



What Should Be the Principle Imaging Test in Heart Failure—CMR or Echocardiography?

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HEART FAILURE (HF) REMAINS ONE OF THE MOST COMMON CAUSES OF HOSPITALIZATION and death in developed countries, with prevalence rates predicted to increase in line with population aging. Imaging has an important role in patients with HF. It can quantify and monitor ventricular performance, establish a diagnosis, stratify risk, and evaluate many of the complications. However, although intense research over recent decades has resulted in the development of many effective treatments, accurate diagnosis of the condition remains difficult, despite significant advancement in cardiac imaging technologies that are capable of evaluating myocardial structure, function, and perfusion.

Echocardiography as the Principle Imaging Test in Heart Failure

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HF IS A CLINICAL SYNDROME THAT REQUIRES COMPREHENSIVE CLINICAL ASSESSMENT TO MAKE THE DIAGNOSIS. As stated in the American College of Cardiology/American Heart Association guidelines, there is no single diagnostic test for HF, and any single symptom or examination finding has relatively low specificity in isolation (1). Given the prevalence of HF and its association with the elderly (who often have mobility problems), the wide availability, relatively low cost, and portability of Doppler echocardiography are key advantages. It is also “patient friendly” and does not usually require intravenous cannulation, which enables

examination at the bedside in unstable patients.

Left ventricular (LV) filling pressure. To determine which cardiac investigation is most useful for the evaluation of patients with possible HF, one needs to consider the pathophysiology of the most common clinical manifestation of the syndrome, namely, exertional dyspnea. Whatever the cause of dyspnea in a given patient, whether it is due to LV systolic dysfunction, diastolic dysfunction, or valvular disease, dyspnea and exercise intolerance are associated with periodic or persistent elevation of left atrial and pulmonary venous pressures. Fortunately, for a decade or more, Doppler echocardiography has been able to perform this function with high feasibility and reproducibility and an accuracy that has allowed the establishment of clinically useful cutoffs for prediction of elevated mean left atrial pressure in patients with suspected HF. The most validated technique uses pulsed-wave Doppler to relate the peak velocity of early diastolic transmitral flow to the peak velocity of early diastolic longitu-

dinal motion at the mitral annulus, the so-called E/e' ratio (2). When the ratio is significantly elevated (for example E/e' >15 using the lateral annulus) and confounders such as mitral valve disease or rhythm disturbance are absent, the clinician can be quite confident that mean left atrial pressure was elevated at the time of the echocardiographic study. In more borderline cases, interpretation can be aided by assessing the effect of load-altering maneuvers on the transmitral flow pattern as well as pulsed-wave Doppler evaluation of pulmonary venous flow (3). The E/e' ratio can also be determined in serial echocardiographic studies to guide pharmacological intervention and monitor response to therapy in HF patients. In addition, the E/e' ratio is a strong prognostic marker and independently predicts adverse cardiac outcomes in the HF population (4).

Pulmonary artery pressure. In addition to estimation of left atrial pressure, Doppler echocardiography has an important application in the estimation of peak systolic pulmonary artery pressure. This is clinically relevant because patients with HF and elevated pulmonary venous pressures often have accompanying elevation of pulmonary artery systolic pressure. This is particularly applicable to hospitalized patients with decompensated HF in whom the degree of pulmonary hypertension helps inform the severity of HF and provides a marker for assessment of response to treatment. The technique uses continuous-wave Doppler interrogation of the tricuspid regurgitant signal (recordable in at least 75% of patients) to determine the instantaneous peak systolic pressure gradient between the right ventricle and the right atrium using the modified Bernoulli equation (5). By adding an estimation of right atrial pressure, the right ventricular peak systolic pressure can be obtained, which equates to pulmonary arterial systolic pressure in the absence of right ventricular outflow obstruction.

Ejection fraction (EF) and LV volumes. The identification of patients with systolic dysfunction is a determinant of appropriate therapy, and it is likely for this reason that the performance of echocardiography is associated with improved outcome in heart failure (6). Likewise, the measurement of LV volumes is an independent and incremental predictor of outcome. The problem is that echocardiographic measurement of both EF and volumes is sometimes inaccurate and often of unacceptable variability (7). Two new technologies have been shown to improve these limitations in multicenter studies: LV opacification (8) and 3-dimensional (3D) echocardiography (Fig. 1) (9).

