About the Authors

Eileen O'Meara, MD

Dr. Eileen O'Meara is a professor at Université de Montréal and at the MontrealHeart Institute. She completed a Fellowship in Heart Failure, and another in Stress Echocardiography. She holds the MHI Carolyn and Richard J Renaud's research chair in Heart Failure and is the co-director of the Myocardial Research Axis at MHI. She is a member of the Internal Review Board, of the Research Core Echocardiography Laboratory and of the Pharmacology Committee at MHI, as well as Chief of Outpatients Clinics at MHI. She was Co-Chair of the Primary Panel for the Canadian Cardiovascular Society and Canadian Heart Failure Society (CCS and CHFS) HF Guidelines and co- chair of the Cardiorenal Protection Guidelines for the CCS/CHFS (2020-2022). She is a section lead for the soon to be published CCS HFpEF guidelines. Her research focuses on cardio-kidney-inflammation interactions and fibrosis in HF, including circulating and cardiac imaging biomarkers; as well as on comorbid conditions that contribute to HF, more specifically diabetes/ adiposity, CKD, anemia and arrhythmia. She is involved in several large HF clinical trials as a National Lead Investigator, SC or EC member.

Affiliations: Montreal Heart Institute, Montreal QC.Universite de Montreal, Montreal, QC

Blandine Mondésert, MD, FCHRS

A French cardiologist who graduated from the University of Grenoble in 2008, Dr. Blandine Mondésert worked for two years as a senior arrhythmia clinician at the Grenoble University Hospital in France. She was also recognized as a cardiologist by the Collège des Médecins du Québec, through the France-Quebec agreements in July 2013. She subsequently completed a fellowship in electrophysiology at the Montreal Heart Institute between 2011 and 2013, where she specialized in the fields of electrophysiology (pacing and ablation), particularly in adult patients with congenital heart disease, within Dr. Paul Khairy's team. She also developed expertise in the extraction of implantable cardiac equipment, for which she completed her extraction training at the Lille University Hospital in France in 2014. In July 2014, Dr. Blandine Mondésert joined the team at the Montreal Heart Institute, where she works as a cardiologist. She also serves as an assistant clinical professor of medicine at the University of Montreal.

Affiliations: Montreal Heart Institute, Montreal, QC

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Role and Indications for Device Therapies in Heart Failure: Condensed Summary

Eileen O'Meara, MD
Blandine Mondésert, MD, FCHRS

Overview of CRT and Electrophysiological Rationale

Over the past decade, the substantial benefits associated with current guideline-directed medical therapy for heart failure with reduced ejection fraction (HFrEF) have been brought into the light, as emphasized in a recent publication from our institution.[1] Despite these advances, device therapy continues to hold an important place in treating heart failure (HF), both for left ventricular (LV) remodeling (and associated prognosis) as well as for preventing sudden cardiac death (SCD).

Cardiac resynchronization therapy (CRT) is a key intervention in heart failure (HF) management, particularly for patients with left bundle branch block (LBBB), which is observed in 15–25% of patients with HF, and is associated with reduced left ventricular function.[2] CRT helps in correcting dyssynchronous ventricular contraction leading to impaired cardiac output. Although less prevalent, right bundle branch block (RBBB) and nonspecific interventricular conduction delay (IVCD) are also associated with adverse remodelling, including increased right ventricular volumes and reduced function.

Clinical Trials

Clinical trials, such as CARE-HF and COMPANION, have demonstrated the benefits of CRT in patients with symptomatic HF, left ventricular ejection fraction (LVEF) ≤35%, and evidence of electrical dyssynchrony (e.g., QRS duration >150 ms or 120–149 ms with echocardiographic dyssynchrony).[3,4] CRT has been shown to improve systolic blood pressure, increase LVEF, reduce mitral regurgitation, and decrease left ventricular end-systolic volume index, leading to reduced hospitalizations for HF and a lower mortality rate. These findings support the physiological mechanism of CRT, which aims to optimize cardiac performance by synchronizing biventricular pacing, and reducing interventricular mechanical delay.

