A Comprehensive Imaging Approach to Guide the Management of Patients with Continuous-Flow Left Ventricular Assist Devices

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KEYWORDS

• Left ventricular assist device • Multimodality imaging • Computed tomography • Echocardiography

KEY POINTS

- Imaging is an integral part in the care of patients supported with left ventricular assist devices (LVADs).
- Echocardiography is a readily available modality that can be used to facilitate the most common LVAD complications.
- Echocardiography has been shown to predict underlying hemodynamics to define left and right ventricular unloading while on LVAD support.
- Cardiac computed tomography is an available modality to diagnose LVAD-related outflow cannula problems, and intracardiac and aortic root clot when echocardiography images are nondiagnostic.

INTRODUCTION

Recent advances in mechanical circulatory support have allowed patients with end-stage heart failure to be successfully bridged to heart transplantation or live for many years on continuous-flow left ventricular assist devices (CF-LVADs) as destination therapy. As survival and quality of life continue to improve and the number of patients supported by CF-LVADs continues to grow,[1,2] utilization of different imaging modalities in the care for these patients has become an integral part of many heart failure centers. In this article, we review the currently available imaging modalities, with a focus on echocardiography, that aid to diagnose and manage common adverse events associated with CF-LVADs that are approved by the US Food and Drug Administration, including persistent heart failure, continuous aortic regurgitation, inflow cannula malposition, low-flow alarms, thromboembolic complications, and suspected pump thrombosis.

IMAGING IN THE MANAGEMENT OF STABLE PATIENTS SUPPORTED WITH CONTINUOUS-FLOW LEFT VENTRICULAR ASSIST DEVICES

Continuous-Flow Left Ventricular Assist Device Monitoring and Surveillance Protocols

For a comprehensive approach to the performance and interpretation of LVAD surveillance protocol, we refer readers to the recently

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published American Society of Echocardiography document on management of patients with LVADs.[3] Although these protocols are center specific, they provide essential information in the monitoring of device function and optimization in addition to detection of device-related complications. In general, most centers perform CF-LVAD surveillance protocols at set time intervals unless clinically recognized complications arise, then problems-focused protocols are performed. CF-LVAD surveillance protocols provide important information to assess (1) underlying hemodynamics to define the degree of left ventricle (LV) unloading provided by the CF-LVAD, (2) right ventricular (RV) function as a surrogate for right heart failure, (3) valvular function with focus on the aortic valve opening status and degree of mitral regurgitation, and (4) CF-LVAD–specific parameters, such as assessment of inflow and outflow cannula flow profiles and the inflow cannula position. After appropriate 2-dimensional (2D) color and spectral Doppler imaging acquisition, a comprehensive echocardiography report can be generated to guide heart failure providers who care for patients supported by CF-LVADs (**Table 1**).

The degree of LV unloading should be assessed during each CF-LVAD surveillance protocol examination. Clues associated with adequate LV unloading consist of a reduction in LV size relative to pre-implant measurements and reduced secondary mitral regurgitation. Other useful parameters include the position of the interventricular and interatrial septum, which reflects the pressure gradient between the LV and RV, and the left atrium (LA) and right atrium (RA), respectively. Adequate LV unloading in the absence of RV failure is associated with a neutral interventricular and interatrial position. A ventricular septum that is deviated to the right or left might indicate inadequate or excessive LV unloading. Similar to imaging patients with congestive heart failure without a CF-LVAD, a combination of Doppler-derived mitral inflow velocities, early mitral annular tissue Doppler, LA size, and pulmonary artery systolic pressure can objectively estimate left-sided and right-sided filling pressures with high accuracy.[4]

Although a closed aortic valve (AV) or intermittent opening of the AV typically reflects a properly functioning CF-LVAD and LV unloading, setting the pump speed to maintain AV opening is a secondary aim to minimize AV fusion and curb the development of continuous aortic regurgitation. A pump speed that is set too low (eg, HeartMate [HM] II pump speed <8600 rpm) may increase the risk of pump thrombosis. The low end of speed for each patient is usually determined during Echo ramp studies, which is the speed that allows at least intermittent AV opening without signs of heart failure.[5] AV opening is best assessed from the parasternal long axis view using 2D and M-mode imaging for at least 3 to 5 consecutive cycles and can be classified as closed, intermittent opening or noted as opening with every cardiac cycle after ventricular systole.

Standard echocardiographic criteria can be used to assess RV function in patients supported with CF-LVADs.[6,7] However, it is important to note that parameters, such as a qualitative assessment of RV systolic function, RV fractional area change, and tricuspid annular plane systolic excursion, are only surrogates for RV failure. Patients may have a reduction in these measurements with underlying normal right-sided filling pressures, normal cardiac output, and absent clinical heart failure symptoms and signs.

Valvular abnormalities should be measured and reported in accord with the latest American Society of Echocardiography guidelines.[8] Although significant mitral regurgitation can be a clue for inadequate LV unloading, significant tricuspid regurgitation can be due to inadequate or excessive LV unloading in addition to primary RV failure.

Normal inflow and outflow cannula flow profiles are defined as continuous and slightly pulsatile due to native LV contraction with a defined peak noted after ventricular systole. Normal peak inflow cannula velocities are between 1 and 2 m/s (typically <1.5 m/s).[3] An increased peak velocity may indicate inlet obstruction and can be due to thrombus, vegetation, LV trabeculae, or inflow cannula malposition and interaction with the endocardium (septum or LV free wall).

Based on a more recent report, peak outflow cannula velocities maybe higher than inflow cannula peak velocities. Based on one study, the average outflow velocity for the HM II was 1.86 m/s (range 0.98–2.73 m/s), whereas the average outflow velocity for the HVAD was 2.36 m/s (range 1.3–3.42 m/s).[9] This study suggests a difference in normal outflow cannula velocities between the 2 most commonly used CF-LVADs. Increased outflow cannula velocities can occur due to partial kinking and internal obstruction by a thrombus or a vegetation when the Doppler sample volume is in proximity to the obstruction. In comparison, outflow cannula velocities are decreased in pump (rotor) thrombosis associated with pump malfunction (decreased diastolic flow velocity), pump stoppage, and intrinsic obstruction when the Doppler sample volume is away from the site of obstruction.