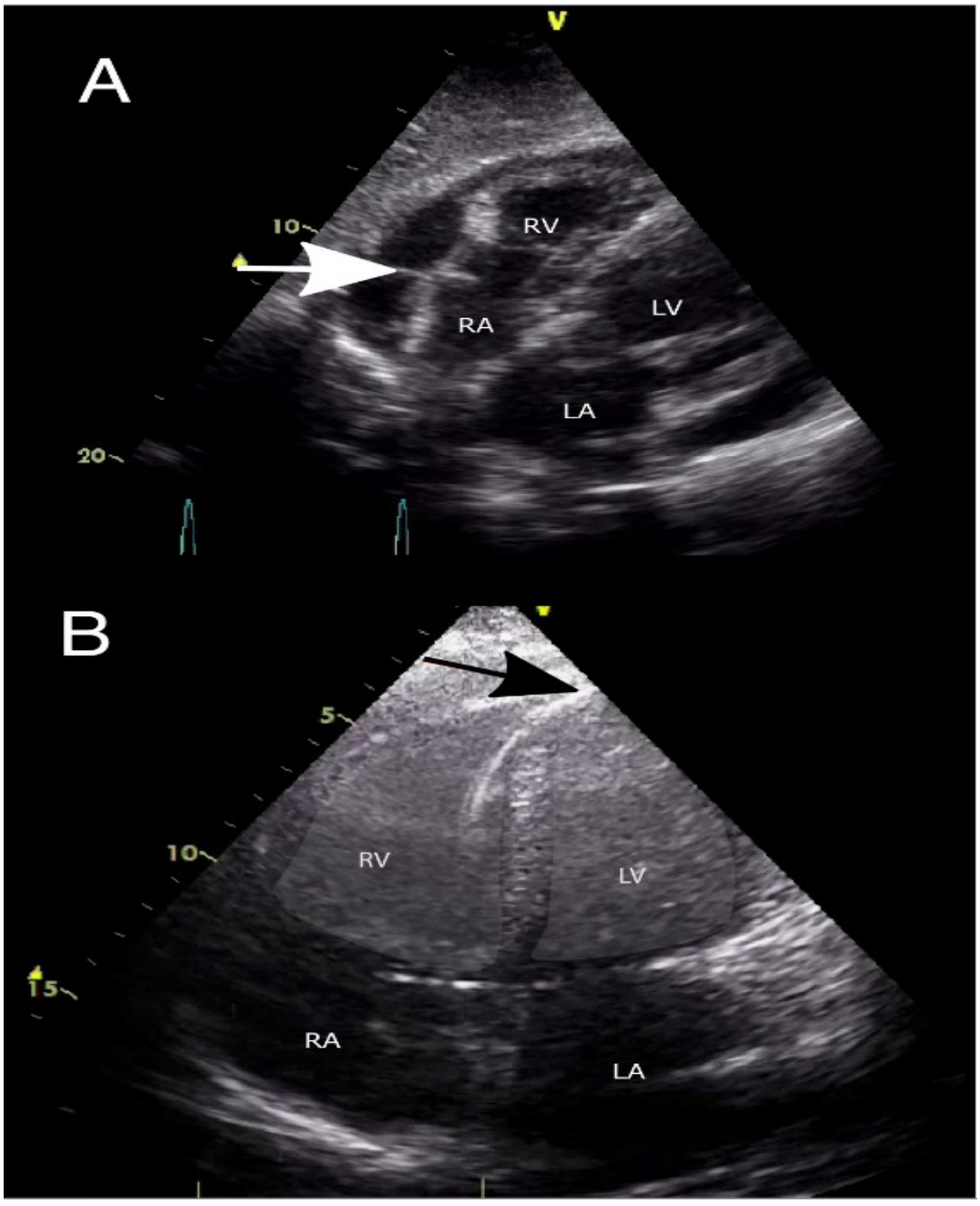

Figure 4: Computed tomography scans of the 4 patients in whom chest radiographs, transthoracic echocardiograms and device interrogation were non-diagnostic - In all cases, the lead tip (white arrow) is seen outside the confines of the cardiac chambers. Initial diagnostic uncertainty was compounded by suspicion of aortic dissection and pulmonary embolism in A and B, pericardial effusion predating implantation in C and hemothorax in D.