Guidelines-Based Indications for CRT

According to the 2021 European Society of Cardiology (ESC) guidelines, the 2013 Cardiovascular Canadian Society (CCS) guidelines—with updates expected in October 2025—and the 2023 HRS/APHRS/LAHRS guideline on cardiac physiologic pacing, CRT is indicated for patients with HF who are in sinus rhythm, have an LVEF of 35% or less, and a wide QRS complex.[5-7] CRT is strongly recommended for patients with LBBB morphology and a QRS duration of 150 ms or greater. It should also be considered in patients with LBBB and QRS duration between 130 and 149 ms. For those with non-LBBB morphology (RBBB or IVICD), CRT is recommended when the QRS duration is 150 ms or greater. CRT is not indicated for patients with a QRS duration of less than 130 ms unless there is another indication for pacing. Although CRT was initially indicated after optimization of medical treatment, data showing the poorest response in patients with LBBB has suggested that earlier CRT implantation would be beneficial.[8,9]

Sex-based differences in response to CRT have been well documented. Women, who generally have smaller left ventricular dimensions, tend to benefit from CRT at shorter QRS durations compared to men. Modelling studies suggest that a QRS duration threshold approximately 10 ms shorter may be appropriate for women to derive similar benefit, reinforcing the need for sex-specific criteria in device-based therapies. Patients with non-ischemic cardiomyopathy are also known to respond better to treatment than those with ischemic cardiomyopathy.

CRT in Atrial Fibrillation

Delivering effective CRT in patients with atrial fibrillation (AF) is more complex due to the

irregular ventricular response and the presence of fusion or pseudo-fusion beats. These can significantly reduce the percentage of biventricular pacing, which is a major determinant of CRT efficacy. For patients with persistent or permanent AF who have HF and an LVEF of 35% or less, CRT is appropriate if the QRS duration is 130 ms or more and a strategy is in place to ensure a high percentage of biventricular capture (>90% at least, higher is better). In most cases, this will require atrioventricular junction (AVJ) ablation to suppress native conduction and ensure CRT efficacy (ablate and pace strategy).

In patients undergoing AVJ ablation, CRT is recommended for those with HFrEF, defined as an LVEF <40% and may be considered for those with mildly reduced EF (41–49%) and selected cases of preserved EF (≥50%). For HFrEF patients who require ventricular pacing, CRT should be preferred over right ventricular (RV) pacing to avoid pacing-induced cardiomyopathy and slow the progression of HF for patients in whom the expected percentage of pacing is more than 20 to 40% (still debated).

CRT-D vs. CRT-P and ICD Considerations

The estimated annual risk of fatal ventricular arrythmias is approximately 4–5% in primary prevention of sudden cardiac death (SCD). Implantable cardioverter-defibrillators (ICDs) are thus indicated in HFrEF with an LVEF <35%, even without prior ventricular arrhythmias, provided they are receiving optimal medical HF therapy, to reduce the risk of all-cause mortality. In the DANISH (Danish Study to Assess the Efficacy of ICDs in Patients with Non-ischemic Systolic Heart Failure on Mortality) trial, ICDs significantly reduced the rate of SCD, but did not reduce all-cause mortality in patients with non-ischemic cardiomyopathy, except in the subgroup of patients younger than 70 years. Importantly, optimal guideline-directed medical therapy for HFrEF also reduces all-cause mortality and SCD.

ICDs are well established for preventing SCD in patients with HFrEF or in selected cardiomyopathies. When patients meet indications for both CRT and ICD, the implantation of a CRT-D device is recommended. The decision to proceed with CRT-D involves a shared decision-making process that incorporates an individual risk assessment. In patients who have existing pacemakers or ICDs and subsequently develop symptomatic HFrEF and a high RV pacing burden (>20–40%), upgrading to CRT should be considered.