Although there is no doubt as to the powerful prognostic significance of LV ejection fraction (EF), its relationship to the clinical syndrome of HF is often misunderstood. For example, one patient with a dilated LV and poor EF of 25% may be severely symptomatic, whereas another patient with similar LV function who is aggressively treated with neurohormonal blockade and diuretics may be completely asymptomatic. The difference between these 2

patients largely relates to differences in intravascular volume status and cardiac filling pressures and highlights the clear disconnect between LVEF and clinical symptoms in a given patient. In HF with reduced EF, information from the transmitral flow pattern and E/e' ratio can, therefore, be applied clinically to guide diuretic therapy as well as to inform prognosis (10).

HF with normal EF. The clinical importance of being able to estimate cardiac pressures may be most apparent in the subgroup of HF patients who have preserved LV systolic function. Clinical HF frequently occurs in the setting of impaired LV systolic function, but it is now well established that approximately half of HF patients (including both community and hospital presentations) have LVEFs >45% to 50% (11). According to the European Society of Cardiology guidelines for the diagnosis of HF with normal EF, the diagnosis should be made in the presence of signs and symptoms of HF, preserved LVEF, and either invasive or Doppler echocardiographic evidence of LV diastolic dysfunction and elevated filling pressures (12). Doppler echocar-

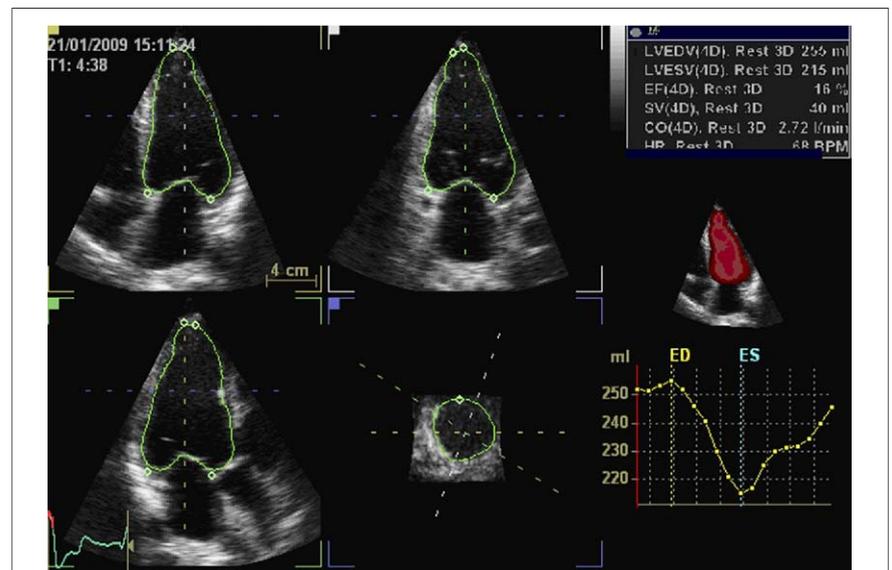


Figure 1. Accurate Measurement of LV Volumes Using 3D Echocardiography

The ability to trace the left ventricular (LV) border in multiple long-axis planes (and to cross-check against short-axis images [bottom row, center]) provides an accurate means of measuring LV volumes, even in irregularly shaped ventricles.

diography has demonstrated an increased E/e' ratio in patients with HF with normal EF (13), and an elevated E/e' ratio has also been shown to correlate with invasive measures of diastolic dysfunction (by pressure volume loop analysis) in this population (14).

In addition to the estimation of LV filling pressure, Doppler techniques can be used to characterize the physiology of LV filling, which is predictive of outcome, independent of other variables (15). Moreover, the persistence of a restrictive filling pattern, despite medical therapy, is predictive of outcome (16).

Left atrial volume. Left atrial volume increases in proportion to the degree of left atrial pressure elevation and can be viewed as a marker of chronic LV diastolic pressure burden. As such, left atrial dilation is the single most important anatomic feature to implicate a "left heart" cause of a patient's dyspnea, and a diagnosis of HF should be reviewed when the left atrial size is shown to be normal. Although cardiac magnetic resonance (CMR) may be considered a gold standard for the measurement of left atrial volume, real-time 3D echocardiography will likely provide similar accuracy. However, left atrial volume can also be obtained rapidly and reliably with 2-dimensional (2D) echocardiography techniques. Indeed, outcome studies that have demonstrated the strong independent prognostic value of left atrial size for predicting adverse cardiovascular events have been based on 2D echocardiography data (17). In addition, as the current published normal ranges are also largely derived from 2D echocardiography, it is very appropriate to apply echocardiography-derived cutoffs for left atrial volumes in the clinical setting. Most importantly, because left atrial size varies with patient size, it is essential that volumes be adjusted for body surface area.

