How to Do Echocardiography in Heart Failure Patients with Long-term Left Ventricular Assist Devices: A Consensus Statement of the Italian Society of Echocardiography and Cardiovascular Imaging

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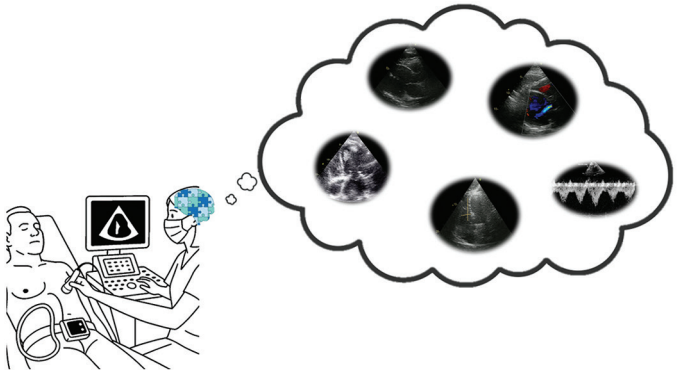
Graphical Abstract



1. LVADs have emerged as destination therapy for advanced heart failure, however, these are still limited by many potential complications after implant, such as right heart failure, aortic regurgitation, thrombosis, infections
2. A seriate and accurate echocardiographic evaluation is needed in LVAD carriers but may sometimes be challenging, due to artifacts or poor acoustic windows due to the device
3. Left ventricular unloading is the main feature to consider to evaluate and adjust device function and requires many echocardiographic parameters to be assessed
4. Ramp test during echocardiography may be of additional value to optimize device speed and to early identify pump dysfunction

Keywords: Echocardiography, heart failure, left ventricular assist devices

Access this article online

Quick Response Code:

Website: https://journals.lww.com/JCEG

DOI: 10.4103/jcecho.jcecho_63_25

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Submitted: 09-Jun-2025 **Accepted:** 12-Jun-2025
Published: 30-Jul-2025

How to cite this article: Cameli M, Pastore MC, Agricola E, Piccione MC, De Luca A, Mandoli GE, *et al*. How to do Echocardiography in heart failure patients with long-term left ventricular assist devices: A consensus statement of the Italian Society of Echocardiography and Cardiovascular Imaging. J Cardiovasc Echography 2025;35:193-8.

Introduction

Advanced heart failure (HF) is a complex clinical syndrome characterized by severe and irreversible cardiac dysfunction causing severe and persistent HF symptoms and impairment of functional capacity, episodes of pulmonary, or systemic congestion requiring high-dose IV diuretics or of low output requiring inotropes/vasoactive drugs or malignant arrhythmias, despite optimal medical treatment.[1] Due to the increasing demand of advanced therapeutic strategies for advanced HF, parallel to a shortage in heart transplantation, the management of this condition has evolved significantly over the years.[2] One of the advancements in treatment for advanced HF is represented by left ventricular assist devices (LVADs), which have gained increasing importance as long-term "destination therapy" for patients with contraindications for cardiac transplantation.[3] However, this may be burdened by early and long-term life-threatening postoperative complications, which should be early recognized and treated with the help of multimodality imaging.[4]

Echocardiography serves as a crucial tool in the assessment and management of HF, providing real-time imaging that helps evaluate cardiac structure, function, and hemodynamics.[5] In patients with LVADs, echocardiographic evaluation remains the first-line tool for the assessment of complications, therefore, it becomes pivotal yet poses unique challenges. The presence of LVADs alters normal hemodynamic parameters, potentially complicating the interpretation of echocardiographic findings.[6] Moreover, the integration of various types of LVADs can lead to diverse impacts on echocardiographic assessments of heart function.[7]

Serial echocardiography, more frequent in the 1st year after implantation, is recommended in the same center, which should preferably be an LVAD reference center with the chance of integration with other imaging modalities [Figure 1]. This may be challenging, due to possible artifacts and poor visualization caused by the device [Figure 2]. First of all, the good functioning of the device should be checked up, assessing left ventricular (LV) unloading, and aortic opening and regurgitation grade [Flowchart 1]. Then, possible complications, such as right ventricular (RV) failure, device or aortic thrombosis [Figure 3], mechanical complications, and infections should be excluded [Table 1]. Ramp test, with device performance improvement while performing echocardiography, is useful to optimize device settings, being careful not to overload the RV, and early detect possible complications [Figure 4].[8]

This consensus document aims to address the specific considerations and methodologies pertinent to performing echocardiography in HF patients with LVADs. By clarifying the best practices for echocardiographic assessment in ventricular assist device patients, we aim to improve patient management, optimize device performance, and ultimately enhance outcomes in this unique patient population.

