Advancing Functional Assessment with Flow-Sensitive Magnetic Resonance Imaging

Grant S. Roberts

Under the supervision of Dr. Oliver Wieben and Dr. Laura Eisenmenger at the University of Wisconsin-Madison

Abstract

Phase-contrast magnetic resonance imaging (PC-MRI) is a non-invasive imaging method capable of quantifying time-resolved hemodynamics. This dissertation aims to develop novel acquisition methods and post-processing tools for the robust assessment of intracranial and aortic hemodynamics using PC-MRI and to study their relationship with aging and neurodegeneration.

The associations between cerebrovascular health, arterial stiffness, aging, and neurodegeneration are poorly understood. 4D flow MRI is a noninvasive, quantitative imaging technique well-suited for the comprehensive assessment of cerebrovascular anatomy and function. However, its use in large-scale studies and clinical translation requires automation and robustness to accurately visualize and quantify hemodynamic parameters of interest. Currently, no adequate freely-available analysis tools exist and commercial post-processing packages are targeted toward cardiac applications.

Here, I develop and validate a method to improve 4D flow MRI streamlines for generating ‘virtual injections’, enabling visualization of complex blood flow patterns in the brain. In addition, I introduce and validate an automated tool designed for simplified, robust, and reproducible cranial 4D flow MRI analysis, reducing post-processing times and interobserver variability.

This tool is subsequently used to establish normative intracranial hemodynamics in one of the largest 4D flow studies to date from 759 older adults. Blood flow rates and pulsatility indices are tabulated in all major intracranial vessels and show a strong age dependency. This tool is also used to assess the relationship between cerebrovascular hemodynamics and white matter microstructure in cognitively unimpaired and Alzheimer’s disease subjects. We find that white matter integrity is reduced in Alzheimer’s disease and that white matter microstructure correlates with cerebral blood flow and pulsatility in cognitively unimpaired subjects.

Furthermore, aortic stiffening, caused by aging or cardiovascular disease, can propagate harmful pulsatility into the cerebral microvasculature. PC-MRI methods have been developed to probe aortic stiffness by measuring pulse wave velocity (PWV), however, temporal resolution and breath-holds are methodological limitations, particularly in older adults. A free-breathing, radial, 2D-PC sequence with advanced image reconstruction is introduced to overcome these limitations and is validated in a custom-manufactured aortic phantom. Obtained PWVs are repeatable and comparable to standard breath-hold sequences. The image acquisition is further advanced by using a simultaneous multislice acquisition and reconstruction methodology to acquire two PC slices simultaneously which reduces scan time, improves physiological consistency, and maintains image quality.

Together, these novel post-processing and acquisition techniques provide a means to quantitatively and comprehensively assess both intracranial and aortic vascular health. Using these techniques, a strong relationship between aging, aortic stiffness, cerebral blood flow and pulsatility, and white matter integrity was observed in older adults. These methods and results will help elucidate the pathophysiological contributions of vascular health in the context of aging and neurodegeneration.