Synchrony. The current selection criteria for cardiac resynchronization ther-

apy are clinical (New York Heart Association functional class III or IV on maximal medical therapy) and electrocardiographic (QRS width usually >0.12 ms), but the only imaging component relates to the estimation of LVEF <35%. The evaluation of mechanical synchrony has been proposed as a means of avoiding device insertion into likely "nonresponders" to cardiac resynchronization therapy (at least 20% to 30% of those implanted) and broadening the indications for insertion in those without a wide QRS interval who are likely to respond. Although echocardiography has the highest temporal resolution of standard cardiac imaging modalities, the results of the Predictors of Response to CRT (PROSPECT) trial have been exceedingly unfavorable (18), with limited predictive ability and poor reproducibility. The application of echocardiography (or other imaging modalities) for this purpose should be considered as a source of ongoing investigation until a simple, robust parameter of mechanical synchrony is described.

Mitral regurgitation (MR). The extent of MR, as quantified by echocardiography, is predictive of outcome in HF (19). Echocardiographic quantification of MR severity is most often calculated by the proximal isovelocity surface area method. In dilated ventricles, however, it has been shown that echocardiographic measurements may be misleading (20).

CMR as the Principle Imaging Test in HF

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CMR IS THE SOLE IMAGING MODALITY WITH THE ABILITY TO ASSESS VENTRICULAR FUNCTION, CARDIAC MORPHOLOGY, VASCULATURE, PERFUSION, VIABILITY, AND METABOLISM (21). It provides complementary and often additional information to

that of standard echocardiography or nuclear imaging without the burden of ionizing radiation.

Ventricular function and morphology. The increasingly sophisticated treatment of patients with HF has created the need for accurate and reproducible measurements of cardiac chamber volumes and function (22). CMR has the ability to provide this information for both ventricles.

LV. CMR provides optimal measurements of LV volume, wall thickness, and mass and is more reproducible than 2D echocardiography (23). CMR provides accurate measurements to guide critical clinical decisions based on LVEF in patient groups such as those with implantable defibrillators, those receiving cardiotoxic chemotherapy, or those after cardiac transplantation. The high spatial resolution and high signal-to-noise ratio of steady-state free-precession imaging permits unparalleled endocardial definition and delineation of ventricular morphology. This has particular application in the assessment of abnormal trabecular appearances and focal wall abnormalities. Despite recent echocardiographic innovations such as contrast echocardiography, 3D and single heart beat 3D echocardiography, CMR remains the gold standard for measurements of LV mass, volume, and EF as well as for regional wall motion abnormalities (24,25).

CMR techniques using steady-state free-precession imaging show promise in the evaluation of mechanical dyssynchrony (26). Improved temporal resolution electrocardiography-gated steady-state free-precession images allow the acquisition of approximately 40 frames per heart beat and have been proposed as an alternative technique to echocardiography for the assessment of dyssynchrony. Real-time CMR allows assessment of the ventricular interdependence and abnormal septal motion seen in constrictive physiology and often difficult to diagnose by standard

imaging modalities (Fig. 2, Online Video 1). Pericardial thickness can be measured accurately from double inversion recovery images.

RIGHT VENTRICLE. There is increasing recognition of the important role of the right ventricle in HF. Right ventricular (RV) dysfunction as assessed by CMR predicts a poor prognosis after myocardial infarction (27). The particular importance of RV failure in pulmonary hypertension and in the growing population of adults with congenital heart disease is also being recognized. Accurate RV assessment demands the use of 3D techniques because of the nongeometric shape of the ventricle. The RV position has also traditionally made reliable echocardiographic measurements difficult. CMR is unsurpassed in the assessment of RV volumes and systolic function. RV quantification and reproducibility can be improved by using axial views or, preferably, the RV short-axis view in which the tricuspid valve is consistently well defined (28).

Myocardial fibrosis. Myocardial late gadolinium enhancement (LGE) imaging provides a unique method of tissue characterization with many applications in HF. CMR is now considered the gold standard investigation for the assessment of myocardial viability and scarring. The presence and transmural extent of LGE after myocardial ischemia give important predictive information about the likelihood of functional recovery after revascularization (30). The extent and location of scar tissue within the myocardium are also predictive of outcomes in cardiac resynchronization therapy (29).