Conclusions

Periodic echocardiographic evaluation is pivotal in patients with LVAD and should be comprehensive of an accurate assessment of potential complications [Table 1] and device function and position. Ramp test should be performed to optimize LVAD settings and expedite the detection of device dysfunction [Figure 4]. This expert consensus document provided practical information on which parameter to focus on during echocardiography and how to interpret the possible findings in patients with LVAD.

Starting from parasternal long-axis view, LV diameters and the distance between the interventricular septum (IVS)

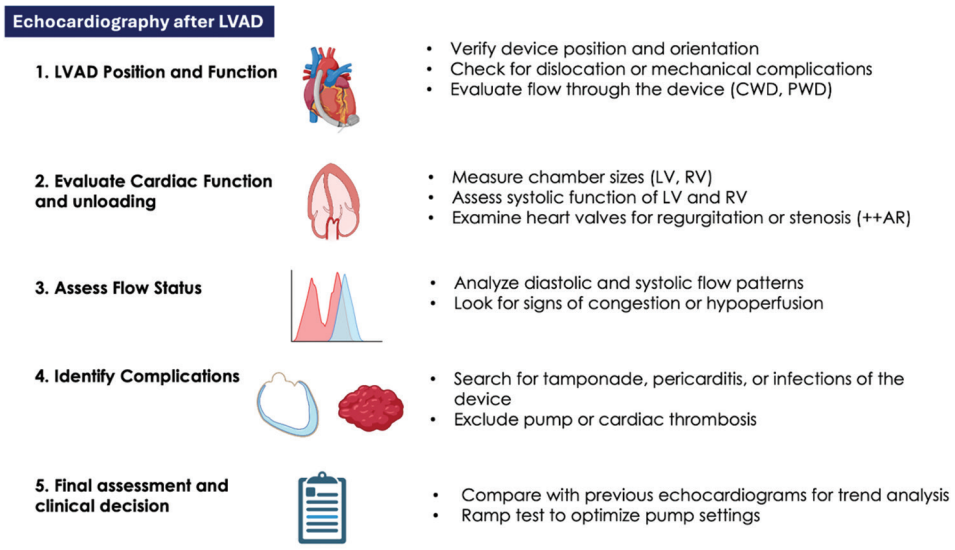


Figure 1: What to assess when performing echocardiography after left ventricular assist device implantation. AR = Aortic regurgitation, CWD = Continuous wave Doppler, LVAD = Left ventricular assist device, LV = Left ventricle, PWD = Pulsed wave Doppler, RV: Right ventricle

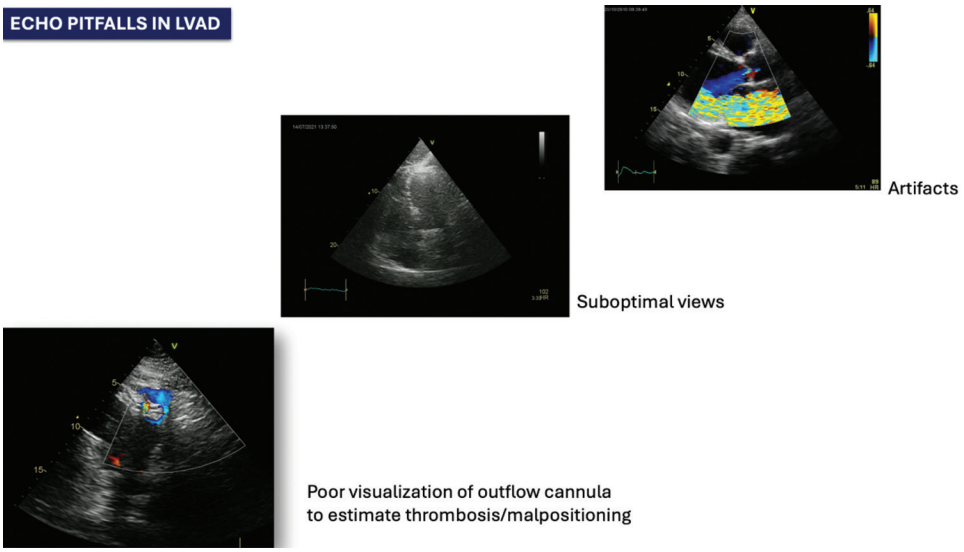


Figure 2: Representative cases of possible challenges of echocardiography in left ventricular assist device patients

