How to Do Echo in Left Ventricular Assist Device Candidates: A Consensus Statement of the Italian Society of Echocardiography and Cardiovascular Imaging

Matteo Cameli, Maria Concetta Pastore, Eustachio Agricola[1], Maurizio Cusmà Piccione[2], Antonio De Luca[3], Roberta Manganaro[2], Scipione Carerj[2], Antonella Moreo[4], Concetta Zito[2]

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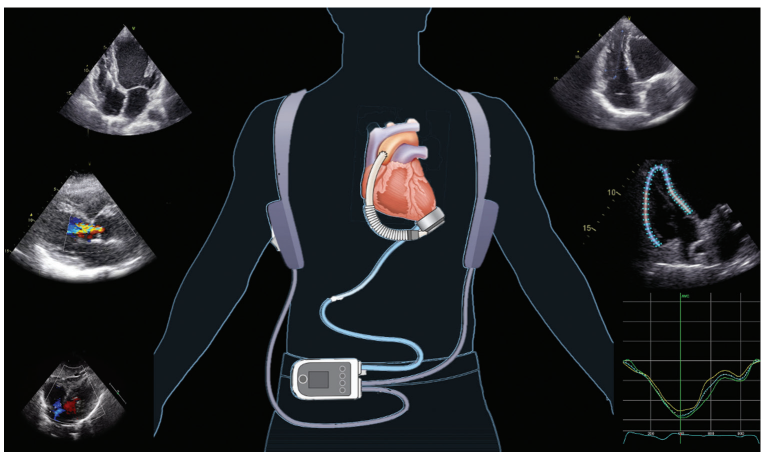
Department of Medical Biotechnologies, Division of Cardiology, University of Siena, Siena, [1]Unit of Cardiovascular Imaging, IRCCS San Raffaele Hospital, [4]Cardiology, De Gasperis Cardio Center, ASST Grande Ospedale Metropolitano Niguarda, Milano, [2]Department of Clinical and Experimental Medicine, University of Messina, Messina, [3]Department of Cardiothoracovascular, Echocardiography and Cardiac Magnetic Resonance Unit, Azienda Sanitaria Universitaria Giuliano Isontina, University of Trieste, Trieste, [5]Department of Medical Sciences and Public Health, University of Cagliari, Monserrato, [6]Cardiology and Cardiovascular Medicine Division, Fondazione Toscana Gabriele Monasterio, Pisa, [7]Department of Perioperative Cardiology and Cardiovascular Imaging, Centro Cardiologico Monzino IRCCS, Milan, Italy

Graphical Abstract



- Accurate selection of patients referred for LVADs is essential to prevent peri- and postoperative complications
- Echocardiography is the first line imaging modality for the evaluation of LVAD candidates
- Study of RV geometry and function is mandatory to detect subclinical RV dysfunction which could cause RV failure after-LVAD implantation, a frequent and potentially life-threatening complication
- Severe valvular heart disease, ascendant aorta and possible intracardiac thrombi or shunts should be carefully evaluated, since these may represent some limit to LVAD implantation.

Keywords: Heart failure, echocardiography, left ventricular assist devices, left ventricle, circulatory support

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Address for correspondence: Prof. Matteo Cameli, Department of Medical Biotechnologies, Division of Cardiology, University of Siena, Viale Bracci 1, Siena, Italy. E-mail: matteo.cameli@unisi.it

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Introduction

Heart failure (HF) represents a global health burden affecting millions of individuals worldwide. Despite advances in treatment, it remains a major cause of mortality, hospitalization, and worsening quality of life. In advanced HF [Table 1], medical therapy alone often fails to provide improvement in clinical outcome, and the therapeutic options are limited.[1,2] Particularly, heart transplantation is limited by the shortage of heart donors, with an imbalance between demand and offer of hearts. Mechanical circulatory support with ventricular assist devices (VADs) has emerged as an alternative therapeutic option. VADs are mechanical devices supporting the heart pump function by assisting or replacing the action of the ventricles. Left VADs (LVADs) were first used as bridge-to-transplant or bridge-to-recovery in refractory HF patients, but have recently emerged as destination therapy over the long term [Table 2].

