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Management of Arrhythmias and Cardiac Implantable Electronic Devices in Patients with Left Ventricular Assist Devices

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Ventricular Arrhythmia

Catheter Ablation

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Left Ventricular Assist Device (LVAD)

Congestive Heart Failure

Abstract

For patients with end stage heart failure, the use of mechanical circulatory support has increased in the last decade due to improved outcomes with durable left ventricular assist devices (LVADs). The management of these complex patients requires coordinated care by a multidisciplinary team including cardiac electrophysiologists since atrial and ventricular arrhythmias are prevalent in this population. There have been an increasing number of studies that attempt to address issues regarding arrhythmia management in patients with LVADs. The purpose of this review is to provide electrophysiologists with an evidence-based approach to manage a broad spectrum of arrhythmia issues in these patients.

Abbreviations

AF: atrial fibrillation

BTT: bridge-to-transplant

CF-LVAD: continuous-flow left ventricular assist device

CIED: cardiac implantable electronic device

CRT: cardiac-resynchronization therapy

DFT: defibrillation threshold

DT: destination therapy

ECG: electrocardiogram

EMI: electromagnetic interference

ERI: elective replacement indicator

HMII: Heartmate II

HMIII: Heartmate III

HVAD: Heartware

ICD: implantable cardioverter-defibrillator

ICM: ischemic cardiomyopathy

INR: International Normalized Ratio

LAA: left atrial appendage

LAVA: local abnormal voltage activity

LBBB: left bundle branch block

LV: left ventricle

LVAD: left ventricular assist device

NICM: non-ischemic cardiomyopathy

PVI: pulmonary vein isolation

RBBB: right bundle branch block

Sub-Q ICD: subcutaneous implantable cardioverter-defibrillator

TE: thrombo-embolic events

VA: ventricular arrhythmia

VF: ventricular fibrillation

VT: ventricular tachycardia

Introduction

The use of mechanical circulatory support to treat end stage heart failure has increased in the last decade due to improved clinical outcomes from durable continuous flow (CF) left ventricular assist devices (LVADs) (1-4). In the US the yearly implantation rate has increased from 242 LVADs in 2007 to around 2500 LVADs presentlyduring the last 4 years (5). Approximately half of these patients receive LVADs as a bridge-to-transplantation (BTT), while the other half receive LVADs as destination therapy (DT) (5), but these treatment strategies often change over time (6). There is also increasing interest in using these devices as a bridge to recovery with explantation for certain indications (7). In all these patients, arrhythmias are associated with morbidity and mortality (8), and electrophysiologists are essential in their multidisciplinary management. The purpose of this review is to provide a comprehensive overview of the literature for cardiac electrophysiologists to address the management of atrial and ventricular arrhythmias in patients with LVADs.

Current LVAD Technology and Implantation Technique

Since the development of the first pulsatile flow LVAD, continuous flow (CF) LVADs have become the predominant type of LVAD, due to improved outcomes (2). As depicted in Figure 1, the two main types of CF-LVADs are the axial pumps, including the HeartMate II (HMII, Abbott, Chicago, IL), and centrifugal pumps, including Heartware, (HVAD, Medtronic, St. Paul, MN) and HeartMate III (HMIII, Abbott). Both types of pumps take blood from the left ventricle (LV) via an inflow cannula at the LV apex into a pump thatand ejects blood through an outflow cannula sewn into the ascending aorta (9). The pumps

are powered by a battery via a driveline that exits the skin at the right anterior subcostal abdominal wall. ~~The difference between an axial vs centrifugal pump is that a~~An axial pump has a rotating impeller that directly propels the blood, while a centrifugal pump is smaller and consists of a spinning disk that ejects the blood.

——During LVAD implantation, a core of myocardium is excised from the LV apex, into which an inflow cannula is sewn. Cardiopulmonary bypass is ~~used~~ performed with cannulation of the right atrial appendage. If tricuspid or mitral valve repair is performed, an incision in the anterior atrial wall is made. All these sites are potential substrates for arrhythmias.

The typical anticoagulation strategy after LVAD implantation consists of oral anticoagulation with warfarin (INR goal 2-3) and an antiplatelet agent (usually aspirin) to prevent thrombosis. LVAD patients have a higher risk of bleeding due to anticoagulation and a pump-induced coagulopathy (10). Complications related to both thrombosis and bleeding are common after LVAD implantation, manifesting with gastrointestinal bleeding, ischemic and hemorrhagic strokes and pump thrombosis (5).

Management of Ventricular Arrhythmias in Patients with LVADs -

Epidemiology and Impact of Ventricular Arrhythmias

Ventricular arrhythmias (VAs) are common in patients with LVADs, occurring in 20 – 50% of patients (11-16). Predictors of VAs after LVAD implantation include the presence of pre-LVAD VAs (8), ischemic cardiomyopathy (12) and absence of beta blocker therapy (14). VAs have been

reported to occur more frequently in the first 30 days after LVAD implantation as compared to before LVAD implantation or in the period 30-150 days after implantation (12, 17). The occurrence of VAs, especially within 1 week of LVAD implant, is associated with higher mortality (18, 19). Due to hemodynamic support provided by the LVAD, VAs are frequently tolerated hemodynamically over the short term, though they can have significant consequences (8). For example, VAs have been shown to drop cardiac output by as much as 32% in ~~a study of~~ HMII patients (20). Sustained VAs that are not appropriately treated by ICD therapy (lasting up to 2 weeks) have been associated with cardioembolic events and shown to exacerbate right ventricular (RV) failure requiring treatment with inotropes, pulmonary vasodilators or RVAD insertion (8, 13). These data advocate for the need to promptly recognize and treat sustained VAs.