However, the overall benefit of ICDs for primary prevention has declined due to the decreasing incidence of SCD, now estimated at approximately 1% per year. This evolution necessitates careful patient selection while patients with ischemic heart disease tend to derive greater benefit from ICDs than those with non-ischemic heart disease, the overall rate of responders is higher in patients with non-ischemic cardiomyopathy than in those with ischemic cardiomyopathy. Other factors to consider are patient age, life expectancy, comorbidities, the presence of a genetic mutation, mechanical dyssynchrony, the presence of myocardial fibrosis on cardiac MRI, and any previously implanted devices already in place.[10]

In some patient populations, CRT-P may be favoured over CRT-D. This includes patients with non-ischemic cardiomyopathy, limited life expectancy, significant comorbidities, or advanced age. CRT-P may also be appropriate for those with poor renal function or those anticipated to undergo mitral valve intervention. Additionally, in cases of pacing-induced cardiomyopathy, where a pacemaker is already implanted, upgrading with one left ventricular (LV) lead instead of 2 leads for CRT-D may be sufficient. Additionally, patient preferences should be respected in the decision-making process, especially in light of the modest and declining benefit of ICDs for primary prevention. A frank discussion with the patient should be initiated at the time of the implant decision. CRT-P is more often used in Europe than in the United States.

Subcutaneous and Extravascular ICDs

Traditional transvenous ICD systems are associated with both short- and long-term complications including venous obstruction, vascular injury, systemic infection, lead-related problems, and lead-related tricuspid regurgitation. Subcutaneous ICDs (S-ICDs) offer an alternative that avoids the need for intravascular access, thereby reducing these risks while maintaining effective defibrillation for life-threatening ventricular arrhythmias. However, S-ICDs do not offer pacing support or anti-tachycardia pacing (ATP) and typically require a larger device generator. In the MODULAR ATP trial, the addition of a leadless pacemaker (Empower, developed by Boston Scientific) to the top of an S-ICD enabled

ATP delivery, successfully terminating 61% of ventricular arrhythmias.[11] Notably, the Empower device has not yet received approval in any country.

Extravascular ICD (EV-ICD, Aurora® from Medtronic, offer an alternative approach to avoid lead-related complications by placing the lead in a sub-sternal position. This configuration allows both ATP and defibrillation without requiring intravascular access. However, EV-ICDs do not support permanent pacing (painful) and are contraindicated in patients with a history of thoracic or cardiac surgeries (including left ventricular assist device (LVAD) patients – see below). In the Extravascular ICD Pivotal Study, which included the first 300 patients with indications for single-chamber ICDs, ATP successfully terminated ventricular arrhythmias in 77% of cases.[12]

Conduction System Pacing (CSP)

CSP is an alternative to RV pacing that preserves physiological activation of the ventricles by stimulating the native conduction system. It is particularly beneficial for patients with AV block and an LVEF below 50% who are expected to need frequent ventricular pacing (20–40%). Among CSP techniques, left bundle branch area pacing (LBBAP) has been fully adopted in recent years. Compared to His bundle pacing (HBP), the LBBAP offers greater stability (less lead dislodgement, lower pacing thresholds leading to improved battery longevity) without the need for a back-up right ventricular lead (RV lead). LBBAP may also be used in addition to a coronary sinus (CS) lead (LOT-CRT) or when the CS lead placement for CRT is unsuccessful due to anatomical constraints (bailed-out indications). Several ongoing studies are evaluating LBB pacing in patients with indications for CRT, AV block, and AVJ ablation. However, improvements in implantation materials are still needed to reduce failure rates, particularly in patients with complex anatomies. For patients with rapid AF and narrow QRS who undergo AVJ ablation, CSP may offer a viable alternative to biventricular pacing.

Cardiomyopathies and Device Therapy

Several cardiomyopathies present unique considerations when evaluating device therapy. In some cases, when a pacing indication is present, ICDs should be recommended at the time of implantation, depending on the patient's risk of SCD, to avoid unnecessary early reintervention.

In hypertrophic cardiomyopathy (HCM), AV sequential pacing with a short AV delay may reduce left ventricular outflow tract (LVOT) gradients and improve symptoms in drug-refractory patients (discordant data). Percentage of fibrosis on MRI is now part of the evaluation and recommendations for ICD indications in HCM patients.