Selecting the appropriate candidates for LVAD implantation is a complex procedure requiring an accurate evaluation of multiple factors [Flowchart 1], including hemodynamic status, underlying cardiac function, comorbidities, and overall prognosis. Echocardiography is the first-level tool for assessing cardiac structure and function and plays an essential role in the evaluation of patients with advanced HF referred for LVAD implantation.[3] It provides real-time, detailed information about left and right ventricular (RV) function, cardiac output, chamber sizes, and valvular function, all critical elements to evaluate patients' suitability for LVAD implantation [Figure 1].

Table 1: Definition of advanced heart failure according to current European guidelines[1]

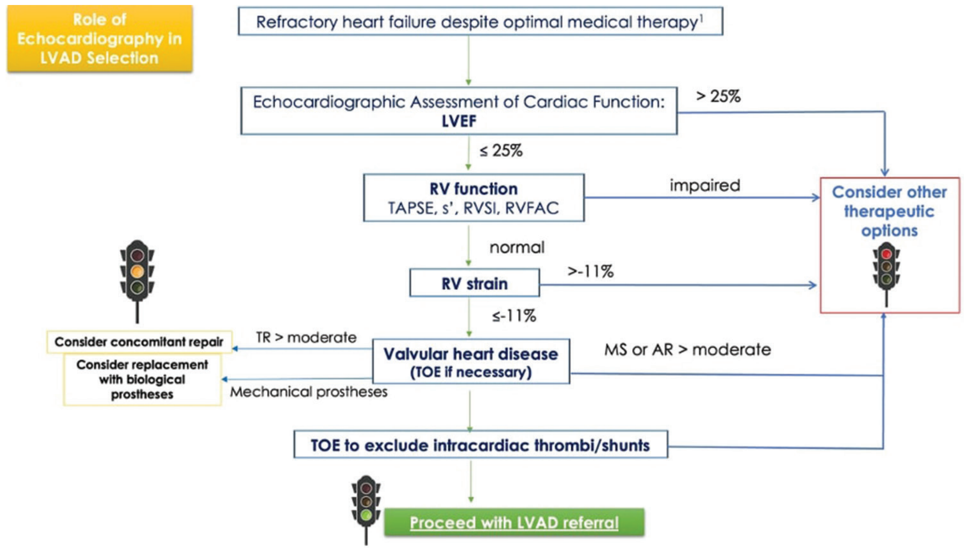
Advanced HF: All the following criteria must be present despite optimal medical treatment
Severe and persistent symptoms of HF (NYHA class III [advanced] or IV)
Severe cardiac dysfunction defined by at least one of the following
LVEF ≤30%
Isolated RV failure
Nonoperable severe valve abnormalities
Nonoperable severe congenital abnormalities
Persistently high (or increasing) BNP or NT-proBNP values and severe LV diastolic dysfunction or structural abnormalities (according to the definitions of HFpEF)
Episodes of pulmonary or systemic congestion requiring high-dose i.v. diuretics (or diuretic combinations) or episodes of low output requiring inotropes or vasoactive drugs or malignant arrhythmias causing>1 unplanned visit or hospitalization in the last 12 months
Severe impairment of exercise capacity with the inability to exercise or low 6MWT distance (<300 m) or pVO_2 <12 mL/kg/min or <50% predicted value, estimated to be of cardiac origin

HF=Heart failure, 6MWT=6 min walking test, BNP=Brain natriuretic peptide, NT-proBNP=N-terminal pro-BNP, HFpEF=HF with preserved ejection fraction, NYHA=New York Heart Association, LVEF=Left ventricular ejection fraction, pVO_2=Predicted oxygen consumption, RV=Right ventricle

