Flow in Radially Acquired Magnetic Resonance Imaging: Methods and Applications in Atherosclerotic Disease

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Atherosclerosis is a recognized cause of cardiovascular disease (CVD) and stroke. Typically, a substantial degree of atherosclerotic disease burden is needed for a patient to be symptomatic. Therefore, the prevention and early detection of atherosclerosis are vital means of decreasing the incidence of cardiovascular events and to decreasing the costs associated with CVD.

A number of flow-related atherosclerotic biomarkers have been derived from phase contrast magnetic resonance imaging (PC MRI) techniques. Pulse wave velocity (PWV) is one such biomarker related to vascular stiffening. As arteries are stiffened by the growth of atherosclerotic plaques, the systolic wave of blood down the aorta is accelerated because of the loss of elastic recoil in the vessel, leading to an elevated PWV. Wall shear stress (WSS) is another biomarker linked to atherosclerosis that represents the drag forces on vessel walls. It is hypothesized that abnormal blood flow patterns, and in turn insufficient stress, lead to dysfunction of the endothelium. Endothelial dysfunction leads to vascular remodeling, such as adaptive intimal thickening, and may progress to advanced atherosclerotic lesions. However, measurements of PWV require high temporal resolution and measurements of WSS require high spatial resolution. Such resolution requirements are challenging to achieve with PC MRI due to the lengthy scan times needed for velocity and reference encoding. In clinical practice, scan times are often reduced for PC MR imaging through the sacrifice of spatial and/or temporal resolution, which would compromise the utility and accuracy of PWV and WSS measurements.

The work in this dissertation aims to accelerate phase contrast imaging for the sake of acquiring and measuring PWV and WSS. Two-dimensional PC MRI with radial undersampling is investigated to determine the degree of undersampling that permits accurate flow measurements. Experiments in both flow phantoms and healthy volunteers demonstrate that accurate flow measurements can be obtained even with high undersampling factors. To measure WSS and PWV, a four-dimensional PC imaging technique with radial undersampling was employed. The repeatability and internal consistency of flow measurements from the four-dimensional PC imaging technique were evaluated in the abdominal vasculature. A PWV tool was developed and a WSS tool was utilized to handle the unique 4D data sets, which provide velocity vector fields throughout the cardiac cycle with volumetric coverage. PWV and WSS were evaluated in a swine model of atherosclerosis. A McKinnon-Bates sparsification algorithm was developed and implemented to further accelerate the acquisition of PC data. It is demonstrated that this algorithm reduces artifacts in PC images and allows for greater undersampling factors.