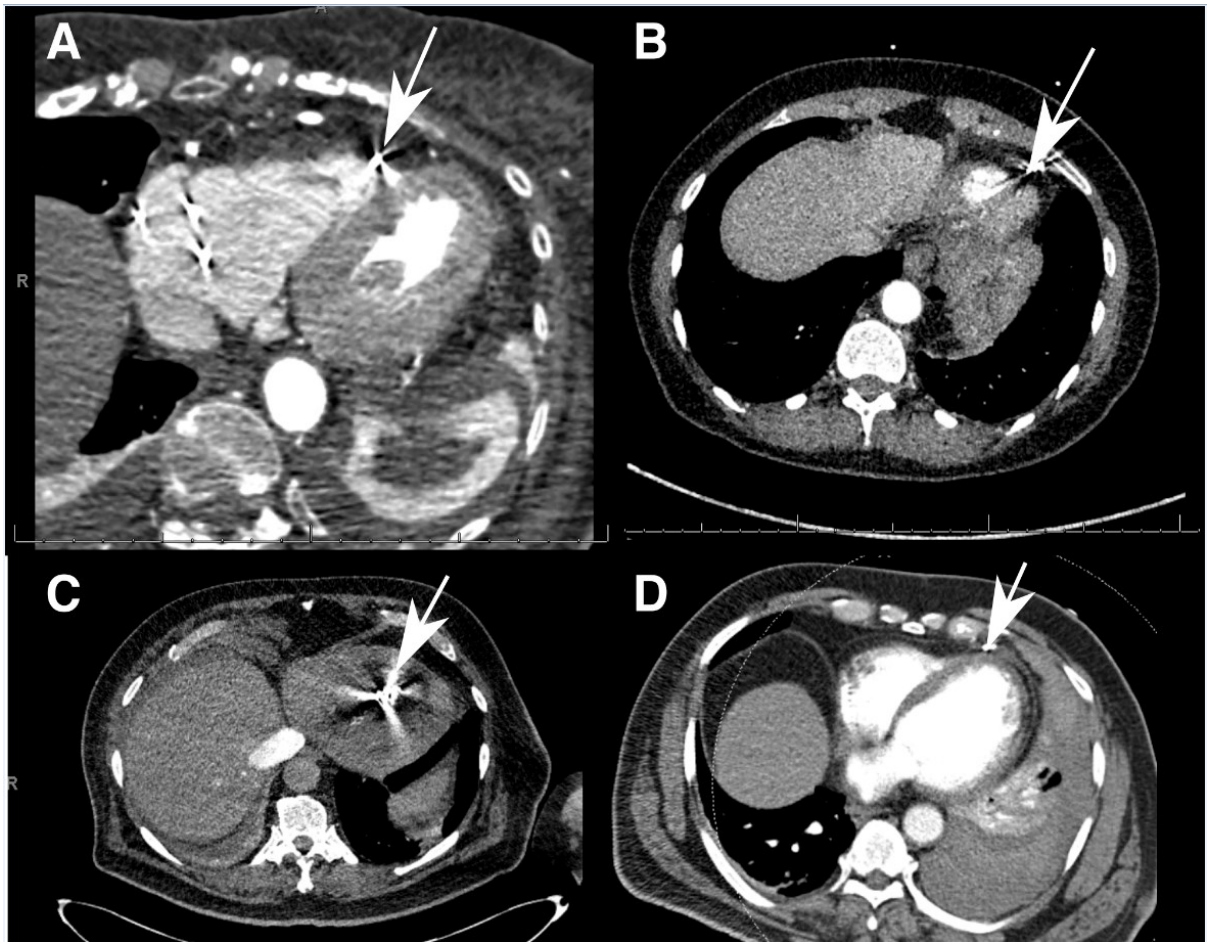

Figure 5: Proposed management algorithm for patients in whom clinical suspicion of CIED-related cardiac perforation is raised- Management is presented in 3 steps: clinical assessment, basic investigations, and CT scanning. A CT scan becomes unnecessary if the diagnosis is confirmed (white boxes) or excluded (black boxes). *Most common symptoms were chest pain, dyspnea and presyncope (seen in 65% of our cases). ** If device interrogation had not been already performed. †This may involve intravenous fluid administration, red blood cell transfusion, pericardiocentesis and intercostal tube as appropriate. As an alternative to CT imaging, altered pacing

parameters can provide sufficient evidence of lead perforation in the absence of other explanations for pericardial/pleural effusion, resulting in lead revision. ‡ Alternative diagnosis is often demonstrated by either TTE (acute coronary syndrome, pulmonary embolism, ascending aortic dissection) or CXR (pneumothorax). CIED= cardiac implantable electronic device; CT= computed tomography; CXR= chest radiographs (posteroanterior and lateral); TTE= transthoracic echocardiography.