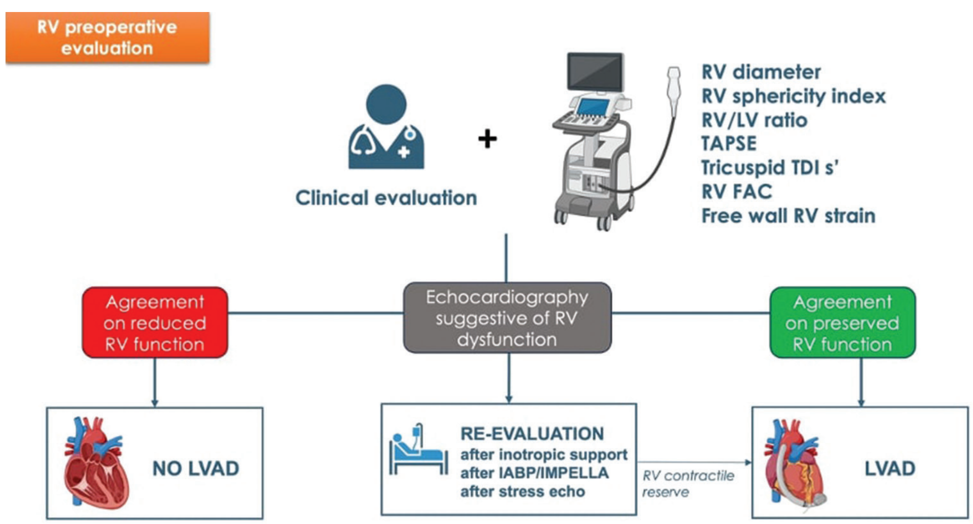
Table 2: Current indications and contraindications to left ventricular assist devices implantation

Indications	Contraindications
Patients with persistence of severe symptoms despite optimal medical and device therapy	Severe RV dysfunction and/or severe TR
Motivated, well informed, and emotionally stable	Active infection
Capable of complying with the intensive treatment required postoperatively	Severe peripheral arterial or cerebrovascular disease
As alternative to heart transplantation in patients with	Active cancer
Pharmacologic irreversible pulmonary hypertension (with subsequent re-evaluation to establish candidacy)	
At least one of the following	Systemic disease with multiorgan involvement
LVEF <25% and unable to exercise for HF or, if able to perform cardiopulmonary exercise testing, with peak VO_2 <12 mL/kg/min and/or <50% predicted value ≥3 HF hospitalizations in the previous 12 months without an obvious precipitating cause	
Dependence on i.v. Inotropic therapy or temporary MCS	
Progressive end-organ dysfunction (worsening renal and/or hepatic function, type II pulmonary hypertension, cardiac cachexia) due to reduced perfusion and not to inadequately low ventricular filling pressure (PCWP ≥20 mmHg and SBP ≤90 mmHg or cardiac index ≤2 L/min/m^2)	
	Other serious comorbidity with poor prognosis
	Pretransplant BMI >35 kg/m^2 (weight loss is recommended to achieve a BMI <35 kg/m^2)
	Current alcohol or drug abuse
	Any patient for whom social supports are deemed insufficient to achieve compliant care in the outpatient setting

Modified from McDonagh *et al*.[1] and Crespo-Leiro *et al.*[2] BMI=Body mass index, HF=Heart failure, LVEF=Left ventricular ejection fraction, MCS=Mechanical circulatory support, PCWP=Pulmonary capillary wedge pressure, SBP=Systolic blood pressure, VO2=Oxygen consumption, RV=Right ventricular, TR=Tricuspid regurgitation



Flowchart 1: Algorithm for the selection of left ventricular assist devices (LVAD) candidates. Patients with advanced heart failure refractory to optimal medical therapy according to the current guideline[1] may be candidate to advanced long-term therapeutic strategies, i.e. heart transplantation or LVADs. First, severe left ventricular dysfunction defines as LVEF ≤ 25%, should be ascertained; then, right ventricular (RV dysfunction should be excluded, both with basic echocardiographic indices of RV function and with RV strain by speckle tracking echocardiography, which, with a cutoff value ≤ −11% may indicate a subclinical RV dysfunction. In case one of these two criteria are not fulfilled, LVADs are to be excluded from therapeutic options. Then, severe valvular heart disease should be excluded; otherwise, a concomitant treatment or a replacement with biological prostheses during LVAD implantation should be considered. Moreover, transoesophageal echocardiography is advisable for the exclusion of intracardiac thrombi or shunts, which prevents LVAD implantation, unless adequately treated before implantation. AR = Aortic regurgitation, LVAD = Left ventricular assist device, LVEF = Left ventricular ejection fraction, MS = Mitral stenosis; RV = Right ventricle, RVFAC = Right ventricular fractional area change, RVSI = Right ventricular sphericity index, s' = Systolic velocity wave by tissue-Doppler imaging, TAPSE = Tricuspid annular plane systolic excursion, TR = Tricuspid regurgitation, TOE = Transoesophageal echocardiography



