Approximately 20% to 30% of ischemic strokes are caused by debris originating from carotid artery plaque. Currently, the percent diameter reduction in the carotid arteries is used as an indication for stroke risk, however the risk factors that lead to plaque rupture remain incompletely understood. Several markers of vulnerable plaque include plaque composition, plaque volume, thickness of the fibrous cap, as well as hemodynamic effects around the plaque. The aim of this work is to investigate the variability of various measures using simulations and imaging of the carotid artery.

The factors studied in this work are the plaque volume and hemodynamic measures. Variability of various measures of carotid artery plaque were studied using ultrasound imaging and simulations. Carotid artery wall volume measurements were conducted using a clinically available 3D ultrasound system on patients with asymptomatic carotid stenosis. Hemodynamics were studied using two methods. The first is a plaque hemodynamic analysis that studies the effect of plaque geometry, degree of stenosis, and initial flow conditions on hemodynamic measures using computational fluid dynamic (CFD) simulations. The second is an arterial network analysis that investigates the effect of downstream circulation, in the circle of Willis (COW), on the hemodynamics around carotid plaque using a lumped parameter simulation. The numerical simulation results are then compared to measured patient data using transcranial Doppler (TCD) ultrasound.

Volume measurements from 3D ultrasound imaging had good inter- and intra-observer variability. The minimum detectable change (MDC) for was 12.9% and 4.5% for multiple observers and a single observer respectively. CFD simulations were used to study the effect of the plaque geometry as well as the flow conditions on various CFD measures. The plaque hemodynamic simulation results showed the trend of the change in a measure as the degree of stenosis increases for patient specific flow and the same flow between simulations. The arterial network analysis showed that when there is a disconnected circuit, the velocity around carotid stenosis increased compared to the velocity around the same degree of stenosis and a complete COW. It also showed that there would be an increased asymmetry of the flow velocity between hemispheres in the COW as the degree of carotid stenosis increased. The TCD mean flow velocities of the main arteries in the COW measured from patients showed large asymmetry of flow between the affected and unaffected side. However, there was no clear trend in the mean flow velocity asymmetry as the degree of stenosis increased, contrary to what was observed from numerical simulations. Larger than expected asymmetry of flow velocity was also observed in control subjects with matching cardiovascular risk factors, but with no carotid stenosis.

The results demonstrate that 3D ultrasound imaging could be a feasible method for longitudinal monitoring of carotid plaque progression. The analysis also demonstrate that hemodynamic measures around the plaque and downstream of the plaque depend on multiple factors, which need to be considered when interpreting clinical measurements. These types of analyses may be helpful in better understanding and identifying vulnerable plaque.
Future work would include comparison of volume measurements of the carotid artery from 3D ultrasound to volumes using a different modality, and faster segmentations for longitudinal analysis using a semi-automatic segmentation algorithm. A more detailed plaque hemodynamic analysis of the carotid artery needs to be done, which would study the effect of carotid artery stenosis location as well as the bifurcation geometry on different CFD measures. As for the last study, validation of the TCD results should be confirmed by concomitant imaging of the COW. This will help to explain the causes of abnormal asymmetries in the mean flow velocities. Also, more patients should be added to include more subjects with higher degrees of stenosis > 70%.