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From Image to Insight

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4D Flow MRI for Valvular Heart Disease: When Echocardiography Is Not Enough

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Transthoracic echocardiography remains the first-line, guideline-mandated modality for evaluating valvular heart disease, yet it is fundamentally limited by geometric assumptions such as PISA and the continuity equation, by operator dependence, and by poor performance with eccentric, multiple, or prosthetic-valve regurgitant jets. Four-dimensional (4D) flow MRI offers a single, time-resolved, three-directionally velocity-encoded acquisition that allows retrospective, geometry-independent quantification of flow across any valve, along with hemodynamic parameters unavailable to Doppler ultrasound, including turbulent kinetic energy, viscous energy loss, and wall shear stress. This talk reviews the clinical evidence for 4D flow MRI as a complementary, problem-solving tool, organized around the specific scenarios in which echocardiography's underlying assumptions break down.

In aortic stenosis, the simplified Bernoulli equation neglects pressure recovery and flow acceleration; 4D flow-derived turbulent kinetic energy is elevated in bicuspid or dilated-aorta patients even when the echocardiographic mean gradient is normal, providing an independent measure of energy loss. In aortic and mitral regurgitation, eccentric or non-laminar jets, common in congenital and bicuspid aortic disease, are best captured by direct jet quantification near the vena contracta rather than at fixed measurement planes, and multicenter data show that when echocardiography and cardiac MRI disagree on mitral regurgitation severity, MRI-derived regurgitant volume better predicts post-surgical left ventricular remodeling. In hypertrophic cardiomyopathy, direct 4D flow jet tracking circumvents the left ventricular outflow tract obstruction that corrupts indirect, stroke-volume-based regurgitant calculations. Tricuspid regurgitation and prosthetic valve disease are among the most challenging targets for echocardiography because of complex annular geometry and prosthesis-related artifact; recent comparative studies show that 4D flow MRI can track the moving tricuspid annulus and resolve paravalvular leak adjacent to metallic components, where conventional two-dimensional techniques fail. The talk also addresses 4D flow MRI's own limitations, including finite spatial and temporal resolution, long scan times, and labor-intensive post-processing, alongside emerging solutions such as acquisition acceleration and deep-learning-based super-resolution.

Echocardiography remains the appropriate first-line test for valvular heart disease. 4D flow MRI should be understood not as a competitor but as an adjudicator for the subset of cases — discordant severity grading, eccentric or multiple jets, complex congenital anatomy, and prosthetic valve or paravalvular leak assessment — where echocardiography's assumptions are most likely to fail.

Keywords: *4D flow MRI, Valvular heart disease, Echocardiography*