Flowchart 2: Algorithm for the evaluation of right ventricular function before left ventricular assist devices (LVAD) implantation. A tailored preoperative evaluation of LVADs candidates should include clinical and echocardiographic assessment, with basic and advanced parameters. In case of agreement on reduced RV function, LVAD implantation should be excluded, vice-versa in case of agreement on preserved RV function and absence of other contraindications*, LVAD implantation could be performed. In doubtful cases when echocardiography is suggestive of subclinical RV dysfunction, re-evaluation after inotropic support (e.g. milrinone, levosimendan), short-term mechanical circulatory supports or dobutamine stress echocardiography, to assess RV contractile reserve in means of improved RV function, is suggested, since in the presence of RV contractile reserve one may proceed with LVAD implantation. IABP = Intra-aortic balloon pump, LV = left ventricle, LVAD = Left ventricular assist device, RV = Right ventricle, RVFAC = Right ventricular fractional area change, RVSI = Right ventricular sphericity index; s' = Systolic velocity wave by tissue-Doppler imaging, TAPSE = Tricuspid annular plane systolic excursion

A complete and precise echocardiographic evaluation is fundamental in the decision-making process for LVAD selection. First, left ventricular ejection fraction (LVEF) should be considered as the standard marker of LV function, which confirms the indication of advanced HF therapy, i.e. LVAD. However, LVEF alone is not sufficient to determine candidacy; a thorough assessment of RV function is also essential [Flowchart 2 and Figure 2] since patients

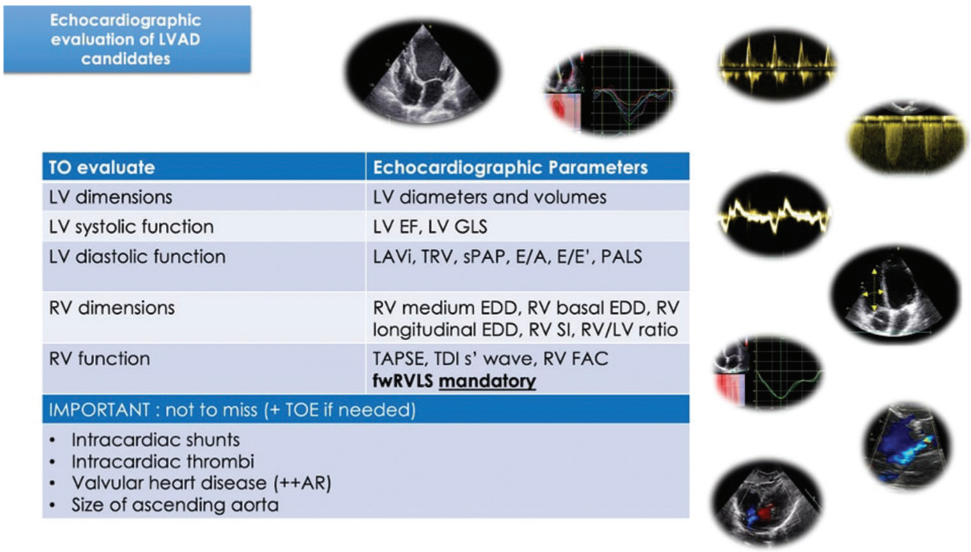


Figure 1: Echocardiographic parameters to evaluate in Left ventricular assist device (LVAD) candidates. The echocardiographic evaluation of patients referred for LVADs should start with transthoracic echocardiography and should focus on the evaluation of left ventricle (LV) systo-diastolic function and RV dimensions and function. RV study could not exclude the application of speckle tracking echocardiography to measure RV-free wall strain. Moreover, particular attention should be paid to the exclusion of intracardiac shunts or thrombi, severe valvular heart disease (above all, aortic regurgitation, mitral stenosis and tricuspid regurgitation) and to the measures of ascending aorta size; the application of transoesophageal echocardiography may be necessary to improve the assessment of these elements. FAC = Fractional area change, EDD = End-diastolic diameter, GLS = Global longitudinal strain; LAVi = Left atrial volume index, LV = Left venricle, sPAP = Systolic pulmonary artery pressure, RV = Right ventricle, s' = Systolic velocity wave by tissue-Doppler imaging, SI = Sphericity index, TAPSE = Tricuspid annular plane systolic excursion, TDI = Tissue Doppler imaging, TRV, Tricuspid regurgitant velocity

