Results

Idealized aneurysms of 3 representative shape index values (ASI = 2, 4, 6) were generated for 5 diameters (z-score = 6, 8, 10, 12, 14) at three positions along the right coronary artery (RCA) and one position in the left anterior descending (LAD) for a total of 40 cases. Hemodynamic simulation results were isolated over aneurysmal regions to identify the effects of shape, diameter, and position on local hemodynamic conditions.

Hemodynamic parameter distributions at the vessel wall have been hypothesized to be an effective way to assess aneurysm hemodynamics. Broadly, we expect similarly shaped aneurysms to give rise to similar hemodynamic behaviors; further, we expect that increases in Z-score correspond to decreases in fluid velocity and the potential for turbulence or recirculation. Indeed, these expectations are reflected qualitatively in distributions of TAWSS over the vessel surface. We observe that surface hemodynamic patterns vary consistently with respect to increasing Z-score, with overall decrease in TAWSS as the diameter increases. Additionally, for each value of ASI, aneurysms appear to bear similar spatial distributions of TAWSS.

Distributions of hemodynamic parameters can also be quantified in an aggregate manner. The average TAWSS was computed over each aneurysm surface and plotted with respect to ASI, stratified by aneurysm Z-score (Figure \_\_\_\_). A similar aggregate measure can be obtained by computing the fractional aneurysm surface area exposed to TAWSS values less than a critical threshold . It has been hypothesized that consistently low WSS values and flow stagnation correspond to increased risk of thrombosis; the fractional area exposed to low TAWSS has thus been proposed as a measure of evaluating CAA hemodynamics and stratifying patient risk. A plot of fractional area exposed to low TAWSS as a function of ASI, again stratified by aneurysm Z-score is given in Figure \_\_\_. Together, both aggregate measures suggest that multiple combinations of aneurysm shape and size can produce similar hemodynamics.

CAAs secondary to KD often present in multiple regions along the RCA and LAD. Aneurysms were generated in proximal, medial, and distal positions along the RCA, enabling comparison of hemodynamics as a function of position.

[need to have figure of aggregate value]

The average WSS over the aneurysm surface at different points along the cardiac cycle better illustrates the relationship between aneurysm diameter and hemodynamics . Previously, we expected the relationship between diameter and velocity to produce monotonic variation of shear stress with respect to Z-score. In fact, this is consistent with observed average WSS over the cardiac cycle in proximal and medial aneurysms of ASI=2 in the RCA, where values of average WSS are ranked in decreasing order by Z-score (Fig \_\_\_). However, in aneurysms in the distal RCA, intermediate values of Z-score (8, 10, 12) correspond to increased values of average WSS compared to both low and high values (Z-score = 6, 14) throughout much of the cardiac cycle (Figure \_\_\_\_).

The relationship between aneurysm size and hemodynamics, then, also appears dependent on position. What mechanism, then, allows position along the vessel to influence hemodynamics? To further investigate hemodynamic mechanisms underlying the relationship between average WSS and Z-score in the distal RCA, velocity streamlines were computed at various time points (Figure \_\_\_), comparing aneurysms of Z-score = 8, 14. Velocity streamlines and WSS distributions suggest that impingement of the inflow jet into the aneurysm produces combinations of high WSS regions as well as regions of stagnation. While small diameter aneurysms may allow the inflow jet to directly flow out of the aneurysm and larger diameter aneurysms feature sufficient decrease in flow velocity prior to impingement, contributing to low average WSS, jet impingement behavior in medium diameter aneurysms produces higher average WSS values. The proximal and medial RCA aneurysms, on the other hand, do not feature the same inflow jet curvature behavior.

The role of the aneurysm inflow jet suggests that vessel curvature may be an effective low-dimensional predictor of hemodynamic behavior.

[need to do curvature plot, discuss curvature plot]

The potential for similar hemodynamics to arise under multiple combinations of ASI and aneurysm Z-score suggests that a combination of both parameters may be predictive of aneurysm hemodynamics. Plotting aggregate hemodynamic parameters with respect to volume shows a strong linear relationship.

Discussion

Averaging TAWSS over the surface of the aneurysm presents a single-dimensional summary value of internal aneurysm hemodynamics, yet the potential for multiple shape and size combinations to achieve similar average TAWSS values suggests that this aggregate measure is insufficient to represent the complexity and variability of CAA hemodynamics.