Myocardial Deformation Imaging
Current Status and Future Directions

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Myocardial deformation imaging is a novel echocardiographic method for assessment of global and regional myocardial function. As this technology has evolved, it has been applied to an increasing number of research questions, and the number of publications incorporating deformation imaging has grown in parallel. Although not yet sufficiently vetted for routine clinical use, these methods offer the long-term potential for more complete, accurate, and reproducible assessment of myocardial function.

What Is Myocardial Deformation Imaging?
Evaluation of contractile function with echocardiography has traditionally been limited to volume-based assessment of ejection fraction (EF) and assessment of regional wall motion or visual estimation of regional thickening. These methods have suffered from lack of reproducibility and standardization and are generally considered to be extremely sensitive to loading conditions. These limitations have led to an interest in techniques that provide more objective and reproducible measures of contractile function.

During systole, the ventricular myocardium simultaneously shortens in the longitudinal and circumferential planes and thickens in the radial plane, with reciprocal changes in diastole (Figure). Deformation imaging, in the broadest sense, allows for more direct assessment of myocardial muscle shortening and lengthening throughout the cardiac cycle by assessing regional myocardial strain and strain rate. Strain is defined as the change in length of a segment of myocardium relative to its resting length and is expressed as a percentage; strain rate is the rate of this deformation. Longitudinal and circumferential shortening results in negative strain values, whereas radial thickening results in a positive strain value. Previously, assessment of myocardial strain could be performed with the use of sonomicrometry crystals, which can only be performed experimentally or with magnetic resonance imaging–based myocardial tagging, which is limited by relatively low temporal resolution and the limited availability and expense of cardiac magnetic resonance imaging. Extension of these techniques to echocardiography has allowed for substantially greater utility in a broader range of patients.

Myocardial deformation imaging with echocardiography can be performed with the use of either tissue Doppler–based or 2-dimensional speckle tracking–based methods. Doppler methods, developed initially, utilize the velocity gradient present along the length of the left ventricle (LV) to calculate strain rate, which is then integrated to derive strain. This technique suffers from limitations similar to those of traditional Doppler because it can only accurately assess deformation in the plane incident with the ultrasound beam and requires prospective acquisition of dedicated images at high frame rate. B-mode speckle tracking, sometimes referred to as feature tracking, utilizes the movement of the coherent ultrasound backscatter speckle pattern within B-mode echocardiographic images to assess myocardial strain throughout the cardiac cycle. Essentially, the movement of individual speckles toward or away from one another represents regional myocardial shortening or lengthening. Regional myocardial strain can be assessed in the 3 principal planes of deformation: longitudinal, circumferential, and radial. Because speckle tracking can be performed on 2-dimensional B-mode images, the method is independent of angle of incidence, has proven more robust than Doppler-based methods, and has demonstrated good correlation with both sonomicrometry and myocardial tagging with magnetic resonance imaging.

Moreover, the technique can be applied to images of adequate quality post hoc in a vendor-independent platform.

Deformation Imaging as a Measure of LV Function

Detection of Altered Myocardial Performance Beyond EF
Noninvasive assessment of myocardial strain and strain rate has allowed for the increasing recognition of abnormalities of LV deformation despite preserved LVEF. Although LVEF is one of the most powerful echocardiographic predictors of death or cardiovascular morbidity, it is limited as a measure of contractility by load dependency, it has limited prognostic value when in the low-normal range or higher, and gross reductions in EF likely represent fairly advanced LV functional impairment. Myocardial deformational measures such as strain rate appear less load dependent and may have greater utility within the normal LVEF range.

One area of particular interest in which strain imaging has been applied is in better understanding the progression from preclinical disease to overt heart failure. Subclinical impairments in longitudinal deformation (likely reflecting impairment primarily of the subendocardial myofiber bands) and circumferential deformation (possibly occurring with more widespread myocardial dysfunction), alterations in ventricular twist, and greater dyssynchrony have been observed in the...
setting of many conditions predisposing to overt heart failure, including advancing age, hypertension, diabetes mellitus, renal insufficiency, obesity, and atrial fibrillation. The potential insights that deformation imaging may offer into ventricular dysfunction beyond EF may have particular utility in heart failure with preserved EF, a prevalent and morbid condition in which EF clearly fails to describe the cardiac contribution to disease pathogenesis. Indeed, early studies in select patients with heart failure with preserved EF suggest significant impairments in myocardial contractile function measured by strain imaging.

The sensitivity of these measures to alterations in deformation has resulted in their application, in both animal and human studies, to a variety of pathological conditions characterized by myocardial dysfunction despite preserved EF, including asymptomatic carriers of hypertrophic cardiomyopathy sarcomeric mutations, Fabry’s disease, mycardial steatosis, and rodent models of Duchenne muscular dystrophy. Perhaps because of their less load-dependent nature, these measures have also proven informative in the setting of valvular heart disease in which alterations in loading conditions make EF a less reliable measure of contractile function, including severe aortic stenosis, aortic regurgitation, and mitral regurgitation. In the case of coronary disease, global strain values obtained early after an acute myocardial infarction may effectively predict subsequent remodeling and functional recovery.