Patients with Lamin proteins A and C (LMNA) mutations, including those with Emery-Dreifuss or limb-girdle muscular dystrophies, are at high risk for arrhythmias and may benefit from ICD implantation if they meet conventional pacing criteria and have a life expectancy exceeding one year.

Infiltrative cardiomyopathies, such as those caused by amyloidosis, Fabry disease, hemochromatosis, or glycogen storage diseases, frequently involve conduction abnormalities and both atrial and ventricular arrhythmias. Device implantation in these patients should follow standard pacing and defibrillation criteria, with special attention to amyloidosis given its strong association with SCD.

Inflammatory cardiomyopathies, whether caused by infections (e.g., Lyme disease), autoimmune conditions (e.g., sarcoidosis, giant cell myocarditis), or toxins (e.g., chemotherapy, radiation), often involve the atrioventricular node and conduction system. In cardiac sarcoidosis, pacing is recommended for both permanent and transient AV block. In patients with cardiac sarcoidosis and an LVEF below 50%, the use of CRT-D or ICD should be considered due to the significantly elevated risk of ventricular arrhythmias (VA) and sudden cardiac death.[13]

LVADs and Device Integration

For patients with advanced HFrEF who are not eligible for heart transplant, LVAD therapy offers a life-sustaining option. Prior to LVAD implantation, it is essential to optimize device-based therapies such as CRT and ICD to ensure clinical stability. In patients with CRT indications, CRT and/or CSP may be considered before or after the LVAD. Strategic decisions on lead selection and placement strategies, including epicardial versus endocardial routes, and MRI compatibility are important considerations when planning durable mechanical support. For patients with a narrow QRS and no indications of pacing,

