Valve, Ventricle, and Vessel
The Triumvirate of Aortic Stenosis Assessment

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Cardiac magnetic resonance (CMR) imaging can be used for the assessment of aortic stenosis in terms of both anatomic and hemodynamic measures of stenosis severity and for evaluation of the left ventricular response to valvular obstruction. In addition, CMR-based assessment of aortic flow patterns has been implicated in poststenotic ascending aortic aneurysm development. In this issue of Circulation: Cardiovascular Imaging, von Knobelsdorff-Brenkenhoff et al explore the upstream consequences of postvalvular aortic flow patterns in terms of its association with left ventricular remodeling. The study provides arguments for a relationship between left ventricular remodeling and changes in aortic blood flow patterns in patients with aortic stenosis. The results also raise the notion of novel CMR parameters to consider for studies of outcome in, for example, patients with moderate aortic stenosis or for whom incongruent data on stenosis severity are obtained by conventional imaging.

See Article by von Knobelsdorff-Brenkenhoff et al

Aortic Stenosis Imaging
In clinical routine, Doppler echocardiography represents an accurate tool for the diagnosis and assessment of aortic stenosis. In some cases, however, additional imaging modalities may help to refine the diagnostic and prognostic information. As an example, aortic valve calcification quantification by computed tomography may provide additional support for clinical decisions when stenosis severity measures are incongruent. Novel concepts in valve calcification imaging also include nuclear medicine using positron emission tomography to detect valvular uptake of 18F-fluoride, which is a radiotracer of active calcification.

The CMR detection of an excess in myocardial fibrosis, as an early sign of deleterious left ventricular remodeling, has also been shown to have prognostic implications in aortic stenosis patients. Furthermore, CMR offers possibilities for direct valvular evaluation by means of planimetric measurements of the aortic valve area. In addition, phase-contrast CMR can be used to determine flow and hence allows hemodynamic measures of transvalvular velocities and calculations of the aortic valve area.

Aortic Blood Flow Patterns in Aortic Stenosis
Doppler echocardiography today remains the standard method for assessing blood flow in the proximal aorta and to obtain velocity–time tracing of the systolic flow over the aortic valve. However, this measure does not take into consideration that the aortic blood flow is highly unsteady. Assessing the complex aortic blood flow pattern in the aorta solely based on velocity does, for example, not allow detection of vortical flow structures, defined as regions within which the blood is at rotational motion. Time-resolved 3-dimensional (3D) phase-contrast magnetic resonance imaging (4D-flow magnetic resonance imaging), however, has the capacity of visualizing flow patterns in the ascending aorta. In fact, flow vorticity has been determined as one of the main factors responsible for discrepancies in terms of aortic transvalvular pressure gradients between CMR and echocardiography. In addition to vortical structures, 4D-flow magnetic resonance imaging allows quantifying the eccentricity of the flow, which can be calculated as the normalized flow displacement.

The loss of mechanical energy caused by the perturbations of the aortic blood flow as a result of vorticity and eccentricity might lead to a significant increase of the left ventricular afterload, hence offering a possible explanation for the observed association between flow displacement and left ventricular hypertrophy in the study from von Knobelsdorff-Brenkenhoff et al. Indeed, the energy loss index, which is dependent on the size relationship between the stenotic aortic valve orifice and the aorta, provides additional prognostic value in the evaluation of patients with asymptomatic aortic stenosis. It is, therefore, tempting, albeit premature, to speculate on the prognostic value of phase-contrast 4D-flow magnetic resonance imaging assessment of poststenotic aortic blood flow patterns.

Valvulovascular Coupling
The shear stress of the aortic wall is a direct consequence of the blood flow. For example, vortical dynamics determine the distribution of wall shear stress. The study by von Knobelsdorff-Brenkenhoff et al clearly demonstrates that the aortic flow perturbations visualized by CMR were associated with increased wall shear stress within the aortic walls of aortic stenosis patients.

The increased vascular wall shear stress is sensed by mechanoreceptors and triggers an activation of endothelial cells,
inducing the release of vasoactive substances, as well as an inflammatory activation and atherosclerosis initiation, eventually leading to a stiffening of the arterial wall.\textsuperscript{14} It should, in addition, be emphasized that aortic valve stenosis and sclerosis are associated with atherosclerosis and vascular calcification,\textsuperscript{15} which in turn may be the cause of decreased aortic elasticity. Finally, also hypertension, which is commonly observed in aortic stenosis patients, may contribute to an increased vascular stiffness.\textsuperscript{16}

Regardless of the cause, the resulting reduced arterial compliance will contribute to further increase the left ventricular afterload and thus predispose to myocardial remodeling and dysfunction. In this context, the notion of valvuloarterial impedance ($Z_{va}$) has been introduced for assessing the global hemodynamic load on the left ventricle exerted by the valvular and arterial components.\textsuperscript{2} This index is calculated by Doppler echocardiography and has gained increasing interest for its predictive value in aortic stenosis\textsuperscript{5} and indicates the importance of the valvulovascular coupling.

**Aortic Flow Patterns and Left Ventricular Remodeling**

In the study which is reported in this issue,\textsuperscript{1} the left ventricular remodeling was independently associated with both the aortic valve area and the aortic blood flow displacement, indicating that increased poststenotic flow perturbations may further aggravate the ventricular response regardless of the degree of stenosis. It should also be considered that changes in left ventricular shape or function alters intraventricular flow patterns\textsuperscript{17} but that how such ventricular vortices in turn may affect the aortic flow is difficult to assess at the moment. Prospective studies evaluating the prognostic value of altered aortic flow on left ventricular remodeling are needed to shed more light on the sequential order of events.

**Perspectives**

It is likely that CMR still lacks sufficient spatiotemporal resolution, when compared with echocardiography, to specifically image the valve leaflets and for planimetry of the aortic orifice area. However, CMR may surely be a useful adjunct to echocardiography in this setting because of a lower interobserver variability for assessing left ventricular mass and volume\textsuperscript{18} and also for its ability to detect cardiac fibrosis.\textsuperscript{5,19} Moreover, the specific ability of the 4D-flow sequences to analyze the blood velocities in all 4 spatiotemporal dimensions is another advantage of CMR. The latter opens up the potential for imaging of aortic flow patterns and the possibility of associating, for example, vorticity and arterial components.\textsuperscript{2} This index is calculated by Doppler echocardiography and has gained increasing interest for its predictive value in aortic stenosis\textsuperscript{5} and indicates the importance of the valvulovascular coupling.

Finally, however, it is likely that these 4D-flow sequences provide a unique view point on the abnormalities of the aortic flow and, more generally, on the variable way by which energy is dissipated by frictional losses within the aorta. These data are likely to interfere with the left ventricular afterload and remodeling not only for patients with aortic stenosis\textsuperscript{1} but also for most patients with cardiomyopathies whatever the stage and origin.

**Disclosures**

None.

**References**


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