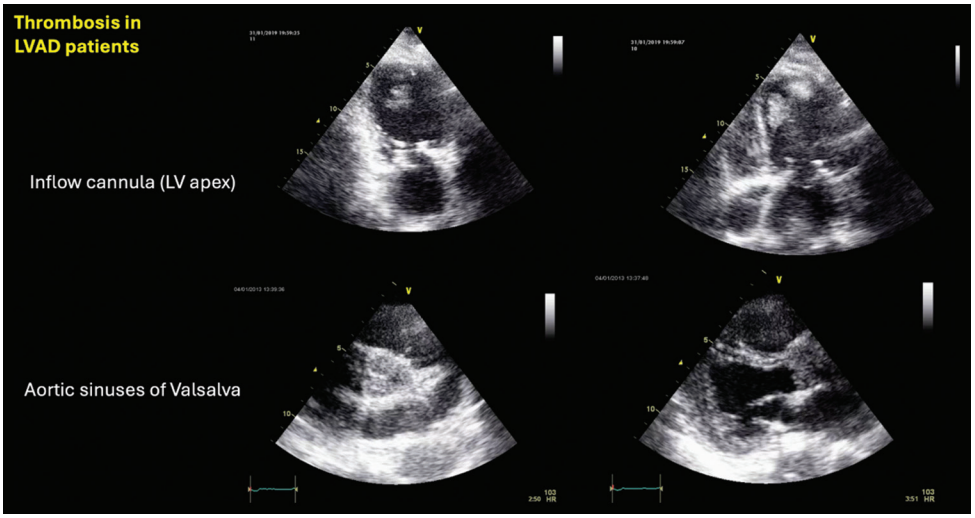
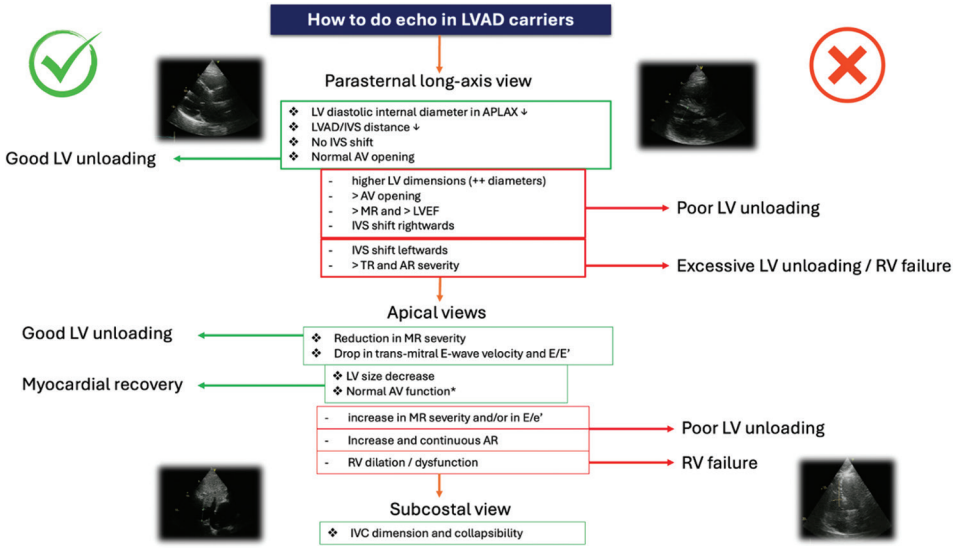


Figure 3: Representative cases of thrombosis in patients with left ventricular assist device

and the inflow cannula should be assessed; their reduction compared to the previous echocardiogram is a sign of good unloading. IVS position is also important since the shift of IVS from the right to the LV could indicate RV failure, increased LV unloading due to high pump speed, or reduced LV preload or afterload; while the shift of the IVS from the left to the RV could indicate decreased LV unloading due to low pump speed or dysfunction, aortic regurgitation (AR), tachyarrhythmias or increased RV afterload. Aortic valve (AV) opening, preferably assessed by M-mode to see aortic cusps excursion, is also fundamental, since increased AV opening compared to the * normal * situation of different LVADs (for Jarvick 2000 AV opening should happen during the few seconds of intermittent low speed, while for HeartMate III AV opening should occur every 3–4 beats) could indicate increased LV output due to poor unloading or LV recovery, while reduced AV opening could indicate decreased LV output due to decreased preload, tachyarrhythmias, or increased AR or pump thrombosis (thus, reduction of LVAD speed should be tried, to facilitate AV opening, if pump thrombosis is not suspected). On the other hand, higher LV dimensions, increased AV opening, mitral regurgitation (MR), and tricuspid regurgitation or impaired IVS position may suggest impaired LV unloading. In apical views, the improvement in diastolic function, assessed by a reduction in transmitral E wave velocity by pulsed-wave Doppler and of E/E' ratio by Tissue Doppler, and an improvement of MR, may suggest good LV unloading. The reduction of LV size, together with normal AV opening, may suggest myocardial recovery (estimated in 1.4% of LVAD patients). Conversely, a worsening diastolic function and increase in MR and AR will suggest poor LV unloading, while particular attention should be paid to the RV, since its dilation and dysfunction may indicate RV failure. Finally, assessment of vena cava diameter and collapsibility in subcostal view will suggest good or poor unloading.