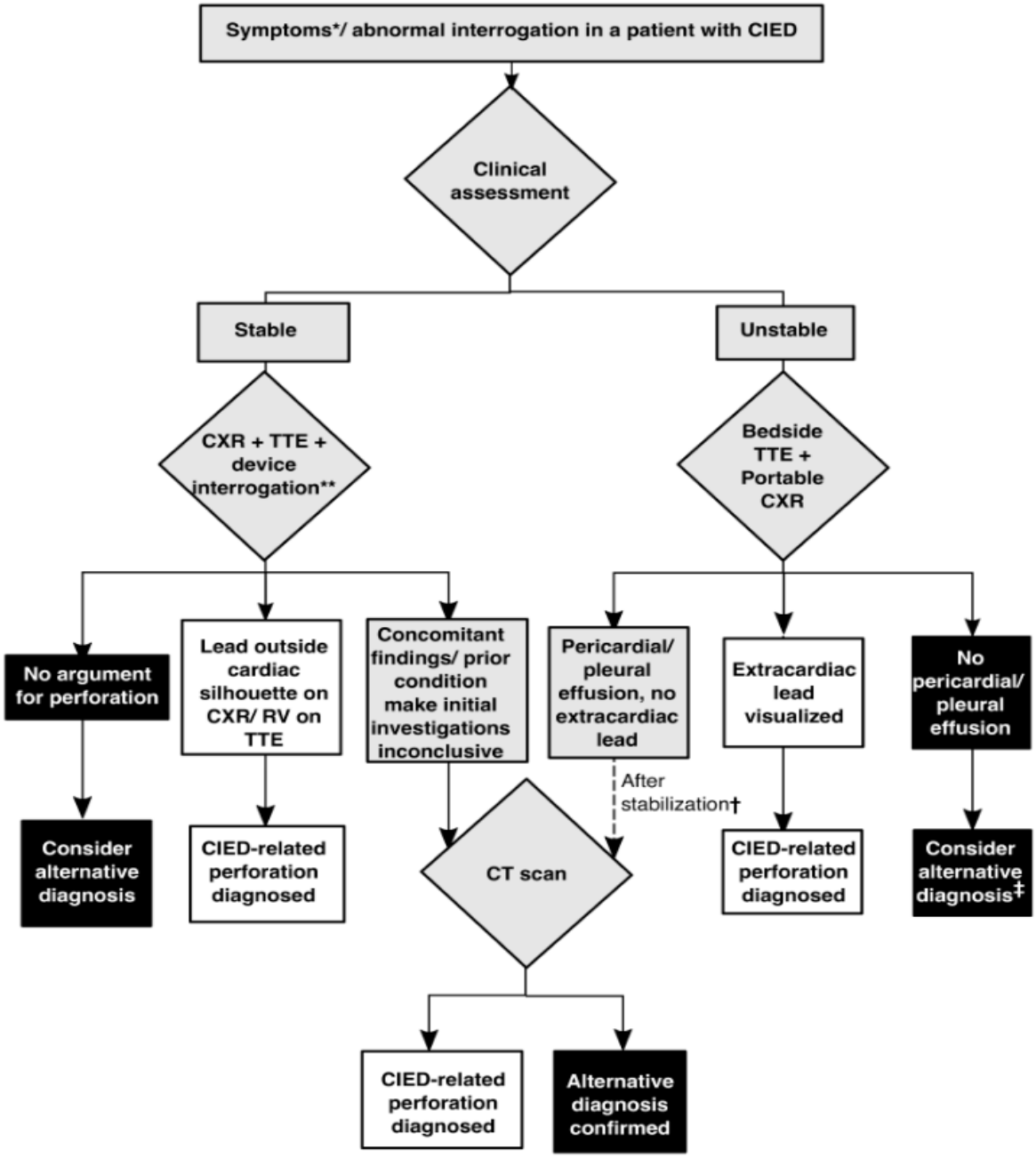

Table 1: Patient and device characteristics

Variables	**Cases (n= 46)**
Age (y)	*77 ± 12*
Female sex	*29 (63)*
BMI (kg/m2)	*27.2 ± 6.4*
Comorbid conditions	
Hypertension	*28 (61)*
Diabetes mellitus	*8 (17)*
Coronary artery disease	*14 (30)*
ICM	*2 (4)*
NICM	*2 (4)*
AF	*13 (28)*
Atrial flutter/ tachycardia	*3 (6)*
Chronic kidney disease	*8 (17)*
COPD	*3 (7)*
Cancer	*9 (20)*
Previous cardiac surgery	*0 (0)*
LVEF (%)	*52 ± 11*
Pericardial effusion before implant	*2 (4)*
INR	*1.3 ± 0.8*
Hemoglobin (g/l)	*117 ± 16*
Platelets (x 10^3/mm^3)	*224 ± 65*
Indication for device implantation	
AV block	*22 (49)*

