Magnetic Resonance Imaging (MRI) is a powerful diagnostic modality, able to capture both functional and anatomical data noninvasively. The aim of this dissertation was to develop and assess novel MRI methodology in acquisition, reconstruction, and post-processing to advance in-vivo assessment of disease in two regions of the body: 1) the placenta and 2) the heart.

1) The placenta plays a critical role in the development and long-term health of both fetus and mother; the ability to adequately quantify placental function in vivo, especially in early pregnancy could be a powerful tool for clinical decision making and therapeutic monitoring yet is currently not available. Ultrasound is commonly used in prenatal care, but its value to assess placental function is limited by a narrow field of view and poor contrast between uterus and placenta. Here, the value of dynamic contrast enhanced MRI for identifying underlying placental structures, quantifying their volumes and functional parameters associated with contrast bolus passage, and assessing their changes with pathology is demonstrated in a Rhesus Macaque model of zika virus, potentially laying the foundation for feasibility studies in humans. A promising alternative to flow associated functional analysis without the need for a contrast agent is velocity selective arterial spin labelling (VS-ASL) MRI; we present a large human study of normal and high body mass index (BMI) patients and report perfusion heterogeneity and trends that offer insight into placental development.

2) Heart disease is the leading cause of death in the United States. Imaging approaches that quantify changes in cardiovascular form and function can aid early detection and guide treatment and cardiovascular MRI plays an important role in clinical decision making. Heart failure with preserved ejection fraction (HFpEF) is a common disorder accounting for nearly half of all heart failure patients, and while cardiac function may appear normal, HFpEF often leads to secondary pulmonary hypertension (PH). PH leads to rising pressures in the pulmonary circulation and can lead to abnormal remodeling and right heart failure if left untreated. The current gold standard of HFpEF and PH diagnosis is invasive right heart catheterization which is associated with significant risk and discomfort for the patient, motivating a need for noninvasive evaluation of the effects of elevated pressure on the cardiopulmonary system. The potential value of 4D Flow MRI to quantify rising pressures in a swine model of PH is also discussed in this dissertation. The use of a flow compartment analysis to classify intra-ventricular flow patterns in the left and right ventricle in this novel swine model is discussed, offering greater information on the efficiency of ventricle contraction.

Physiological exercise is desired to reveal underlying symptoms of HFpEF and PH, but exercise in the MR bore is challenging and requires advances in acquisition, reconstruction, and postprocessing to achieve fast imaging capable of visualizing the heart during exercise and minimizing motion artefacts. The viability of ‘real-time’ exercise cardiovascular MR that can capture beat-to-beat variations is demonstrated in this dissertation along with methodology required to achieve the necessary temporal resolution. The potential value of the technique is then shown in a cohort of normal controls and heart disease patients.

The techniques and tools presented in this dissertation demonstrate and advance the ability of MRI to characterize several disease states: from the irregular perfusion of the placenta to poor cardiac adaptation to exercise. From development *in utero* to end of life, these techniques have the potential to advance diagnosis and prognosis in affected subjects.