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Echocardiography and Continuous-Flow Left Ventricular Assist Devices

Evidence and Limitations

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ABSTRACT

Echocardiography is the most used imaging modality in the growing population of patients with advanced heart failure undergoing continuous-flow, durable mechanical circulatory support. However, no guidelines for the use of echocardiography in this population exist, evidence for core applications is limited and conflicting, and newer centrifugal-flow devices have been subject to minimal study. As a first step toward addressing these deficits, this review summarizes the evidence and expert opinion for the use of echocardiography in pre-operative planning and perioperative management, prediction of post-operative right ventricular failure, the use of echocardiographic surrogates for invasive hemodynamic measurements, and the performance of speed ramp studies for the diagnosis of thrombosis and optimization of device settings. (J Am Coll Cardiol HF 2015;■:■–■) © 2015 by the American College of Cardiology Foundation.

Mechanical circulatory support for advanced heart failure has evolved from its origins in bulky extracorporeal machines used for days to weeks in intensive care units, to implantable pumps intended for months of waiting on the transplantation list, to durable devices designed for permanent use (1,2). Continuous-flow left ventricular (LV) assist devices (LVADs) have almost entirely supplanted earlier pulsatile flow devices, and destination therapy—the long-term use of durable mechanical circulatory support (DMCS) in patients for whom heart transplantation is not appropriate—is on track to become the dominant indication (3). The DMCS-supported population is growing rapidly, patients are living longer with their LVADs, the number of centers offering DMCS is growing, and the diversity of commercially available devices is expected to expand. Cardiac imaging is an indispensable tool to optimize pump performance and ensure successful outcomes. Consequently, there is a real need for standardized, evidence-based cardiac imaging to guide decision making in LVAD-supported patients.

Echocardiography is the most used imaging modality in patients with advanced heart failure undergoing DMCS (4,5). Echocardiography is portable, noninvasive, and inexpensive; involves no exposure to radiation or nephrotoxic contrast agents; and, unlike cardiac magnetic resonance imaging, can be performed in the presence of LVAD support.

The International Society for Heart and Lung Transplantation recommends the use of echocardiography for pre-operative assessment, routine follow-up, and evaluation of circulatory dysfunction in DMCS patients (6). However, guidelines for the use of echocardiography in the DMCS population do not currently exist. In the absence of such standardization, the use of echocardiography varies widely among centers, with differing degrees of comfort and sophistication. Technical issues pertaining to image acquisition pose only 1 barrier to the optimal use of echocardiography in DMCS patients. Other fundamental issues include the limited and often conflicting evidence basis for core applications such as the prediction of post-operative right ventricular (RV) failure, the use of echocardiographic surrogates for invasive hemodynamic measurements, and the performance of speed ramp studies for the diagnosis of thrombosis and optimization of device settings (**Central Illustration**). Of critical importance, the overwhelming majority of evidence for the use of echocardiography in DMCS patients is derived from

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ABBREVIATIONS AND ACRONYMS

AI = aortic insufficiency

DMCS = durable mechanical circulatory support

LV = left ventricular

LVAD = left ventricular assist device

LVEDD = left ventricular end-diastolic diameter

MR = mitral regurgitation

PCWP = pulmonary capillary wedge pressure

RV = right ventricular

TEE = transesophageal echocardiography

TR = tricuspid regurgitation

TTE = transthoracic echocardiography

experience with axial-flow LVADs (Table 1). Centrifugal-flow devices are being implanted with increasing regularity, posing unique challenges to image acquisition and necessitating independent validation.

It should be noted that a growing variety of continuous-flow devices are available for the temporary circulatory support of patients with cardiogenic shock. The role of echocardiography in managing such temporary assist devices is outside the scope of this review. It should also be noted that this review is not intended to be a "how-to" guide for using echocardiography in LVAD-supported patients with heart failure. Rather, as a first step toward eventual protocol standardization, we summarize the available evidence for the use of echocardiography in continuous-flow DMCS, highlighting both its utility and limitations as a tool for pre-operative evaluation, perioperative assessment, longitudinal follow-up, diagnosis of complications, and speed optimization. We conclude by highlighting opportunities for systematic investigation and further standardization.

PRE-OPERATIVE EVALUATION

OPERATIVE PLANNING. In addition to documenting baseline cardiac structure and function, pre-operative echocardiography is vital for surgical planning (Table 2). Aortic insufficiency (AI) tends to worsen after LVAD implantation (7–9), and the presence of moderate or greater AI is typically an indication for valve replacement or oversewing at the time of surgery (6). Although tricuspid regurgitation (TR) might be expected to improve with reduction in pulmonary vascular resistance after LVAD placement, the increase in RV preload and subsequent distortion of RV and septal geometry may actually worsen tricuspid regurgitant flow (4). Moderate to severe TR should therefore be considered for repair or replacement, although surgical intervention at the time of implantation remains a debated practice (6,10). Although a stenotic mitral valve should be addressed at implantation, repair of even a severely regurgitant mitral valve is rarely indicated, as functional regurgitation usually diminishes considerably with mechanical unloading of the left ventricle (5,6).

The fall in left atrial pressure and increase in right atrial pressure after LVAD placement may exacerbate a right-to-left atrial shunt, resulting in hypoxemia and raising the risk for paradoxical embolus (5,11). Meticulous assessment for a patent foramen ovale or an atrial septal defect with both color Doppler and agitated saline contrast should be performed (6) and repeated in the operating room at the time of implantation (11).

RISK STRATIFICATION FOR RV FAILURE. RV failure remains one of the most ominous complications after LVAD placement, resulting in substantial morbidity and mortality (12–14). The reported incidence is widely variable but clinically significant in all cohorts, ranging from 13% to 40% (15). Pre-operative risk stratification is important not only for its prognostic value to patients and physicians but also for its potential to alter surgical strategy, because planned biventricular support is associated with better in-hospital and 1-year mortality than delayed conversion (16).

Post-LVAD RV failure is poorly understood but is hypothesized to derive in part from geometric changes that occur with increased RV preload and leftward shift of the interventricular septum (12,13,15), making echocardiography a practical tool for risk stratification. Unfortunately, the use of standard quantitative echocardiographic predictors of RV failure in this population is limited by conflicting evidence (Table 3). Furthermore, definitions of RV failure vary among these studies.

Given the limited reproducibility of standard echocardiographic techniques, attention has turned to more novel techniques, including tissue Doppler and strain imaging. Both have shown promise, though evidence remains limited (Table 3). Although tissue Doppler circumvents the need for comprehensive views of the right ventricle, it is dependent on the angle of the transducer, can be confounded by cardiac motion (17), and may understate myocardial performance because of tethering by adjacent hypokinetic segments or adherent scarred pericardium (15).

Strain imaging by speckle-tracking echocardiography, a sensitive method for quantifying myocardial deformation, is less dependent on insonation angle than tissue Doppler (17) and less affected by regional hypokinesis (15). As with all echocardiographic methods of quantifying RV function, RV strain imaging requires adequate views of the right ventricle (18). In addition, there are limited data on intervendor reproducibility and test-retest variability (19).

PERIOPERATIVE ASSESSMENT

Intraoperative transesophageal echocardiography (TEE) is vital to successful LVAD placement (6).