Sinus node dysfunction	*18 (39)*
Slow AF	*1 (2)*
Cardiac arrest	*1 (2)*
Heart failure	*4 (9)*
Medications	
Aspirin	*10 (22)*
Clopidogrel	*1 (2)*
Warfarin	*10 (22)*
NOACs	*8 (17)*
Steroids	*9 (13)*
Indication for antithrombotic medications	
CAD	*9 (32)*
AF/ flutter	*16 (35)*
VTE	*2 (4)*
Post- TAVI	*1 (2)*

Values are mean ± standard deviation or n (%). AF= atrial fibrillation; BMI= body mass index; CAD= coronary artery disease; COPD= chronic obstructive pulmonary disease; CRT-P= cardiac resynchronization therapy pacemaker; g/l= grams per liter; ICD= implantable cardioverter defibrillator; ICM= ischemic cardiomyopathy; INR= international normalized ratio; LVEF= left ventricular ejection fraction; mm^3= cubic millimeters; NICM= non-ischemic cardiomyopathy; NOAC= non-vitamin K oral anticoagulants; TAVI= transcatheter aortic valve implantation; VTE= venous thromboembolism; y= years.

Table 2: Characteristics of the CIED responsible for lead perforation

Manufacturer	**CIED implanted**	**N (%)**	**Culprit lead model**	**N (%)**	**Fixation**	**N (%)**
Medtronic	*Dual chamber pacemaker*	24	*5076*	29 (64.4)	Active	28 (62.2)
					Passive	1 (2.2)
	Single chamber pacemaker	3				
	Biventricular pacemaker	1				
	Dual chamber ICD	1 *				
Boston Scientific	*Dual chamber pacemaker*	7	*Ingevity 7742*	7 (15.6)	Active	7 (15.6)
	Dual chamber ICD	3	*Endotak Reliance*	3 (6.7)	Active	3 (6.7)
Biotronik	*Dual chamber pacemaker*	1	*Solia*	1 (2.2)	Active	1 (2.2)
St Jude Medical†	*Single chamber ICD*	1	*Durata*	1 (2.2)	Active	1 (2.2)
Sorin‡	*Dual chamber pacemaker*	4	*Vega*	4 (8.9)	Active	4 (8.9)

Values are represented as number (N) and percentage of the total cohort (%). CIED= cardiac implantable electronic device; ICD= implantable cardioverter defibrillator. * The culprit lead was the right atrial pace-sense lead. † Currently Abbott, St. Paul, MN, USA. ‡

Currently Microport, Shanghai, China. The implantation procedural details could not be retrieved for one case involving a dual chamber pacemaker with active fixation leads.

Table 3: Diagnosis and management of perforation

Variable	**Perforation cases (n=46)**
Presenting features	
Chest pain	20 (44)
Presyncope	6 (13)
Dyspnea	15 (33)
Asymptomatic abnormal device interrogation parameters	16 (35)
Cardiac tamponade at presentation	11 (24)
Pericardial effusion before revision	26 (57)
Pericardiocentesis performed	14 (30)
Hemothorax at presentation	4 (9)
Implantation site of culprit lead	
Right atrium	9 (20)
Lateral wall	*5 (11)*
Right atrial appendage	*4 (9)*
Right ventricle	37 (80)
Apex	24 (52)
Free wall	2 (4)
*Interventricular septum**	11 (24)
Extracardiac lead tip	
No	3 (7)
Pericardial	23 (50)
Pleural space	10 (22)

Intercostal muscles	1 (2)
Not reported	9 (20)
Time since implant (days)	14 (4-50)
Acute (< 24 hours)	7/46 (15)
Subacute (24 hours - 30 days)	23/46 (50)
Delayed (> 30 days)	16/46 (35)
Indication for CT scan	
CT performed	19 (41)
Suspected pulmonary embolism	5/19 (26)
Suspected lead perforation	8/19 (42)
Suspected aortic dissection	3/19 (16)
Investigation for suspected hemothorax	2/19 (11)
To investigate the source of sepsis	1/19 (5)
Transvenous lead revision successful	46 (100)
Standard stylet only	45 (98)
Locking stylet	1 (2)
General anesthesia	11 (24)
30-day mortality	0 (0)
30-day complications	12 (26)
Sepsis	3 (7)
Pneumonia	6 (13)
Pocket infection	1 (2)
Hemothorax	1 (2)
Esophageal perforation	1 (2)
Length of stay (days)	7 (3-10)

Home discharge	37 (82)

Values are n (%), or median (interquartile range). CT= computed tomography. * While perforation of the interventricular septum is unlikely, these may be due to difficulty distinguishing the right ventricular free wall from the septum with challenging patient anatomy or subsequent lead dislodgement.