Flowchart 1: Algorithm for the execution of transthoracic echocardiography in long-term left ventricular assist device carriers, with possible positive and negative findings. AV = Aortic valve, AR = Aortic regurgitation, IVS = Interventricular septum, LV = Left ventricle, RV = right ventricle

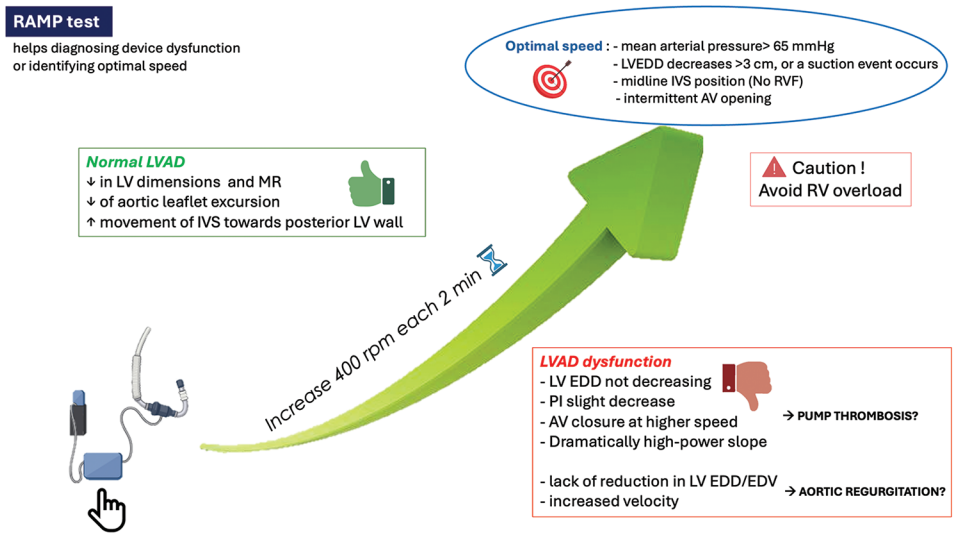


Figure 4: Ramp test in patients with left ventricular assist device using echocardiography. AV = Aortic valve, EDD = End-diastolic diameter, EDV = End-diastolic volume, ESV = End-systolic volume, IVS = Intraventricular septum, LV = Left ventricle, MR = Mitral regurgitation, PI = Pulsatility index, RVF = Right ventricular failure

Serial echocardiographic evaluation is recommended in patients with LVAD. These should include (1) the assessment of LVAD position and function, excluding device displacement or mechanical complications (inflow/outflow cannula twisting or kinking, driveline issues), where the suspicion could be raised by turbulent flow with elevated velocities or low flow; (2) the evaluation of cardiac function and unloading, to assess the correct function of the device [Flowchart 1] and the exclusion of RV failure, the most common complication after LVAD implant; (3) the estimation of flow status, measuring the flow through the cannulas by continuous-wave or pulsed-wave Doppler together with the presence of clinical signs of congestion or hypoperfusion; (4) the exclusion of complications, such as pump or intracardiac thrombosis or cardiac tamponade; (5) final report comparing the findings with previous echocardiographic exam (this suggest that serial evaluation in the same center would be suggestable) and optimizing the device setting through the Ramp test [Figure 4]. Importantly, in each echocardiographic report, LVAD type, velocity, flow, power, and pulsatility index should be reported.[2]

Artifacts and possible poor acoustic views should be encountered in patients with LVAD (particularly, apical view may be challenging in patients with HeartMate III). Often it is also difficult to estimate the flow across both the cannulas and verify device position. In case of high clinical suspicion of LVAD complications with insufficient

Table 1: List of possible complications in patients with long-term left ventricular assist devices and practical recommendations for the echocardiographic assessment

