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EDITORIAL COMMENT

Left Atrial Reservoir Strain

Its Time Has Come*

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The left atrium (LA) modulates left ventricular (LV) filling and cardiovascular performance by functioning as a reservoir for pulmonary venous return during ventricular systole, a conduit for pulmonary venous return during early ventricular diastole, and a booster pump that increases ventricular filling during late ventricular diastole. Critical to understanding the biophysical determinants of these functions is the recognition that interplay exists between phasic atrial activity and ventricular performance throughout the cardiac cycle. For example, although reservoir function is governed by atrial compliance (or its inverse, stiffness) during ventricular systole and, to a lesser extent, by atrial contractility and relaxation, it is influenced by descent of the LV base during systole and the LV end-systolic volume (1). Conduit function is determined by atrial compliance, is reciprocally related to reservoir function, and, by necessity (because the 2 chambers freely communicate in diastole), is closely related to LV relaxation and chamber compliance. Finally, atrial booster pump function reflects the magnitude and timing of atrial contractility but is dependent on the degree of venous return (atrial preload), LV end-diastolic pressures (atrial afterload), and LV systolic reserve.

LA function can be measured with a wide assortment of echo and Doppler techniques but is most often assessed using either volumetric or speckle tracking echocardiography (STE) strain analysis. Volumetric assessment of LA reservoir, conduit, and booster pump functions can be obtained by measuring LA volumes at their largest (at end systole, just before mitral valve opening), smallest (at end diastole, when the mitral valve closes), and immediately before atrial systole (before the electrocardiographic P-wave). From these volumes, total, passive, and active emptying fractions (corresponding to the reservoir, conduit, and booster pump functions) can be calculated. In contrast, STE strain (a measure of global and regional deformation) is derived from the frame-by-frame tracking of natural acoustic markers (speckles) that are generated from interactions between ultrasound and myocardium. Frame rates of approximately 50 to 70 are needed to avoid speckle decorrelation and maintain spatial resolution, and good image quality is needed for accurate tracking. Compared to the LV, strain imaging of the LA is thought to be more difficult and time consuming because of the far-field location of the atrium, the thin atrial walls, the presence of the appendage and pulmonary veins, and the need for nonforeshortened atrial views. Nevertheless, in research papers, STE is increasingly used as the method of choice to analyze atrial functions. Although the interdependence of atrial and ventricular functions is well recognized, the independence of instantaneous phasic LA and LV strains throughout the cardiac cycle has been neither critically nor quantitatively analyzed.

In this issue of *iJACC*, Malaescu et al (2) attempt to fill this gap in our understanding of atrial function. These investigators compared instantaneous phasic LA strain parameters with those of LV systolic and diastolic function in 127 patients with a wide variety of cardiovascular pathologies (excluding atrial fibrillation, valvular heart disease, congenital heart disease, previous heart surgery, conduction abnormalities, and mobile atrial septum) to determine the feasibility, reproducibility, and independence from LV deformation of LA strain. This highly selected

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cohort (representing only 19% of the original group) questions the ability to extrapolate to the large number of patients with atrial fibrillation or atrial cardiomyopathies. Notably absent in this study are invasive hemodynamics. Nevertheless, in this proof-of-concept analysis, close coupling of the linear relation between LA and LV strain ($r > 0.95$) was found using LA and LV strain loops throughout the cardiac cycle; interestingly, the slopes of these strain loops were highly correlated ($r > 0.87$) with the ratio of LV/LA maximal volumes. Phasic LA systolic strains could be predicted by a multivariable model that consisted only of LV global longitudinal strain (GLS) and the LV/LA maximal volume ratio; adding all significant univariate echo parameters improved the predictive power of the model by only 4% (for reservoir strain), 1.5% (for early diastolic strain), and 7% (for atrial systolic strain). Remarkably, LA reservoir strain was predicted numerically by the product of LV GLS and the LV/LA volume ratio, which explained 86% of the model's variability. Importantly, there were no significant differences in cardiovascular events or incident atrial fibrillation between the measured and predicted LA strains. Although this finding may have been anticipated by the qualitative mirror-image discordance of LV and LA filling curves, the strengths of the correlations and the simple elegance of the analyses beg the question: in the context of the aforementioned potential difficulties with LA strain measurement, if accurately and reproducibly predicted from the product of LV function (LV GLS) and the ratio of LV and LA volumes, should we bother measuring LA strain?

There are several good reasons why we should. First, as the authors acknowledge, "LA strain integrates several parameters into a single robust and reproducible measurement." Second, LA strain has been shown to incrementally predict cardiovascular events particularly, but not exclusively, in patients with heart failure and preserved ejection fraction (HFpEF) (3-5). For example, LA reservoir strain best discriminated HFpEF from noncardiac causes of dyspnea, outperforming LV GLS, LA enlargement, and E/e′ (6). Third, LA reservoir strain provides a more accurate categorization of diastolic dysfunction than do conventional echo variables, left atrial volume index (LAVi), LV GLS, or E/e′ (7). Fourth, peak atrial longitudinal strain (a measure of reservoir function) has been validated against invasive LV filling pressure (8), and a meta-analysis found that a peak atrial longitudinal strain of ≤19% performs better than an left atrial volume index of >34 mL/m^2 for identifying elevated LV filling pressure (9). LA reservoir strain may also identify patients with intermediate HFpEF scores who develop increased LV filling pressure (E/e′) during exercise (10). Measurement of LA reservoir strain also allows calculation of the LA stiffness index (E/e′/LA reservoir strain), which predicts reduced exercise capacity in patients with heart failure (11) and further discriminates HFpEF from noncardiac causes of dyspnea (6). Moreover, the degree of LA wall fibrosis as determined by delayed-enhancement cardiac magnetic resonance is known to be inversely related to LA reservoir strain and the burden of atrial fibrillation (12). Fifth, recent data suggest that the close coupling observed in the present study may not be invariable. Although LA reservoir strain increases and conduit strain decreases with larger magnitudes of LV GLS, indicating the close interplay of LA and LV functions (13,14), there is some indication that with larger atria, the relation between reservoir and conduit functions and LV GLS changes from a linear to an exponential one. (15) Finally, and perhaps most importantly, Malaescu et al (2) have not shown that a deviation from the tight correlation between LA strain and the LV/LA volumes ratio characterizes an underlying atrial myopathy and a higher risk of clinical events.

Despite substantial data that demonstrate the use of LA function, phasic LA emptying fractions and strains are currently not exploited in clinical practice. Several reasons may be responsible. The methods used to measure LA function all have important limitations, and indices that reflect a specific atrial function often correlate poorly with others obtained during the same phase of the LA cycle. Most often, the hemodynamic and biophysical properties (eg, atrial fibrosis) that are responsible for the functional changes are assumed but not identified. Moreover, atrial function is sensitive to age, sex, and loading conditions in addition to LV systolic and diastolic function (3). Although strain and strain rate are increasingly used, the LA offers unique challenges to their use. As alluded to earlier, deformation analysis requires expertise and trained operators, and the data acquisition and processing steps can be time consuming; variable cutoffs and variances in values between the different speckle-tracking algorithms remain impediments to the use of strain imaging. However, LA reservoir strain is relatively easy to determine and highly reproducible (and may be completely automated); has been studied in a large number of patients; and most importantly, has been shown to have consequential diagnostic and prognostic value. Perhaps it is time that this carefully studied parameter is incorporated in diagnostic models, risk stratification strategies, and consensus documents.

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