In patients with LV dysfunction, scar burden as defined by LGE is predictive of increased mortality or the need for cardiac transplantation (31). The extent of LGE is also predictive of LV remodeling in patients with HF from both ischemic and nonischemic causes (32). Previous reports have shown that the presence of LGE can also distinguish ischemic from nonis-

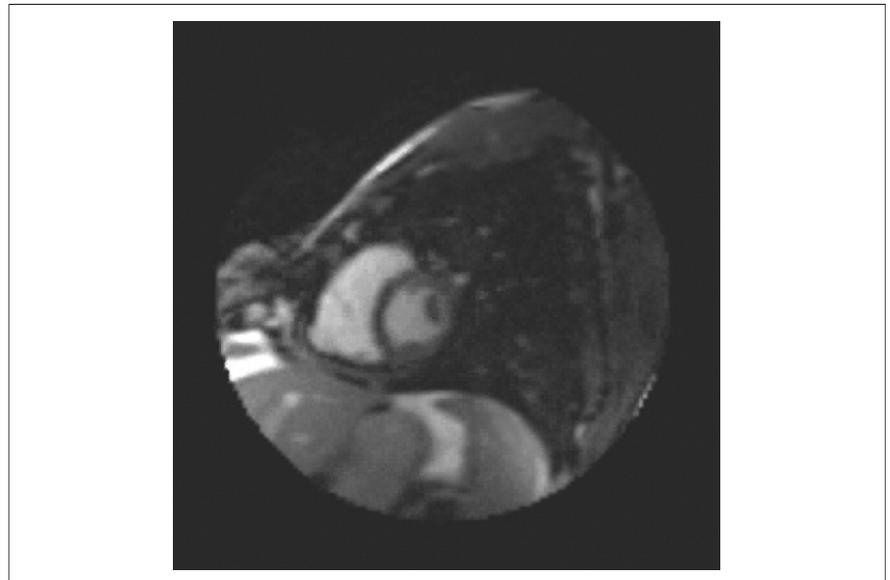


Figure 2. Real-Time Cardiac Magnetic Resonance Short-Axis View of a Patient With Constrictive Pericarditis

There is marked flattening of the interventricular septum during inspiration, indicative of ventricular interdependence. See Online Video 1.

chemic dilated cardiomyopathy (33).

Interstitial fibrosis is a final common pathway for many patients with myocardial damage and HF from various etiologies. Midwall interstitial fibrosis, as demonstrated by LGE, has been shown to correlate with a higher rate of all-cause mortality and hospitalization in patients with nonischemic dilated cardiomyopathy (34). Contrast-enhanced T1 mapping in HF patients has been shown to identify changes in myocardial T1 times that appear to represent interstitial fibrosis (35).

Infiltrative cardiomyopathies. Infiltrative cardiomyopathies can be difficult to diagnose with traditional imaging techniques. CMR provides a more reliable assessment of ventricular morphology and hypertrophy. Characteristic patterns of LGE correlate with underlying infiltrative process in many conditions (36). These include sarcoid, hypertrophic cardiomyopathy, connective tissue diseases, myocarditis, endomyocardial fibrosis, and amyloid infiltration (Fig. 3) (37). These conditions differ significantly in their natural history. Knowledge of such etiologies in patients presenting with HF may influence

treatment decisions, such as the need for early implantable defibrillator insertion, and also provide an opportunity for disease-specific therapy.

By measuring T2 signal characteristics, CMR has the capacity to assess iron content in the myocardium in thalassemia, hemochromatosis, and other states of iron overload (38). T2 quantification has also shown correlation with biopsy-proven heart transplant rejection (39).

Intraventricular thrombus. CMR has advantages over echocardiography in the detection of intraventricular thrombus (40). Thrombus shows reduced signal intensity compared with myocardium on early contrast-enhanced images (Fig. 4). Left atrial appendage thrombus can also be seen on CMR, but the diagnostic accuracy of CMR for this has yet to be determined.

MR. MR can be quantified with CMR by measuring regurgitant volumes (41), which may overcome problems with quantification of inhomogeneous and eccentric MR jets by Doppler (2). Anatomic orifice area, annular dimensions, and mitral tenting areas can also