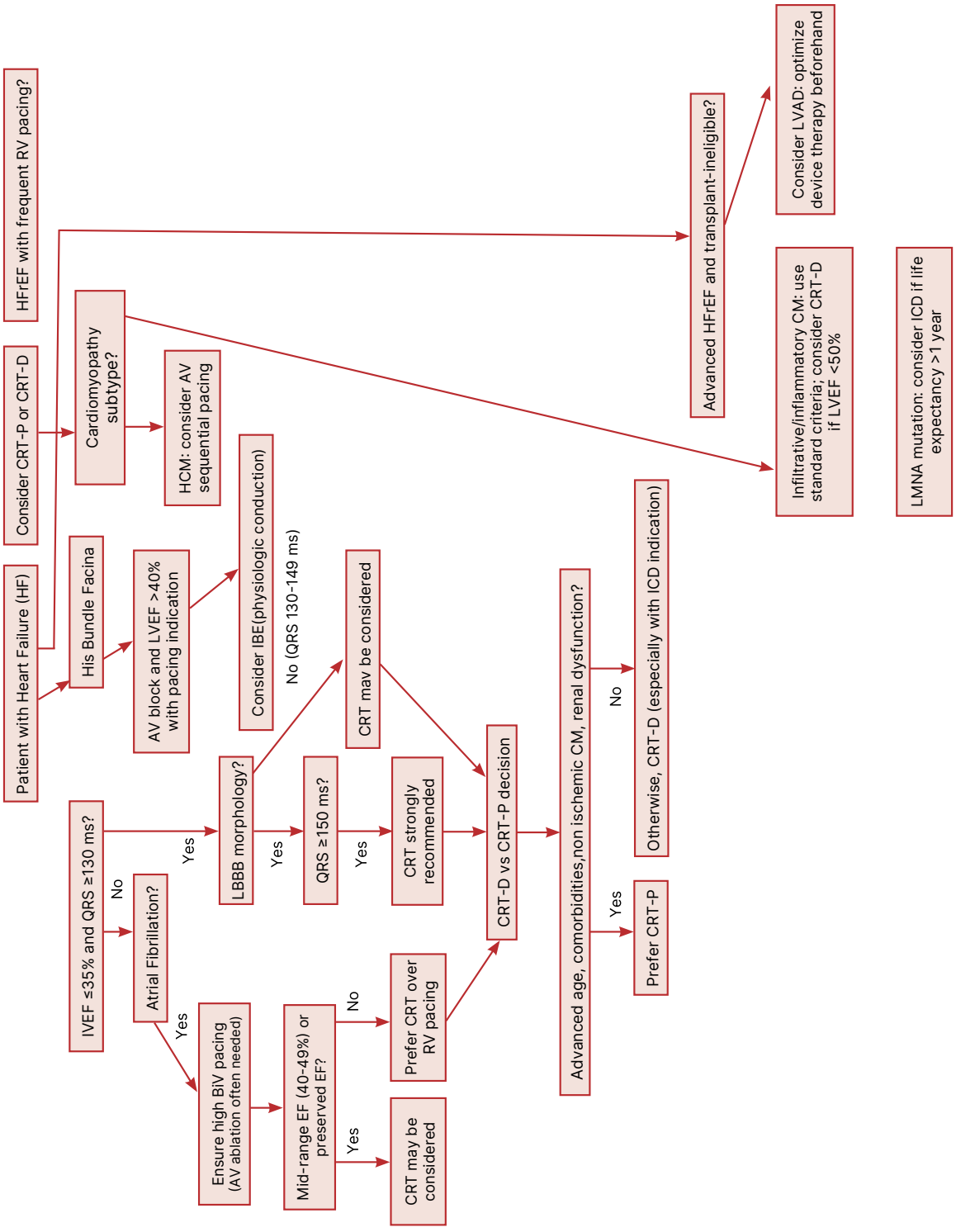

Figure 1. Decision Tree for Device Therapy in HF; *courtesy of Eileen O'Meara, MD, Blandine Mondésert, MD, FCHRS*

Abbreviations: HFrEF: heart failure with reduced ejection fraction; **CRT-D:** cardiac resynchronization therapy with defibrillator; **CRT-P:** cardiac resynchronization therapy with pacemaker; **IVEF:** Indexed left ventricular ejection fraction; **AV:** aortic valve; **LVEF:** left ventricular ejection fraction; **LBBB:** left bundle branch block; **HCM:** hypertrophic cardiomyopathy; **EF:** ejection fraction; **RV:** right ventricular; **ICD:** implantable cardiac defibrillator; **LMNA:** Lamin proteins A and C; **LVAD:** left ventricular assist device; **CM:** cardiomyopathy

using ICDs for primary prevention remains controversial.[14] In such high-risk populations, S-ICDs may help reduce lead-related and infectious complications, although electromagnetic interferences with the Heart Mate 3 pump have been observed. Meanwhile, EV-ICDs remain contraindicated in this population.

Conclusion

Device therapies are essential components in managing heart failure, offering symptom relief, reverse remodelling, and reductions in hospitalization and mortality in appropriately selected patients. The indications for CRT or CSP and ICD (transvenous or non-transvenous) must be tailored based on factors such as QRS morphology, cardiac rhythm, LVEF, comorbidities, and patient-specific factors including age, genetic profile, and personal preferences. As new evidence emerges and technologies evolve, a patient-centred, guideline-informed approach remains the cornerstone of optimal device-based therapy in HF.