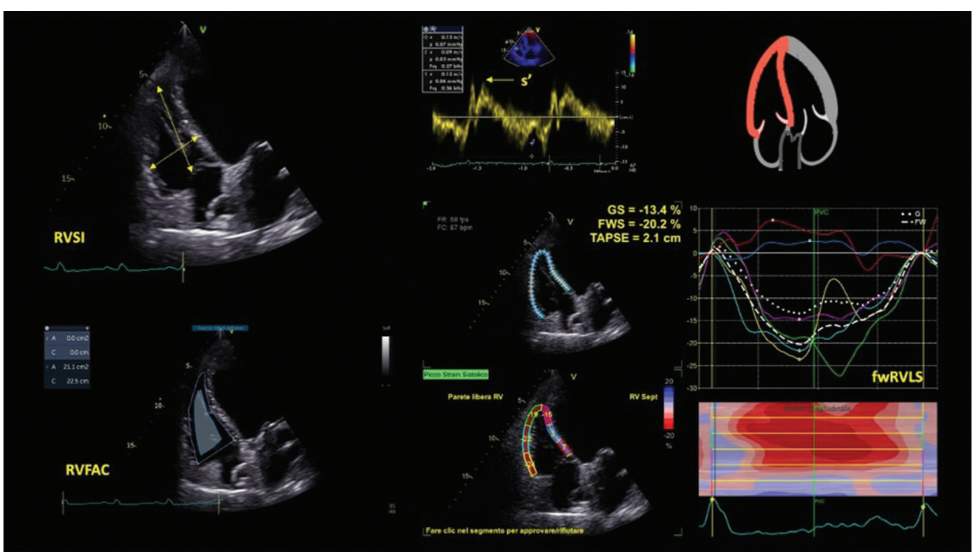


Figure 2: Echocardiographic parameters for the evaluation of the right ventricle in LVAD candidates. Right ventricular (RV) sphericity index on the top, left, assessed as the ratio between medium and longitudinal right ventricular diameters; tricuspid s' wave by tissue Doppler imaging on the top center; right ventricular fractional area change on the bottom, left, assessed as the ratio between (RV telediastolic area-telesystolic area) and RV telediastolic area; right ventricular strain, assessed by a new software which is able to automatically trace the endocardial contour of the RV based on three reference points put by the operator, and then generates the RV strain curves based on 6-segments model; thus calculating (1) RV global longitudinal strain (GS) including both free wall and interventricular septum, (2) free wall RV longitudinal strain including only three segments of the free wall, which is the recommended parameter in clinical practice, (3) tricuspid annular plane systolic excursion, in centimeters

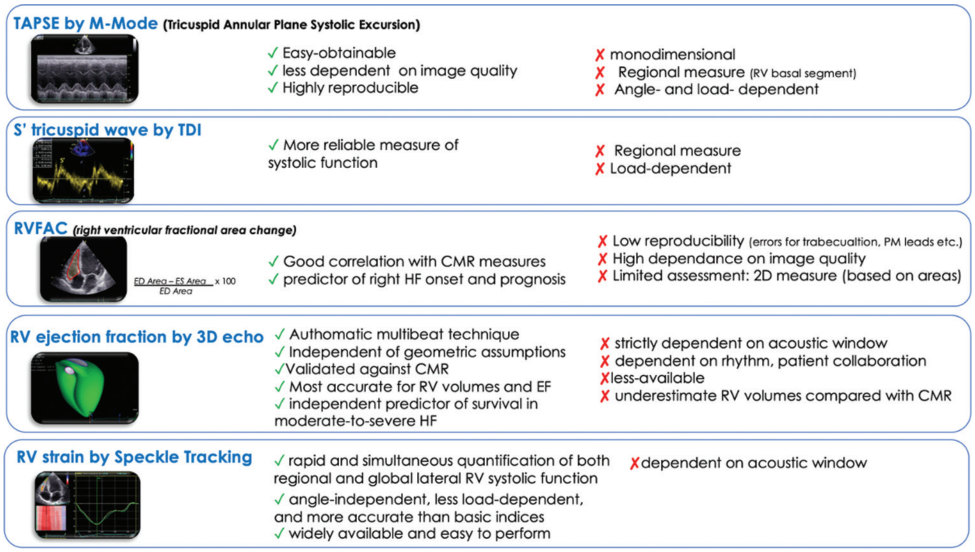


Figure 3: Pros and cons of the different echocardiographic parameters to evaluate right ventricular (RV) function. Cutoff values to consider to exclude candidacy to LVAD: Tricuspid annular plane systolic excursion by M-mode <12.5 mm, RV fractional area change <27%, free-wall RV strain <−11% and three-dimensional (3D) RV ejection fraction <30%, if available (it requires a dedicated 3D probe). Additionally, the RV/left ventricular (RV/LV) ratio > 0.75, RV sphericity index >0.5 and TAPSE/systolic pulmonary artery pressure < 0.34% as index of RV/pulmonary arterial coupling (although less standardized) could be considered