Identification of Reversible Causes of Ventricular Arrhythmias

Although post-LVAD VAs may be due to pre-existing arrhythmogenic substrate, (13, 21, 22) it is important to recognize that the higher incidence of VAs in the immediate post-operative period may be partly due to reversible factors such as suction events (10%), severe electrolyte shifts (4%), and greater use of inotropes post-operatively (43%), as reported in a study of 38 patients with VAs within 30 days of implant (13). Suction events occur from sudden decreases in LV preload such as rapid unloading of the LV ~~acutely~~ post-implant or any event outside of the peri-operative setting that causes hypovolemia~~, bleeding~~, RV failure or tamponade. Decreases in LV preload cause the LV cavity to collapse and forces the apical inflow cannula against the septum, inducing

VAs at the site of contact (23-25). Suction events may occur with any ~~of the 3~~ CF-~~-~~LVAD~~S~~ and can be recognized by a sudden reduction in LVAD power, confirmed by a small LV cavity on echo, and can be resolved by lowering LVAD speed and correcting LV preload.

Medical Therapy of Ventricular Arrhythmias

If no reversible triggers of VAs are found, then standard medical therapy with anti-arrhythmic medications is often attempted. In a study of 42 patients, the development of VAs was associated with non-usage of a beta blocker (14). However, beta blockers including sotalol should be used with caution, especially in patients with right heart failure. There are no other studies evaluating anti-arrhythmic medications in patients with LVADs. Amiodarone and the Class IB agent mexiletine are commonly used but their long-term effect on mortality is unknown (26). It should be noted that the use of amiodarone has been associated with increased risk of complications and increased 1-year mortality after heart transplantation which necessitates critical re-evaluation of such treatment in patients with a BTT strategy (27).

Catheter Ablation of Ventricular Arrhythmias

In cases of medically-refractory VAs, catheter ablation is an attractive therapeutic strategy to decrease arrhythmia frequency and ICD shocks, but the data is limited. Five small observational studies have reported VT ablation in a total of 92 LVAD patients at 13 specialized centers. The largest multi-center series reported 34 patients from nine centers, and found that most VT originated from previously diseased substrate distributed throughout the LV

(24). VT originating near the apical cannula was slightly less common, with a reported prevalence of around 29%-35% of patients (21, 24, 25, 28, 29). Cannula-related VT was found to present early, at a median of 13 days after LVAD implantation, and the surface ECG morphology was commonly RBBB, and superior axis, with precordial transition from V3-V5 (28). Other VT circuits include bundle-branch reentry, usually manifesting with typical LBBB pattern, which was seen in up to 14% of patients (28).

Interference between the LVAD and electro-anatomic mapping system was rare, and there were no occurrences of catheter entrapment in the inflow cannula in any case series. Access to the LV can be successfully performed with both trans-septal and retrograde aortic access. Retrograde aortic access is used less frequently, since the aortic valve may be difficult to cross due to reduced aortic flow and intermittent opening of the valve (24).

Examples of VT ablation in LVAD patients, performed at our institution, are shown in Figure 2. A fluoroscopic view of a patient with a CRT-D and an axial HMII LVAD is shown in Figure 2A. Electro-anatomic mapping and integrated intra-cardiac echocardiography (Figure 2B, CartoSound™, Biosense-Webster, Diamond Bar, CA) depicts substrate homogenization with ablation lesions represented by the ball markers. No complications occurred and this patient was arrhythmia-free until he received a heart transplant 5 months later. In a different patient with a centrifugal Heartware LVAD, fluoroscopy (Figure 2C) shows an ablation catheter near the inflow cannula. Electro-anatomic mapping (Figure 2D, ESI Velocity™, Abbott) depicts substrate and activation mapping of a localized VT circuit that was ablated near the LVAD inflow cannula. No

complications occurred and this patient had reduced VT burden with only 1 episode of VF and ICD shock in the 1.5 years before receiving a transplant.

However, in the absence of long-term outcome data on safety and efficacy, it is not clear that VT ablation definitely improves outcomes in LVAD patients. In all the studies combined, no intra-procedural deaths or tamponade occurred and there was a low incidence of groin complications (3%) and stroke (3%). However, in a single-center study of 24 patients, there was a concerning signal of late LVAD thrombosis after VT ablation, occurring in 5 patients (25%, 2 with a HMII and 3 with an HVAD). Since thrombosis occurred late, at a median of 148 days after ablation, the cause remains unclear (28). One theoretical risk of trans-septal puncture is the possibility of right to left shunting due to the septal defect and low left sided pressures due to the LVAD (30) and potentially increased risk of embolism.

Finally, prophylactic surgical epicardial VT ablation at the time of LVAD implantation has been performed at specialized centers with promising results. Two small studies were conducted with a total of 12 patients who had recurrent pre-operative VA or failed prior endocardial ablation, and both were guided by pre-operative endocardial mapping or surface ECG localization. In one study, (31) serial endocardial and epicardial cryoablation was performed at time of LVAD implantation, while epicardial irrigated RF ablation was performed in the other (32). In these small studies, intra-operative VT ablation appears to be feasible but larger studies are needed to demonstrate the utility of this approach in a more generalized fashion.

