4D Flow MRI Reveals Novel Insights Into 3D Aortic Wall Strain

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Objectives. Whether assessed in the heart or the aorta, strain reveals key insights into tissue function, acting as a marker of disease-related remodeling. Such marker is commonly evaluated from MRI-2D slices despite out-of-plane motion limitations. Although 4D flow MRI velocity fields are commonly used to assess cardiovascular flow, the associated anatomical information remains largely underutilized, mainly due to the absence of dedicated segmentation tools. Aorta being intrinsically a 3D organ with a complex motion, we developed a deep-learning (DL)-based framework to fully characterize its local 3D+t deformation from 4D flow, while assessing its physiological consistency.
Methods. We studied 68 individuals with aortic 4D flow from two sites (site1: N=34, vendor1, 1.5T, 15-25 frames and spatial-resolution=1.7-2.4x1.7-2.4x1.9-2.5mm^3; site2: N=34, vendor2, 3T, 50 frames and spatial-resolution=1.3-1.7x1.3-1.7x1mm^3). An nn-UNet segmented the aortic wall at peak systole, and VoxelMorph tracked its displacement throughout the cardiac cycle, providing local strain maps, derived from distance variations between neighboring wall coordinates. Longitudinal strain was extracted from these maps and its systolic-peak was estimated in the ascending (AA) and descending (DA) aorta.
Results. Strain consistently decreased between AA and DA with a more pronounced trend in younger (≤50years, N=43/19 women, AA=12±2.8%, DA=6.9±2.3%) than elderly (>50years, N=14/11 women, AA=9.8±2.9%, DA=6.1±2.3%) individuals, in-line with the known drop in elasticity from central arteries towards periphery early in life, which tends to equalize with aging. Such physiological trends were found for both sites, as was the drop in AA strain with age. However, strain magnitudes were different between sites, probably due to the lack of standardization in acquisition protocols.
Conclusions. The proposed DL-based approach offers novel and comprehensive analysis of 4D flow MRI, through the addition of consistent 3D aortic strain to the readily available flow measures. Acquisition protocol standardization might be useful before integrating such analysis into multicenter studies for ultimate validation.

Figure. Representative 3D peak aortic strain maps and corresponding time-resolved strain curves for four subjects: two young and two elderly individuals, from sites/vendors 1 and 2.