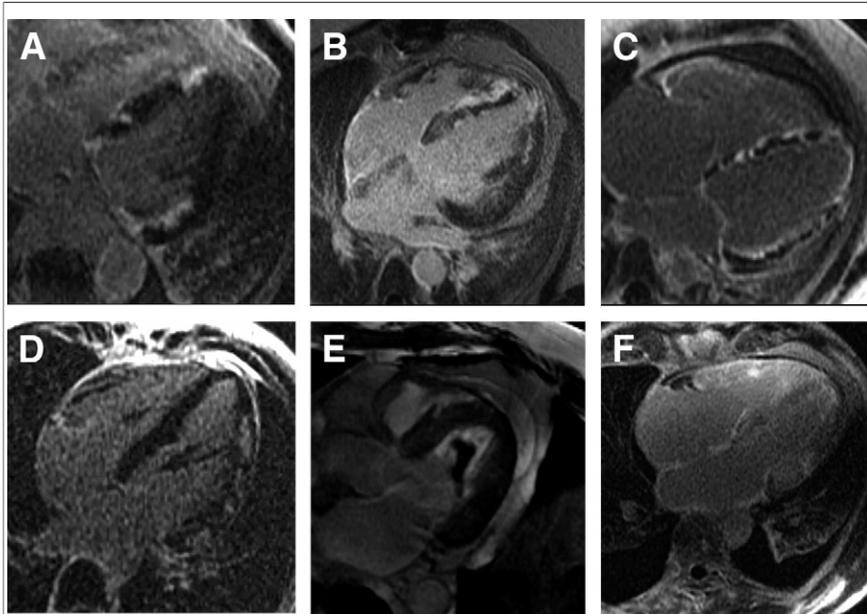


Figure 3. LGE in Infiltrative Myopathies

A series of 4-chamber images from different patients showing the varied appearance of late gadolinium enhancement (LGE) in infiltrative myopathies. (A) Sarcoidosis: patchy LGE in a noncoronary distribution. (B) Burnt-out hypertrophic cardiomyopathy: focal areas of LGE due to autoinfarction. (C) Systemic lupus erythematosus/overlap syndrome: subendocardial, subepicardial, and full-thickness areas of LGE in both ventricles. (D) Midwall and subepicardial LGE in the lateral left ventricle. (E) Endomyocardial fibrosis: subendocardial LGE with apical thrombus. (F) Amyloid: thickened myocardium with diffuse LGE also affecting the atria.

be measured. Prolapse of valve leaflets can be well demonstrated with individual LV long-axis oblique views

transecting each scallop of the mitral valve. LGE imaging may demonstrate papillary muscle infarction and fibrosis



Figure 4. Detection of Intraventricular Thrombus Using Cardiac Magnetic Resonance

Avascular thrombus shows reduced signal intensity on early contrast-enhanced images.

in the inferior LV wall as a cause of MR (42).

Diastolic function. CMR analysis of ventricular filling velocity, 3D myocardial strain analysis, and real-time CMR tissue tagging are promising methods to assess regional diastolic function (43). CMR measurements of mitral A-wave and E-wave velocity and deceleration times and systolic and diastolic wave velocities in the pulmonary flow traces have been shown to be reliable and easy to obtain, with good correlation with echocardiographic measurements (44).

Conclusions

The technology of both modalities is rapidly evolving, and although CMR is becoming more widely available, the availability of miniaturized systems has made echocardiography ubiquitous. As is always the case, both viewpoints in this *iForum* are correct. We should not lose sight of the fact that the main burden of HF is in the community. The primary goal of the initial test is, therefore, to categorize patients according to whether they have HF with impaired or preserved function; this information determines therapy and is probably the reason that imaging has been shown to have an effect on outcome (7) and hemodynamics. Echocardiography is unmatched in its ability to assess cardiac physiology in the clinical setting. It is the only widely available technique that allows accurate noninvasive estimation of left atrial and pulmonary arterial pressures. Both tests are able to evaluate complications of HF such as intracardiac thrombus, LV aneurysm, and valve dysfunction. Echocardiography remains the cardiac imaging test of choice for the initial clinical assessment of patients with HF, not least because of the numbers of patients with HF and its feasibility, availability, and lower cost. CMR is unsuitable for patients with dysrhythmias that affect

electrocardiographic gating, claustrophobia, implantable devices, or severe renal impairment.

CMR provides a comprehensive evaluation of patients presenting with HF and should be an integral part of evaluation in many, but perhaps not all, patients. CMR can establish an etiology and provide information that alters management in a significant proportion of patients, over and above standard echocardiography (28). Accurate assessment of LV function is critical to decisions about device implantation.

Tissue characterization is important for assessment of myocardial viability (regional subendocardial LGE) and infiltrative conditions that are often difficult to diagnose with other techniques (nonischemic patterns of LGE). In the future, fusion imaging approaches may maximize the value of CMR to those components (e.g., tissue characterization) that echocardiography cannot readily provide. In patients unable to undergo CMR, developments in contrast, 3D, and deformation imaging techniques with echocardiography may

enable this test to contribute more in these situations.

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Key Words: cardiomyopathy ■ cardiac magnetic resonance ■ heart failure ■ late gadolinium enhancement ■ ventricular function.

APPENDIX

For a supplementary video and its legend, please see the online version of this article.