Key Points: Ventricular Arrhythmia Management

1. **Ventricular arrhythmias (VA) are common in patients after LVAD implantation, and it is important to first identify and treat reversible causes of VA including suction events and electrolyte disturbances.**

2. **In patients at risk of right heart failure, beta blockers including sotalol should be used with caution to prevent precipitation of RV failure and hypotension.**

3. **Ventricular tachycardia ablation may be considered as a palliative treatment for refractory VT based on a few small case series with short follow-up at experienced centers, but larger studies with longer follow-up are needed to assess safety and efficacy.**

4. **VT may arise from pre-existing scar (most common), apical cannula scar, or bundle branch reentry.**

ICD Management in Patients with LVADs

ICD Indications in Patients with LVADs

Approximately 80% of patients have an ICD implanted prior to LVAD implantation (33). In patients who undergo LVAD implantation without an existing ICD, there is limited data advising whether to implant an ICD. In the recently released 2017 AHA/ACC/HRS Guideline for Management of Patients with Ventricular Arrhythmias, it is a Class IIa recommendation that an ICD can be beneficial in LVAD patients with sustained VAs (34). The 2013 ISHLT guidelines recommend routine placement of an ICD for patients who did not have an ICD prior to LVAD implantation (Class IIa) (35). These recommendations are based only on available retrospective studies, and no randomized trial has ever been performed to evaluate the clinical benefit of ICD implantation in patients with

LVADs. Several retrospective studies have investigated the association between ICDs and mortality in LVAD patients with conflicting results. Earlier studies that included pulsatile LVADs associated the presence of an ICD with a survival benefit after LVAD implantation (16, 36). However, more recent studies of patients with CF-- LVADs (8, 11, 37-39), including a large, propensity-matched INTERMACS registry study of 4418 patients, found no association between an ICD and reduced mortality (40). However, a major limitation of these retrospective studies is the inability to determine causation and risk of bias from under-reporting and unmeasured confounders. Thus, based on recent guidelines and available retrospective data, it appears that patients with pre-LVAD or post-LVAD VAs may benefit from an implanted ICD, while an ICD may not always be needed in patients with no history of VAs (Figure 3), although randomized studies are needed.

Generator replacement after LVAD Implantation

No studies have evaluated the necessity of ICD generator replacement in patients with a LVAD who reach elective replacement indicator (ERI) status. The benefits of ICD therapy must be weighed against risks of generator replacement, including infection which occurs in up to 7% **(41)** of LVAD patients. In a study of 247 LVAD patients (42), 3% ~~of patients~~ developed CIED infections. Half of these patients (n=3) developed a pocket infection without bacteremia, and were all preceded by a generator replacement. The other half (n=3) had ~~a lead vegetation and~~ bacteremia. All patients underwent complete CIED removal. ~~Those who had bacteremia were placed on~~Despite chronic suppressive antibiotic therapy~~, although~~ in the patients with bacteremia, one

patient required LVAD exchange and one patient died from infection-related complications. ~~From this small sample size~~This small study suggests that ~~, patients~~ patients with isolated pocket infection ~~without bacteremia~~ had a good outcome with only CIED removal, but patients with bacteremia had a worse outcome ~~despite the use of chronic antibiotics~~. Another study reproduced these findings and reported 6 patients with CIED infections, of which 5 patients also presented with bacteremia (43). These patients experienced recurrent bacteremia despite complete CIED removal. The majority of these patients (n=4) eventually died due to infection-related complications including one patient who underwent LVAD exchange. These studies suggest that it is difficult to clear bacteremia in the presence of a LVAD despite complete CIED removal. ~~Larger~~ More studies are needed to assess whether LVAD exchange may improve the outcome in these patients.

Given the high burden of post-LVAD VAs and associated complications, it is reasonable to pursue generator change in all secondary prevention patients or those with pacemaker indications (35). However, patients without prior VAs and who do not experience post-operative VA may not benefit from generator replacement at ERI, although there are no studies addressing this issue (8, 12, 17).

Use of Subcutaneous ICDs in LVAD Patients

The use of a sub-cutaneous (sub-Q) ICD may be an attractive option in selected patients with higher risk of bloodstream infections or who have limited venous access, but comes with some limitations for patients with LVADs. Although there have been 2 case reports of successful use of sub-Q ICDs with

the HMII and HVAD (44, 45), there has also been one report of electro-magnetic interference (EMI) with an HVAD (46), one report of R wave sensing problems (47) and one report where the sub-Q ICD was in the field of the minimally-invasive mini-thoracotomy approach for LVAD implantation (48), the latter two requiring switching to a trans-venous ICD system. Thus, thorough interrogation of a pre-existing sub-Q ICD is necessary post-LVAD. After LVAD implantation, consideration of a subcutaneous ICD with careful electrogram screening may be an option in select patients with infection or access issues. Further studies of device interactions are needed before recommending this to a more general population.

ICD Troubleshooting after LVAD Implantation

After LVAD implantation, device interference has been reported with older generation ICDs, but still may occur with current generation ICDs. Device interference can manifest as a loss of telemetry with the programmer or with electro-magnetic interference (EMI) leading to inappropriate ICD therapies. Two retrospective studies (49, 50) and case reports (51-55) of HMII patients have reported interactions with older generation St. Jude and Sorin ICDs, with an incidence of about 2-17% of all patients prior to 2012. More recently there have been case reports of loss of telemetry in two patients with the HMIII in combination with current generation Biotronik (Ilesto ~~7 VR-T DX~~ and Iforia~~)~~ ~~5 VR-T)~~ and Sorin ICDs (56, 57). Both cases were successfully temporarily resolved using maneuvers to minimize interference during interrogation. These techniques involve creating a metal insulation shield between the LVAD and the programmer (53, 55, 58). Table I (see Appendix) shows the ICD models that

have been reported to Thoratec/Abbott, the manufacturer of the Heartmate™ devices.

