Redefining MRI:
From Image to Insight

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Cardiovascular 2

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4D Flow Imaging Aorta Application

Jong Eun Lee

Asan Medical Center, Korea

Four-dimensional flow magnetic resonance imaging (4D Flow MRI) has become an important imaging technique for comprehensive evaluation of thoracic aortic hemodynamics by providing time-resolved three-dimensional visualization and quantification of blood flow throughout the entire aorta. Beyond anatomical assessment, it enables measurement of advanced flow biomarkers that improve our understanding of the relationship between abnormal hemodynamics and aortic disease.

This lecture will first review physiological blood flow in the normal thoracic aorta. Normal aging and sex-related differences influence aortic flow patterns, including peak velocity, wall shear stress (WSS), helicity, vorticity, flow eccentricity, and energy loss. Establishing reference values for these parameters is essential for distinguishing normal physiological variation from early pathological remodeling and for appropriate clinical interpretation.

The second part will focus on the role of 4D Flow MRI in aortic dissection. Unlike conventional imaging, 4D Flow MRI allows comprehensive visualization of true and false lumen hemodynamics, entry tears, flow communication, retrograde flow, and false lumen stasis. Quantitative assessment of flow distribution and false lumen characteristics has demonstrated potential for predicting aortic enlargement, false lumen thrombosis, and adverse clinical outcomes, thereby supporting risk stratification, treatment planning, and longitudinal surveillance.

The final section will discuss aortic aneurysm, where abnormal hemodynamic forces contribute to disease development and progression. Altered flow eccentricity, abnormal WSS distribution, increased helicity, and disturbed flow patterns have been associated with regional aortic remodeling and aneurysm growth, particularly in patients with bicuspid aortic valve–associated aortopathy. Recent studies suggest that 4D Flow MRI-derived hemodynamic biomarkers may complement conventional diameter-based assessment and enable earlier identification of patients at increased risk of disease progression.

Finally, recent technological advances, including accelerated image acquisition, artificial intelligence-based post-processing, and standardized quantitative analysis, will be highlighted. These developments are expected to facilitate broader clinical implementation of 4D Flow MRI and establish hemodynamic biomarkers as an integral component of precision imaging for thoracic aortic diseases.

Keywords: *4D flow MRI, Thoracic aorta, Aortic hemodynamics, Aortic dissection, Aortic aneurysm, Hemodynamic biomarkers, Cardiovascular magnetic resonance*