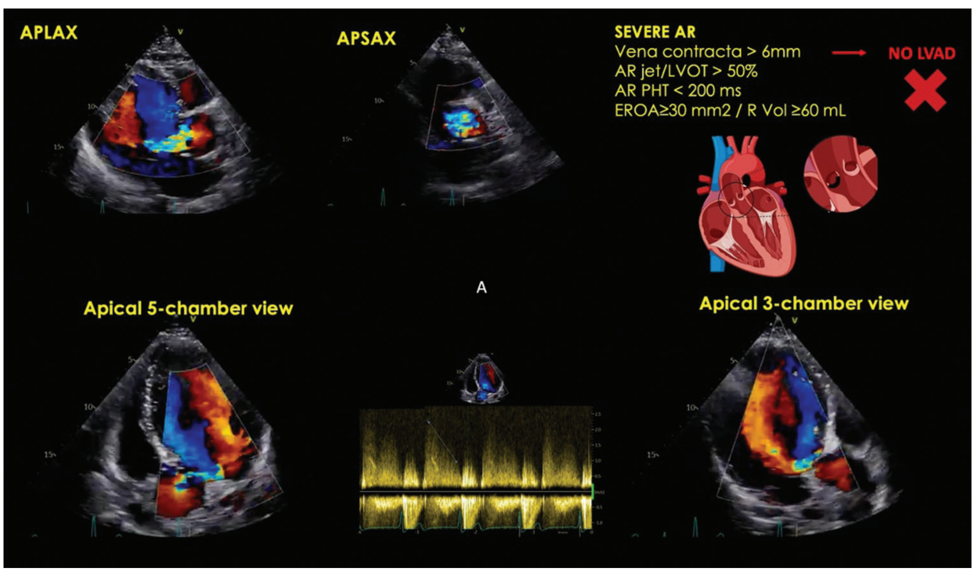


Figure 4: Echocardiographic parameters for the evaluation of aortic regurgitation in left ventricular assist device candidates. Parasternal long-axis view (APLAX) and short axis-view (APSAX) on the top, left and top, center; apical 5-chamber view on the bottom, left; continuous-wave Doppler across aortic valve on the bottom, center; apical 3-chamber view on the bottom, right. AR = Aortic regurgitation, EROA = Effective regurgitant orifice area, LVOT = Left ventricular outflow tract, PHT = Pressure half-time, R Vol = Regurgitant volume

with underlying RV dysfunction are more prone to develop RV failure after LVAD implantation, which is one of the most frequent and fatal complications in these patients. Therefore, patients with RV dysfunction represent a contraindication to LVAD implantation, and a multiparametric evaluation, including more sensitive indices, for example, speckle tracking echocardiography [Figures 2 and 3],[4] showed to improve the assessment of RV in LVAD candidates. In addition to these parameters, the evaluation of the patient's hemodynamic profile and the presence of significant valvular disease, is also critical. Echocardiography provides valuable information about the severity of valvular lesions, such as mitral stenosis or aortic regurgitation, which may pose some challenges to LVAD therapy [Figure 4]. Moreover, the exclusion of mechanical or functional obstructions to blood flow is important, and may require integration with transesophageal echocardiography.

This article aims to provide a comprehensive and practical guide on how to effectively use echocardiography to optimize the selection of HF patients who may benefit from LVADs, from the identification of the most suitable candidate to the exclusion of potential contraindications.

Conclusions

LVADs are currently considered an alternative destination therapy to heart transplantation in advanced HF. However, the selection of patients referred for an LVAD should include the evaluation of biventricular function and hemodynamic status, for which echocardiography plays a crucial role. This review discussed the main principles that clinicians should bear in mind for decision-making in the management of potential candidates for LVAD implantation, giving practical indications for the echocardiographic assessment of these patients.

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Conflicts of interest

There are no conflicts of interest.

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