Inappropriate ICD shocks due to EMI rarely occur, but have been reported. In a retrospective study of 44 LVAD patients, one patient (2%) experienced five inappropriate shocks due to EMI (detected at 250 bpm) from a Boston Scientific ICD. At our institution, one patient with a Sorin Paradym CRT-D received two inappropriate shocks due to EMI (detected at 480 bpm) which occurred 1 hour after HMII implantation (Figure 4). This was resolved by adjusting the RV sensing threshold and extending detection intervals.

Significant changes in lead function have also been reported after LVAD implantation, with mixed clinical implications. Several studies report significant reductions in RV sensing amplitude and increases in capture thresholds and defibrillation thresholds (DFTs) (50, 59, 60). These changes continued to persist beyond 30 days post-op and led to an intervention in about 20% of patients. Under-sensing of clinical VT due to a decrease in lead sensing was noted in up to 5% of patients and required RV lead revisions. Unsuccessful shocks occurred in up to 9% of patients, and high DFTs requiring subcutaneous array implantation occurred in up to 7% of patients. There were rare occurrences of direct lead damage, including one RV lead fracture and one dislodged epicardial LV lead. Given significant persistent changes in RV lead parameters after LVAD implantation, it is imperative to perform ICD interrogation post-operatively to monitor for EMI, RV lead under-sensing and inappropriate or ineffective ICD therapies.

Programming Optimal ICD Therapy Zones

In large randomized ICD trials of non-LVAD patients comparing less aggressive ICD programming versus conventional programming, the conventional ICD programming patients received more shocks and had a significant increase in mortality, suggesting an association with ICD shocks and higher mortality (61-64). Given that VAs are usually not immediately hemodynamically compromising in patients with LVAD support, an optimal ICD programming strategy might be to maximize detection times, rate zones and enable ATP to minimize ICD shocks.

A recent small trial- randomized 83 patients to conventional ICD programming compared to ultraconservative programming, which included 1) VT zone at 180bpm with maximal detection time at 33 seconds, 3-8 rounds of ATP and shocks, 2) VF zone at 220-240 bpm with maximal detection time 15-32 seconds and shock therapy, with variations depending on the manufacturer (65). Although there was a trend towards less ICD shocks in the ultraconservative group, the results did not reach statistical significance, with median follow-up 11 months. As the authors admit, the study may have been underpowered to show a significant effect. Additionally, conventional programming was noted to be already relatively conservative and most of the shocks were for VF. Another limitation faced by the authors was the programming limits allowed by the device firmware and the inability to extend detection times longer. Nevertheless, as the first randomized trial evaluating conservative ICD programming, an important finding was that conservative programming was not associated with adverse events such as mortality or cardiovascular-related hospitalizations, which suggests that this programming strategy could safely be implemented. However, larger multicenter studies with

longer follow up need to be conducted to fully evaluate the effect of these programming strategies.

Cardiac-Resynchronization Therapy and Pacemaker Indications

The effects of cardiac-resynchronization therapy (CRT) on outcomes after LVAD are not well characterized. In the study above by Richardson et. al., LVAD patients with CRT-D devices were also randomized to CRT-on (n=20) and CRT-off (n=21), and there was a nonsignificant trend towards a reduction in ICD shocks in the group with CRT-on (38% vs 10%, p=0.08) and no difference in mortality or HF hospitalization (65). Again, this study was underpowered to adequately detect a difference. These findings extend the results from a retrospective study that compared 39 patients with CRT-on versus 26 patients with CRT-off and found that patients with CRT-on had a reduction in VAs but no difference in mortality(66). On the other hand, a similarly-sized retrospective study did not find any difference in VA frequency, mortality, or hospitalization (67) at almost 2 years follow-up. In one case involving a non-LVAD patient, initiation of LV pacing induced VT (68). Given the lack of data, no guidelines exist regarding continuation of LV pacing, and management of CRT is center specific. In patients with VA thought to be due to LV pacing, high LV pacing thresholds and early battery depletion, discontinuation of LV pacing could be considered.

In LVAD patients with pacemaker indications, the clinical practice is to continue pacing to support the RV. No studies have addressed this issue and pacemaker-dependent patients were excluded from randomization in the CRT

study above (65). Studies are needed to evaluate the necessity of pacing in these patients, especially in patients with a device infection.