Quantification of Regional Function
The traditional assessment of regional LV function by imaging has been qualitative. Deformation imaging offers the opportunity to quantify both the magnitude and timing of regional systolic and diastolic deformation. Given its spatial resolution, magnetic resonance imaging–based strain has been particularly useful in detecting regional myocardial dysfunction related to ischemia and in correlating regional function with regional fibrosis and metabolism. Regional myocardial function assessed by regional strain analysis correlates
with regional scar burden in the post-myocardial infarction setting and in the case of hypertrophic cardiomyopathy has also allowed assessment of the relative contribution of scar versus other myocardial derangements to regional functional impairment. A particularly promising application of deformation imaging is the assessment of regional myocardial function as it relates to local differences in myocardial metabolism and activity of enzymatic pathways of fibrosis. The ability to better quantify regional function has also provided insight into the mechanisms underlying disease processes, such as ischemic mitral regurgitation.

The ability of strain imaging to quantify the regional timing of deformation has led to its widespread application in the assessment of ventricular synchrony. Quantifying the temporal dispersion in contractility has provided important insights into the load dependency of ventricular dyssynchrony, the linkage between dyssynchrony and impaired contractile function, and the prognostic relevance of dysynchrony in select groups of patients with QRS duration <120 ms. These measures have also been used to assess the relationship between dyssynchrony measures and response after resynchronization therapy. Using both the magnitude and timing of regional deformation, Delgado et al demonstrated the importance of both lead positioning and contractile function, as they relate to the most delayed myocardial segment, in predicting response to cardiac resynchronization therapy. Although the relationship between echocardiographic measures of dyssynchrony and response to cardiac resynchronization therapy remains controversial, deformation imaging has allowed an integrated assessment of myocardial contractility and efficiency and has demonstrated the important role of both in predicting response to cardiac resynchronization therapy.

Association of Strain Measures With Clinical Outcomes
Several studies have investigated the relationship between deformational measures and clinical outcomes and demonstrated significant associations with mortality among patients with acute decompensated and symptomatic heart failure, with stable heart failure with reduced LVEF and wide QRS, and after myocardial infarction, as well as among unselected patients referred for echocardiography. In general, global strain measures tend to perform better than LVEF in predicting risk, and at least 2 studies suggest that they also offer incremental value beyond clinical information and LVEF. Importantly, although many of these studies were single center, 2 of these studies were multicenter and suggest potential applicability of these findings in a “real-world” setting.

Next Steps in the Application of Deformation Imaging
Few studies have investigated the translation of this technology into routine clinical practice, and routine clinical use of deformation imaging at this point appears premature. A major hurdle is the proprietary nature of deformation software and resulting intervendor variability in the values produced. An additional fundamental limitation is the number of deformation measures produced; with the inclusion of strain and strain rate in systole and diastole in the longitudinal, circumferential, and radial dimensions, 9 values are generated to characterize global myocardial deformation without consideration of segmental function or the temporal dispersion in regional deformation. Although these measures may each reflect a different aspect of deformation and provide insight into subtle alterations in deformation patterns, the sheer number can generate confusion, and many parameters are highly correlated with each other. The ability to simplify this plethora of measures into a more succinct set of parameters that describe deformation would aid clinical translation. One approach is to focus on those parameters more closely associated with clinical outcomes, and in this respect longitudinal deformation currently appears most promising.

In addition, few data are available regarding the feasibility and reproducibility of these measures when applied broadly, particularly for the regional measures. Moreover, data are lacking from large community-based cohorts to define normal ranges for these measures and to describe the manner in which they may vary by age and gender and to establish the relationship between these measures and clinical outcomes. Larger studies in more diverse populations are needed to establish the incremental value of these measures beyond routine clinical assessments in a broad range of cardiovascular conditions.

Applications of Deformation Imaging Beyond the LV
Beyond the LV, deformation imaging is increasingly being applied to other cardiac chambers. Longitudinal shortening makes a major contribution to right ventricular (RV) contraction, and longitudinal strain may allow assessment of RV longitudinal function along the entire RV. There is early evidence to support the utility of deformation imaging in pulmonary arterial hypertension, and data show dynamic improvement after treatment of acute decompensated heart failure and acute worsening after ultraendurance exercise. Further studies will need to address the hemodynamic correlates of change in RV strain and its prognostic value in relation to other measures of RV function in various disease states.

Recently, these techniques have also been applied to the left atrium, a thinner-walled structure than the ventricles that functions as a reservoir and conduit for filling of the LV in addition to a pump at end-diastole. As a result, atrial deformation through the cardiac cycle appears largely to reflect passive phasic changes in atrial volume. Atrial strain may correlate with the degree of atrial fibrosis and left atrial strain has therefore been explored as an index of atrial distensibility, a potentially important contributor to the transition from hypertensive heart disease to heart failure.

Conclusions
Myocardial deformation imaging can provide a quantitative assessment of both global and regional myocardial function and offers unique insight into alterations of myocardial performance beyond established measures like LVEF. Clini-
cal translation of this promising field will depend on future studies to determine the widespread feasibility of these measures, define population norms, and establish whether they provide additional prognostic information beyond established measures.

Disclosures

None.

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Correction

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