Improved Correction, Reconstruction, and Analysis Methods for 4D-Flow MRI

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07/19/2015

4D-Flow Magnetic Resonance Imaging allows for the measuring of dynamic vascular hemodynamics with full volumetric coverage and sub millimeter resolution. While successful clinical applications of this technique are plentiful, many vascular pathologies are difficult to image due to the presence of imaging artifacts and insufficient velocity to noise ratios. These errors can in turn prevent some visualization techniques such as streamlines from being used to their full potential. This dissertation describes multiple methods of improving the capabilities of 4D flow MRI, including correction methods, an improved reconstruction, and a visualization technique for computing virtual injections.

Phase aliasing errors are corrected with a novel 4D Laplacian unwrapping method that allows for simple and robust unwrapping of 4D flow data. The method is tested in digital flow phantoms, volunteers, and patients with coarcatations or arterial venous malformations. Additionally, methods of improving data quality by enforcing physical constraints in the form of divergence-free methods are tested as a post-processing step, and used in the development of a phase-regularized reconstruction. Acceleration-induced displacement is also isolated as a significant source of error, and correction methods are developed and tested, particularly to improve streamline visualizations in the brain. Finally, with the use of the previously discussed correction methods and a modified version of probabilistic streamlines, a method for generating 'virtual injections' with 4D flow data is introduced and investigated.