Key Points: ICD Management

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1. **Current guidelines recommend ICD implantation and generator replacement in patients with LVADs with any prior history of VA, although a prospective, randomized study is needed.**

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2. **CIED interrogation should be performed in all patients after LVAD implantation given potential for changes in lead parameters and device interactions even in current-generation devices.**

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3. **After LVAD placement, permissive ICD programming should be considered, including more tailored ATP use, higher rate zones and longer detection times.**

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4. **Discontinuation of LV pacing may be considered in select patients with LVADs, though limited data exist.**

Management of atrial arrhythmias

Thromboembolic risk in patients with AF

Atrial fibrillation (AF) is common in patients with LVADs, with prevalence ranging from 21-52% of patients (69-72). The additive effect of AF in causing thrombo-embolic events (TE) in therapeutically anticoagulated LVAD patients is uncertain. The largest study, which included 3909 patients in the INTERMACS registry, found that pre-operative AF was not associated with TE or mortality, despite these patients having more comorbidities (69). This finding was

consistent with other studies (70-72). However, a recent smaller retrospective study demonstrated that just as many LVAD patients with AF experienced TE despite a higher INR (mean 2.6) at the time of event compared to patients without AF (mean INR 1.5) (70). An older study of 389 patients found that pre-operative AF was associated with TE and this association was strongest when anticoagulation was held due to a GI bleeding event (73). The authors report that they now routinely amputate the left atrial appendage (LAA) in all patients in whom thrombus is detected in the LAA. LAA exclusion at the time of LVAD implantation may be considered in patients with AF and high risk for bleeding and an anticipated need to temporarily stop anticoagulation. However, the efficacy and risks of this strategy have not been systematically studied. Ultimately, the discrepancy in TE risk from AF may also be due to variations in LVAD anticoagulation strategies throughout the years, which is often not reported (35).

Rhythm Control for Atrial Arrhythmias

Atrial fibrillation has been associated with worse outcomes in LVAD patients in small studies, but it is unknown whether rhythm control strategies are beneficial in patients supported by a LVAD. A retrospective study of 106 patients report an association between persistent AF and mortality, early RV failure and HF hospitalization, although these patients were sicker with more comorbidities at baseline (70, 72). ISHLT 2013 guidelines suggest routine management of AF per ACC guidelines (35). In context of the CASTLE-AF randomized trial which found that AF ablation compared to medical therapy was

associated with less mortality and HF hospitalization in heart failure patients, this question has not been studied in LVAD patients (74). In the only case series reporting ablation of atrial arrhythmias, eight patients with HMII who developed poorly controlled atrial flutter post-operatively after LVAD implantation suffered from right heart failure manifesting as syncope or cardiogenic shock (30). All patients had cavotricuspid isthmus–dependent typical atrial flutter and successful ablation led to complete resolution of right heart failure with improved quality of life for all. Only one case report has reported feasibility of segmental pulmonary vein isolation (PVI) in a patient with a HMII and repeated HF hospitalizations thought to be due to poorly controlled atrial fibrillation with rapid ventricular rate (75). No complications were reported from these studies. No interference with electro-anatomic mapping systems was reported for right atrial mapping. In both studies, the ablations were done on uninterrupted warfarin therapy.

Although it appears that right atrial ablation is feasible, studies are needed to assess the safety and possible benefit of left atrial ablations, specifically evaluating the risks of trans-septal puncture discussed in the VT ablation section. In conclusion, more studies need to be performed evaluating the benefits and safety of rhythm control in LVAD patients, with potential approaches including anti-arrhythmic medications, percutaneous left atrial ablation, and surgical AF ablation (cryo-MAZE) at time of LVAD (70).

Key Points: Atrial Arrhythmia Management

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1. **Presently, left atrial appendage exclusion is not routinely performed at the time of LVAD implantation, but could be considered in patients with a history of AF and high risk for**

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bleeding resulting in temporary cessation of anticoagulation.

2. **Right atrial ablation appears feasible for typical atrial flutter. However, further studies are needed to evaluate the benefit and safety of rhythm control strategies (ablation and anti-arrhythmic medications) for atrial arrhythmias.**

Multidisciplinary Approach to Arrhythmia Management

The care for patients with LVADs is complex and these patients need to be treated with close coordination by a multidisciplinary team. In patients with significant history of arrhythmias, ~~multidisciplinary~~ pre-operative discussions should be conducted with surgeons and heart failure specialists to strategize optimal approaches for interventions such as ablation and ICD implantation and programming. Importantly, in patients with a bridge-to-recovery strategy, a collaborative approach to optimize chances for their recovery is critical, such as resynchronization therapy and atrial fibrillation management. Furthermore, remote monitoring can provide an excellent tool for early detection of sub-clinical arrhythmias to initiate pre-emptive interventions to prevent arrhythmia-related complications.

Conclusion

LVADs dramatically improve morbidity and mortality in end stage heart failure, but arrhythmias are prevalent in this patient population ~~t~~To improve the management of arrhythmia in these patients, prospective randomized studies with sufficient power are needed to evaluate questions regarding ICD indications, programming and benefit of catheter ablation.

Techniques utilizing hybrid surgical and catheter ablation to optimize treatment of arrhythmias should continue to be developed and studied. In lieu of such studies, a collaborative team of heart failure cardiologists, electrophysiologists and cardiac surgeons is vital to deliver the best care for these complex patients.

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Victor Pretorius, MBChB - Critically reviewing and editing manuscript, final approval

Ulrika Birgersdotter-Green, MD – Concept/design, critically reviewing and editing manuscript, final approval

Table 1. Interactions with cardiac implantable devices that have been reported to Thoratec (HMII and HM3).