Correspondence

Eileen O'Meara, MD

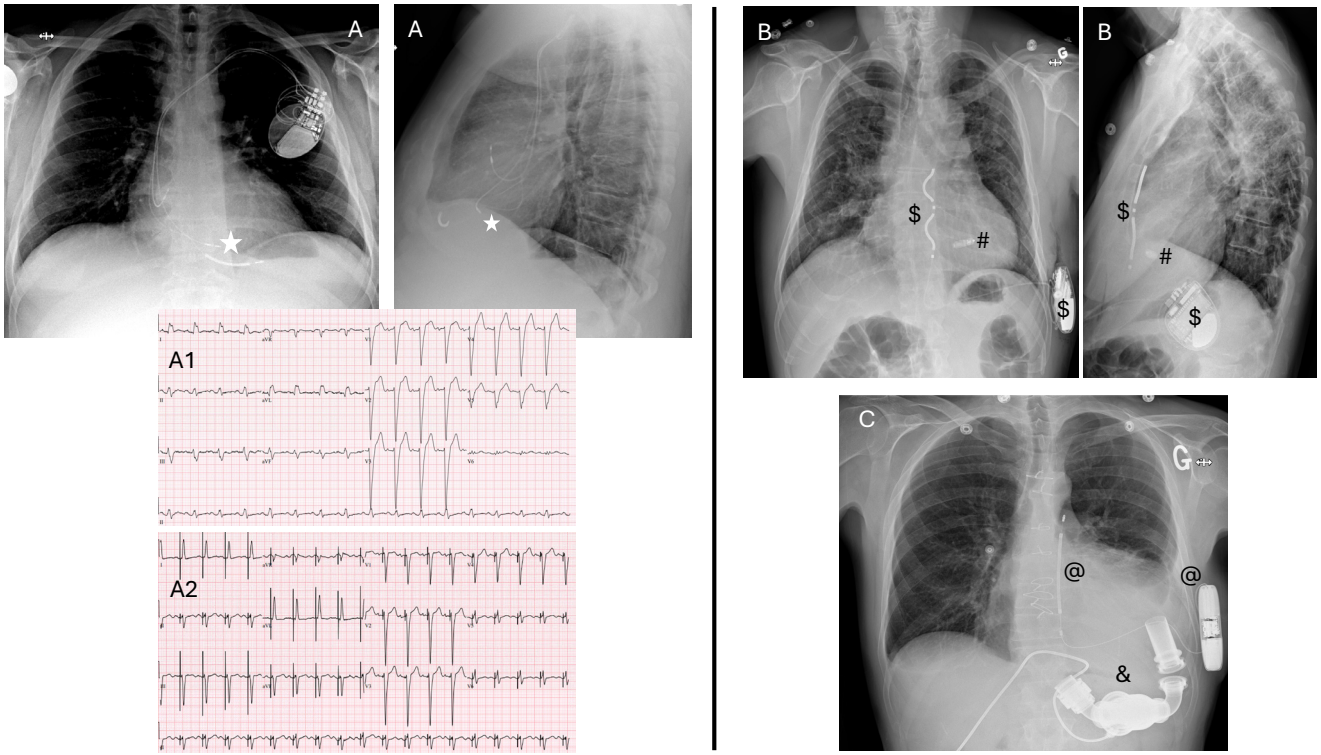

Figure 2. Examples of Devices Implanted in Heart Failure Management:
A- A 42-year-old patient with non-ischemic cardiomyopathy and left bundle branch block has undergone a failed CRT implantation. As a bail-out strategy, an LBBAP-defibrillator was successfully implanted, resulting in QRS narrowing. A: PA and lateral chest X-ray views *: LBBAP lead A1: LBB A2: LBBAP, characterized by a positive and narrow QRS in leads I and aVl, with a small R wave at the end of the QRS in V1
B- A 62-year-old patient with sarcoidosis-related cardiomyopathy, experienced multiple complications following several previous transvenous ICD procedures. The final solution involved implantation of an extravascular ICD (with the lead positioned beneath the sternum) (Medtronic Aurora®), along with a leadless AV Micra® pacemaker (Medtronic)
C- A 35-year-old patient with non-ischemic cardiomyopathy supported by an LVAD with a subcutaneous ICD (S-ICD, Boston Scientific Emblem®); *courtesy of Eileen O'Meara, MD, Blandine Mondésert, MD, FCHRS*

Abbreviations: CRT: cardiac resynchronization therapy; **ICD:** implantation cardioverter defibrillator; **LBB:** left bundle branch; **LBBAP:** left bundle branch area pacing; **LVAD:** left ventricular assistant device; **PA:** posteroanterior; **S-ICD:** subcutaneous implantation cardioverter defibrillator

Email: eileenomearamhi@gmail.com

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