We need to know whether the altered LV vorticity and observed aortic outflow patterns described by the authors relate to reduced functional capacity or worse clinical outcomes. It is unclear whether this is the case, as multiple studies suggest preserved life expectancy and functional status when mitral repair is undertaken early in the course of degenerative mitral valve disease.

In the arena of available structural heart disease therapies, flow dynamics will likely become a central player and may help improve equipoise when deciding on optimal treatment strategies. We applaud the authors for reminding us that as we repair mitral valves, we should not limit our focus to preventing retrograde flow into the atrium but should also consider how the blood will flow through the left ventricle and beyond. Larger-scale studies should be thus encouraged if we hope to achieve a useful translation into clinical practice.

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Commentary: In vortices veritas—quantitative approach

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Vortices generated along the valvular surfaces are governed by hemodynamic forces, anatomic boundary conditions, and myocardial biomechanics. Hence, studying their qualitative and quantitative nature requires comprehensive

Left ventricular velocity and vorticity.

CENTRAL MESSAGE

Qualitative and quantitative 4D-flow MRI analysis enables comprehensive investigation of the intracardiac flow hemodynamic state.

dimensional evaluation by 4-dimensional-flow magnetic resonance imaging (4D-flow MRI). The rising number of

studies using 4D-flow MRI and improved accessibility to complex postprocessing platforms shifts this imaging modality closer to routine in evaluating the outcomes of therapeutic and surgical interventions.

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FIGURE 1. Representative examples of quantitative flow analysis using 4D-flow MRI. The *top 3 panels* represent the particle tracking throughout the cardiac cycle. Each color represents 1 of the 4 components of the end-diastolic volume. The *bottom panel* shows the calculated vorticity vector field inside the left ventricle superimposed upon flow velocity. 4D-flow MRI enables calculation of these and additional flow derivatives from a single acquisition.

In the current issue of the *Journal*, Morichi and colleagues¹ investigated intracardiac flow patterns using 4D-flow MRI in patients undergoing mitral valve repair for degenerative mitral regurgitation using either complete ring or partial band as an annuloplasty device. The authors should be commended for providing novel insights into flow conditions driven by different types of annuloplasty. The authors used 4D-flow MRI capabilities and performed both qualitative and quantitative analysis of the inflow conditions.

From the qualitative perspective, the authors specifically describe different vortex formation patterns along the anterior mitral valve leaflet with respect to the type of repair. Qualitative flow analysis is often easier to perform

but tends to reduce the dimensionality of the flow phenomena and is prone to inter-reader variability. Under normal conditions, vortices are formed along each valve leaflet and are caused by different shear velocities on the 2 surfaces of the leaflet. The authors described different vortex formation patterns in patients repaired with semi-rigid devices versus flexible bands. It is important to note that ventricular diastolic function also contributes to inflow conditions by generating a suction gradient, and this factor should be considered when analyzing the intra-ventricular flow patterns. Hence, age and size-appropriate control groups are necessary. This issue was appropriately noted by the authors and it is an important confounding limitation of the study.

In contrast to qualitative analysis, the quantitative approach minimizes inter-reader analysis variability and provides noncategorical values reflective of the hemodynamic state. Some form of mathematical operation on full 3-dimensional flow (velocity) data is typically performed resulting in quantitative flow derivatives such as vorticity, viscous or turbulent energy loss, and particle tracking throughout the cardiac cycle² (Figure 1). Promising results from studies oriented at diastolic function suggest that quantitative 4D-flow MRI analysis is sensitive for the detection of ventricular pathology at an earlier stage than conventional imaging techniques such as echocardiography.^{3,4} Interestingly, Morichi and colleagues applied a form of viscous energy loss, measuring the irreversible loss in mechanical energy mediated by abnormal chaotic blood flow. Their results suggest that energy loss is elevated in patients undergoing mitral valve repair and suggest that this marker may be a sensitive measure of the post-operative outcome. However, pre- and postoperative comparison is necessary to truly elucidate the effect of mitral valve repair on ventricular flow patterns. In addition, the calculation of energy loss along the ventricular–aortic tract is problematic because both the ventricle and aorta are isolated compartments that are connected by physiologic streamlines only in systole.

The authors have provided a novel means of evaluation for different mitral valve annuloplasty techniques that

could become even more powerful when used for preoperative planning. With recently introduced automated valve tracking technology,⁵ 4D-flow MRI may become one of the most precise flow hemodynamic quantitative tools for assessing valvular disease and postoperative outcomes. Additional studies applying quantitative flow indices are needed to fully demonstrate robustness and clinical utility. However, the focus on flow imaging should remain a priority to fully appreciate valvular pathologies.

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