Heartmate II: *http://www.thoratec.com/medical-professionals/heartmate-ii-reported-icd-experience.aspx*
Heartmate III: *http://www.thoratec.com/medical-professionals/vad-product-information/heartmate3-reported-icd-experience.aspx*

Heartmate II	
Manufacturer	**Model No.**
St. Jude Medical™	Atlas-HF™ V-340
St. Jude Medical™	Atlas-HF™ V-341
St. Jude Medical™	Atlas-HF™ V-343
St. Jude Medical™	Atlas™ V193
St. Jude Medical™	Atlas™ V-242
St. Jude Medical™	Atlas™ V-243
St. Jude Medical™	Atlas™ V-366
St. Jude Medical™	Atlas™ VR model V-199
St. Jude Medical™	Current™ DR RF 2207-36
St. Jude Medical™	Current™ RF VR 1207-36
St. Jude Medical™	Epic™ HF CRT-D model V-337
St. Jude Medical™	Epic™ HF CRT-D model V-338
St. Jude Medical™	Epic™-HF V-350
St. Jude Medical™	Epic™ Plus VR model V-196
St. Jude Medical™	Integrity™SR 5142
St. Jude Medical™	Photon™ Micron DR model V-232
St. Jude Medical™	Promote™ RF CRT-D model 3207-36
St. Jude Medical™	SN V-235

Sorin Group	Alto 2 model 624
Heartmate III	
Manufacturer	**Model No.**
Biotronik	Iforia 5-HF-t
Biotronik	Iforia 5-VR-T
Biotronik	Iforia CRT-D
Biotronik	Ilestro 7-VR-T DX
Biotronik	Ilestro 7-HFT-RF
ELA Medical (Sorin)	Paradyme RF CRT-D9750

Figure Legends

Figure 1: Types of Continuous-Flow LVADs. Comparison of commonly used CF-LVADs, including the axial LVAD (1A, Heartmate II™) and the centrifugal LVADs (1B, Heartware™ and Heartmate III™).

Figure 2: Successful VT Ablation Using Electroanatomic Mapping. Examples of VT ablation with in patients with both axial (2A-B) and centrifugal (2C-D) LVADs are shown in the fluoroscopy images with successful use of electroanatomic mapping (2B: Biosense-Webster Carto™ and 2D: ESI Velocity™). A variety of mapping strategies can be employed, including substrate homogenization (2B) and activation and entrainment mapping (2D).

Figure 3: Algorithm to Guide ICD Implantation. Suggested indications for ICD implantation and generator replacement in patients who undergo LVAD implantation. This figure was inspired and modified from Garan AR et al. J Am Coll Cardiol 2013.

Figure 4: Example of Electromagnetic Interference from LVAD. Example ICD intracardiac electrogram depicting electromagnetic interference between a HMII and Sorin CRT-D leading to an inappropriate shock.

Figure 5. Central Illustration Arrhythmia Management in Patients with LVADs

Figure 1

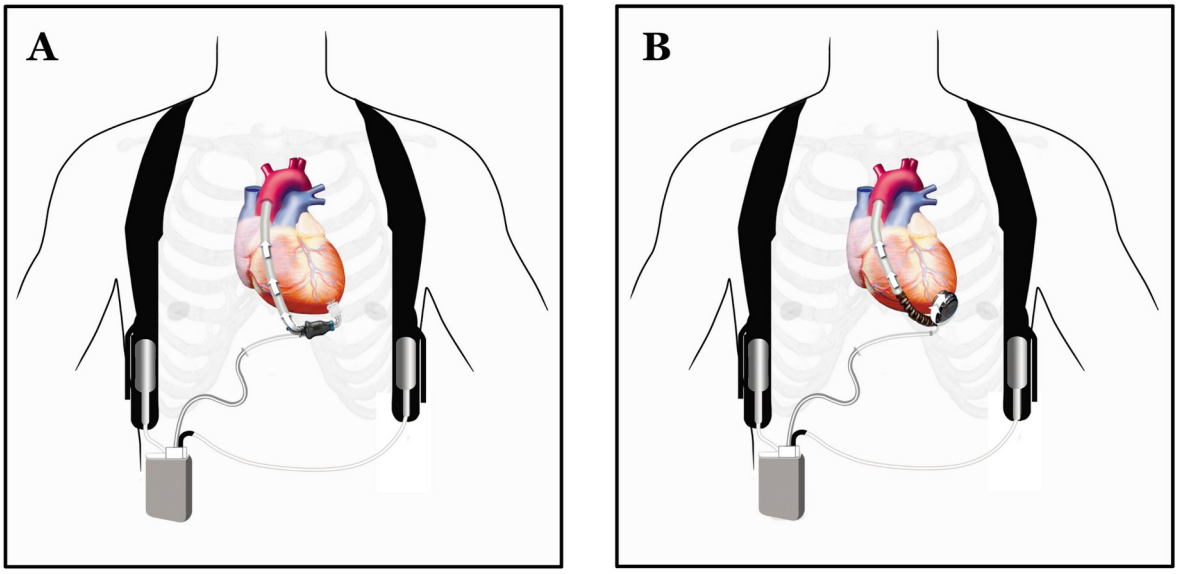


Figure 2:

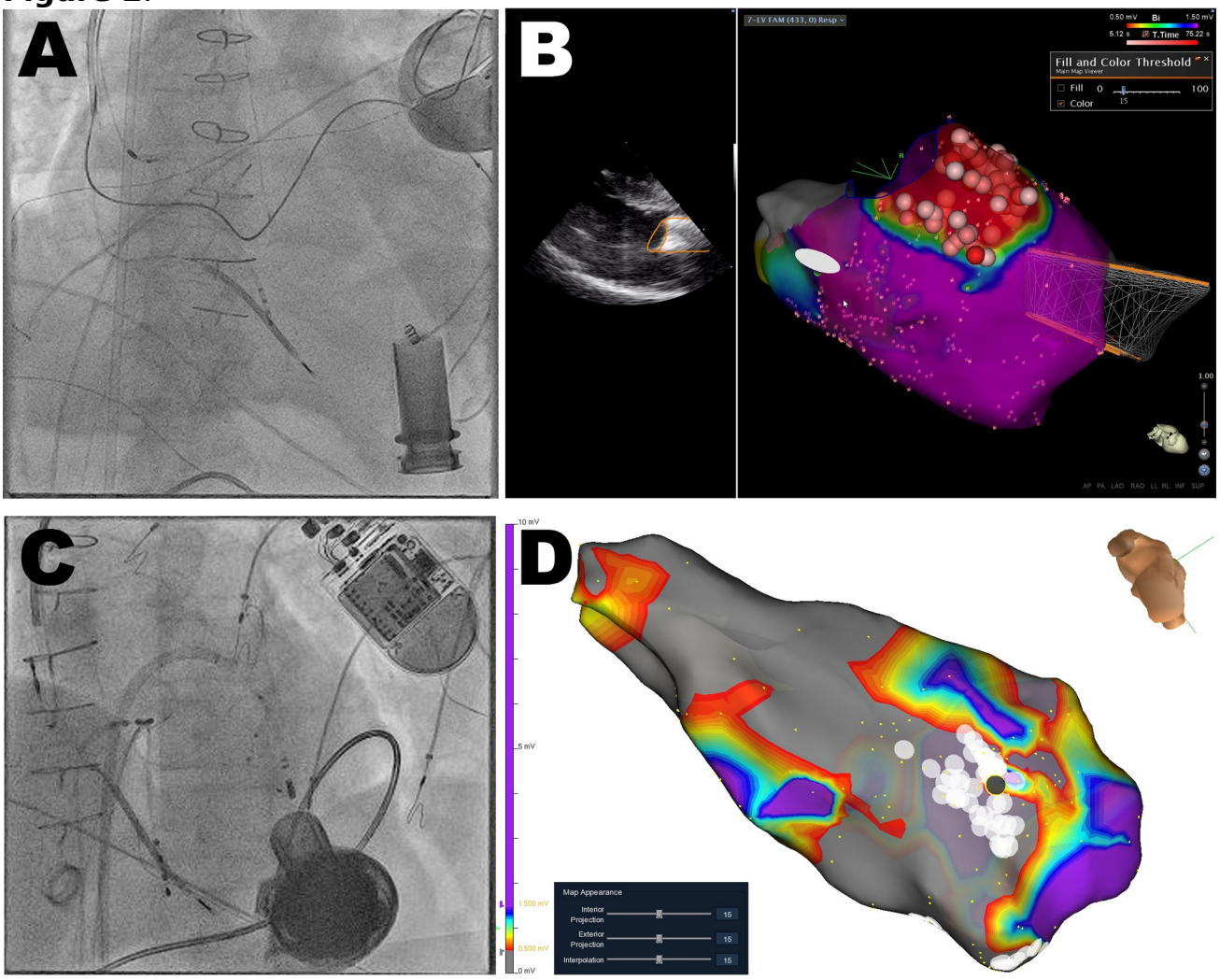
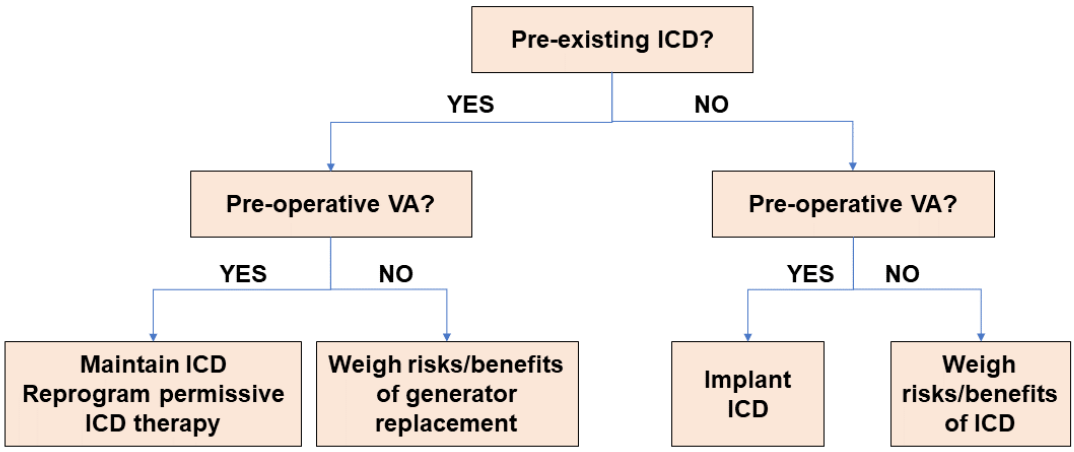

A
B
7 - LV FAM (433, 0) Resp
0.50 mV
Bi
1.50 mV
5.12 s
T.Time
75.22 s
Fill and Color Threshold
Main Map Viewer
Fill
0
100
Color
15
1.00
AP PA LAO RAO LL RL INF SUP
C
D
10 mV
5 mV
1.500 mV
0.500 mV
0 mV
Map Appearance
Interior Projection
15
Exterior Projection
15
Interpolation
15

Figure 3



Modified from Garan AR et al. JACC 2013;61:2542–2550

Figure 4:

