Highly AI Accelerated 4D Flow MRI of the Aorta: Network Performance and Impact on Quantification of Aortic Wall Shear Stress

Summary:

Background: 4D Flow MRI provides insights into changes in cardiovascular blood flow dynamics in common diseases of the thoracic aorta. The shear force of blood along the vessel wall, wall shear stress (WSS), derived from 4D Flow data has been shown to have predictive value progressive aortic dilatation in patients with bioscopes aortic valve (BAV) [1]. However, 4D flow MRI data acquisition is time consuming (5-15 minutes), limiting clinical adoption. The purpose of this study was to evaluate novel, deep learning-enabled highly accelerated 4D flow MRI.

Methods: This study used a combination of two convolutional neural networks (CNNs) that were trained to reconstruct higher-resolution, 4-point encoded images from lower-resolution 4D Flow input data (CNN1) with 2-point velocity encoding (reference scan + one velocity direction per time point, CNN2) [2]. Aorta 4D flow MRI data of n=97 patients (all BAV, 49 ± 15 years, 75% male) were used as ground truth (GT). GT data was retrospectively k-space cropped (factor of 16 and 32) and converted to 2-point interleaved velocity ending (resulting total acceleration factor: R=32,64). All data (GT, R=32, R=64) underwent identical 4D flow MRI pre-processing, aorta 3D segmentation [3], and quantification of aortic WSS.

Results: AI based 4D flow recognition showed good agreement with GT data, even for high acceleration factors for both mean aortic WSS (GT: 0.64±0.15Pa, R=32: 0.64±0.15 [p = 0.02], R=64: 0.64±0.15Pa [p=0.30]) and maximum aortic WSS (GT: 1.55±0.52Pa, R=32: 1.55±0.52Pa [p=0.34], R=64: 1.55±0.52Pa [p=0.51)]). Bland-Altman analyses confirmed good AP performance compared to GT 4D flow derived mean WSS (R=32: bias=-0.002Pa (LOA -0.017 - 0.014), R=64: bias=-0.001 Pa (LOA -0.013 - 0.011) and maximum WSS (R=32: bias=0.002 Pa (LOA -0.038 - 0.036)), R=64: bias=0.0011 Pa (LOA -0.0458 - 0.0435).

Discussion: Deep learning was successfully applied to produce to substantially accelerated 4D flow MRI of the aorta while maintaining WSS quantification accuracy, even for acceleration factors as high as R=64. This opens the possibility to accelerate 4D Flow with scan time under 1 minute in the clinic by using pulse sequences that only capture a fraction of k-space. Additional prospective payments studies are needed for further validate this approach. Future work will also involve a regional WSS analysis of the AI reconstructed images compared to the GT.

Contributions:

This work validates the application of AI reconstruction to accelerate 4D Flow MRI for quantification of WSS, a key hemodynamic parameter.

References: [1] Guala, A et al. JACC: Cardiovascular Imaging. 2022 [2] Berhane, H et al. SMRA 2024 [3] Berhane, H et al. Magnetic Resonance in Medicine. 2020