Complications	Echocardiographic findings
Impaired LV unloading	Higher LV dimensions (++ diameters)
	>AV opening
	increase in MR severity and/or in E/e'
RV failure	Smaller LV diastolic than systolic diameter
	RV dilatation (RV/LV diameters>1)
	IVC dilatation
	Worsening TR
	Reduced RVFAC
	To exclude: Too high LVAD pump speeds (output) for excessive RV preload (LV suction event) or inadequate LV unloading
Impaired AV opening	Record 5–6 cardiac cycles at a slow sweep speed (25–50 mm/s) in M-mode and 2D
	Jarvik 2000: AV does not open either during ILS
	HeartMate III: AV opens every 1-2 beats (increased opening) or every>5 beats (reduced opening)
	If reduced AV opening: Exclude aortic root thrombosis, fusion of the AV cusps, or AR
Pump thrombosis	Suspicion: Insufficient LV unloading with continuous AV opening; sudden increase in pump velocity
	Inflow cannula → obstruction: Elevated flow velocities and turbulent flow, sometimes backflow (in pump stop)
	Regurgitation through both cannulae
	Reduced diastolic (LVAD) flow → increased S/D ratio
	Ramp test: LV EDD not decreasing, PI slight decrease, AV closure at higher speed, high-power slope
Aortic regurgitation	APLAX preferred
	Aortic jet "vena contracta" width: >6 mm severe
	AR jet height/LVOT diameter ratio: >30%
	outflow graft S/D ratio by PWD: <5.0 at least moderate AR
	Diastolic acceleration of the outflow graft >49 cm/s
	Continuous regurgitation (++ CF-LVAD) worse grade and outcome
	PHT/EROA usually not assessable
	Ramp test: Lack of reduction in LV EDD/EDV with increased velocity highly suggestive of severe AR
	Avoid speed reduction if suspected Ao thrombosis
Mechanical complications	Turbulent flow with elevated velocities or low flow by CWD (normal values 1–2 m/s)
Inflow/outflow cannula malpositioning/kinking	Outflow graft anastomosis (at the level of the RPA) >2.0 m/s: Obstruction?
Graft twisting	Inflow cannula uncorrect alignment: Contact with LV wall, impaired MV closure
Driveline issues	> Angle of insertion of the LVAD outflow graft into the native aorta
Infections	Vegetations
	destructive valve lesions and abscesses in the surrounding cardiac structures ++ adjacent to the device
	clinical signs to be assessed
	++complete with MMI (TOE, CT, PET)

AR=Aortic regurgitation, AV=Aortic valve, CF=Continuous flow, CWD=Continuous wave Doppler, CT=Computed tomography, E/E'=Early diastolic wave by pulsed-wave Doppler/average early diastolic wave by Tissue Doppler imaging, EDD=End-diastolic diameter, EDV=End-diastolic volume, EROA=Effetticve regurgitant orifice area, IVC=Inferior vena cava, LV=Left ventricle, LVAD=Left ventricular assist device, LVOT=Left ventricular outflow tract, MMI=Multimodality imaging, MR=Mitral regurgitation, MV=Mitral valve, PHT=Pressure half time, PI=Pulsatility index, PET=Positron emission tomography, RPA=Right pulmonary artery, RV=Right ventricle, S/D=Systolic-to-diastolic velocity, TOE=Transoesophageal echocardiography, TR=Tricuspid regurgitation

information by transthoracic echocardiography, second-level imaging modalities could be used, such as transesophageal echocardiography, computed tomography (CT, particularly useful to detect device thrombosis and/or mechanical complications) or positron emission tomography (PET)/PET-CT for infections. Cardiac magnetic resonance imaging (MRI) is not possible in almost all patients with LVAD since the devices are not MRI-compatible.[2]

In upper panels we may see pump thrombosis involving the inflow cannula of the device in LV apex, lower panels show thrombosis of the aortic sinuses of Valsalva. Importantly, in the suspect of thrombosis, pump speed increase should be avoided to prevent embolization. In doubtful cases, CT could be performed to detect pump thrombosis.

The ramp test is used to evaluate and optimize LVAD settings based on hemodynamic response and echocardiographic parameters. During the test, the pump speed is progressively increased, typically 400 rpm each 2 min, while transthoracic echocardiography is performed.[7] During the test, LV size and geometry, RV function, AV opening pattern, IVS position and motion, degree of mitral and AR, and estimation of cardiac output are performed. The goal is to reach the optimal pump speed that achieves maximal LV unloading without compromising RV function (aiming at left ventricular end-diastolic diameter [LV

EDD] reduction of at least 3 cm and mean arterial blood pressure >65 mm Hg), avoiding IVS shift or persistent AV closure. This test can be repeated over time to assess response to therapy. A lack of LV EDD decrease together with a dramatic increase of LVAD power slope and AV closure at higher speed may suggest pump thrombosis, while a lack of LV volumes reduction together with increased pump velocity will suggest increased AR.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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