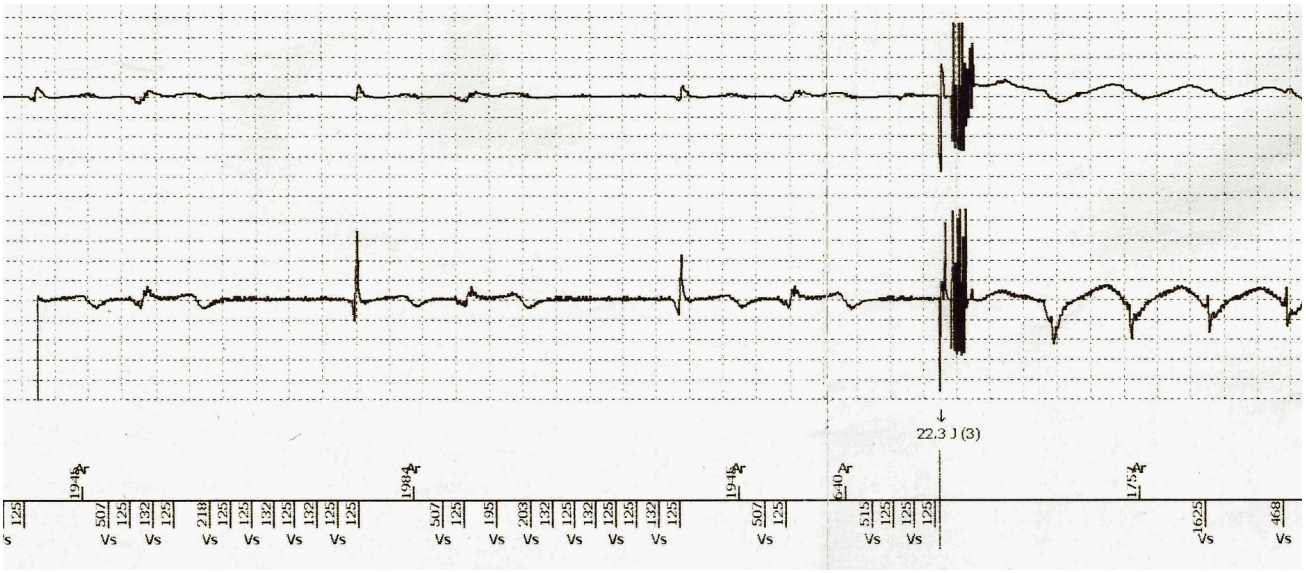
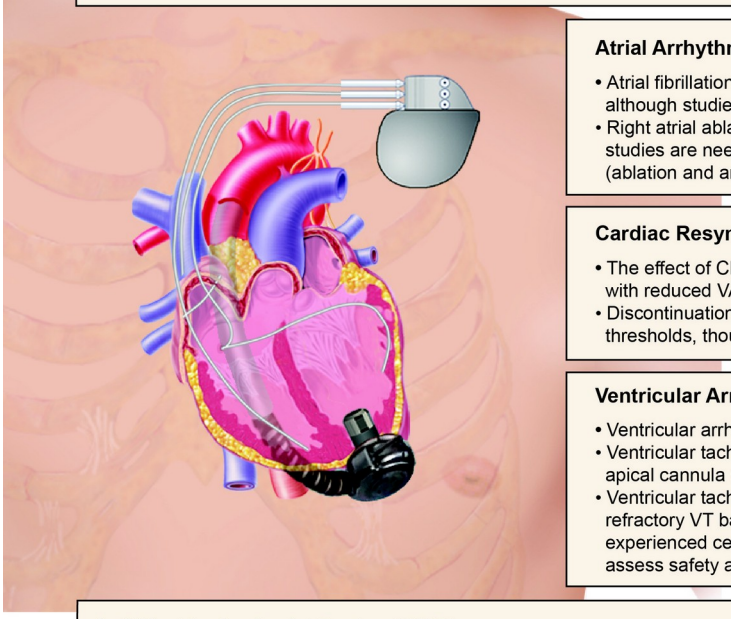


Figure 5: Central Illustration

CENTRAL ILLUSTRATION Arrhythmia Management in Patients with LVADs

Implantable Cardioverter Defibrillators (ICDs)

- ICD implantation should be considered in LVAD patients with prior or recurrent ventricular arrhythmias
- ICDs should be interrogated after LVAD implantation to assess lead parameters and device interference
- Permissive ICD programming should be considered such as longer detection times and higher therapy zones



Atrial Arrhythmias

- Atrial fibrillation may further increase thromboembolic risk in LVAD patients although studies are conflicting
- Right atrial ablation appears feasible for typical atrial flutter. However, further studies are needed to evaluate the benefit and safety of rhythm control strategies (ablation and anti-arrhythmic medications) for atrial arrhythmias

Cardiac Resynchronization Therapy (CRT)

- The effect of CRT on outcomes after LVAD is unclear, but may be associated with reduced VA
- Discontinuation of LV pacing may be considered in select patients with high thresholds, though limited data exist

Ventricular Arrhythmias

- Ventricular arrhythmias occur in up to 50% of LVAD patients
- Ventricular tachycardia may originate from pre-existing scar (most common), apical cannula site or bundle-branch reentry
- Ventricular tachycardia ablation may be considered as a palliative treatment for refractory VT based on a few small case series with short follow-up at experienced centers, but larger studies with longer follow-up are needed to assess safety and efficacy

Left Ventricular Assist Device (LVAD)

- The inflow cannula is placed at the LV apex with both axial and centrifugal LVADs
- LVAD patients are at risk for both bleeding and thrombosis
- Suction events due to LV underfilling may cause VT and are managed by decreasing LVAD speed