Parent Artery Curvature May Help Determine the Effectiveness of Flow Diverter Treatment

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Introduction: Flow diverters (FDs) aim to treat intracranial aneurysms by altering intra-aneurysmal hemodynamics. Reports have suggested aneurysm and parent artery shape may affect flow reduction in FD-treatment [1]. The purpose of this study is to gain insight into the way in which aneurysm shape and parent artery curvature influence the ability of FDs to redirect flow.

Hypothesis: Aneurysm dome size and parent artery curvature affect FD-induced flow reduction within an aneurysm.

Methods: FD models constructed based on the Pipeline Embolization Device (ev3) with 35% area coverage, 30µm strand diameter, and 4mm nominal diameter were implemented for hemodynamic simulation analysis. The flow reduction effects were tested using aneurysm models featuring different dome sizes and parent artery curvatures. Aneurysm blood flow was analyzed before and after FD stenting in regions of the aneurysm neck, body, and dome.

Results: We found that aneurysms with higher parent artery curvature had increased systole flow entering aneurysms before and after stenting. Regardless of aneurysm size, with pre-FD volume flow rates for curvatures of 20 and 30 degrees, respectively, 1.54 and 2.40 times those for 10 degree curvature. Furthermore, FD reduced flow less in aneurysms with higher curvature. For parent artery curvatures of 10, 20, and 30 degrees, overall reductions of flow volume entering the aneurysm were 91.1±0.56%, 88.2±1.2%, and 85.5±0.28%, respectively. 97.2% of models had more flow reduction at the aneurysm dome than neck. Figure 6 shows representative, post-FD flow in 10 - and 30-degree parent arteries, with a greater volume flow rate in (b) depicted by denser streamlines. Aneurysm dome size was not found to have a significant effect on volume flow rate.

Conclusions: We found that parent artery curvature may have a large influence on FD flow reduction, indicating that <u>FD may be less effective at reducing blood flow entering aneurysms located within higher curvature arteries.</u>

Representative Six of the Twelve Models Tested

1.2 AR with 10° Curvature | 1.2 AR with 20° Curvature | 1.4 AR with 30° Curvature

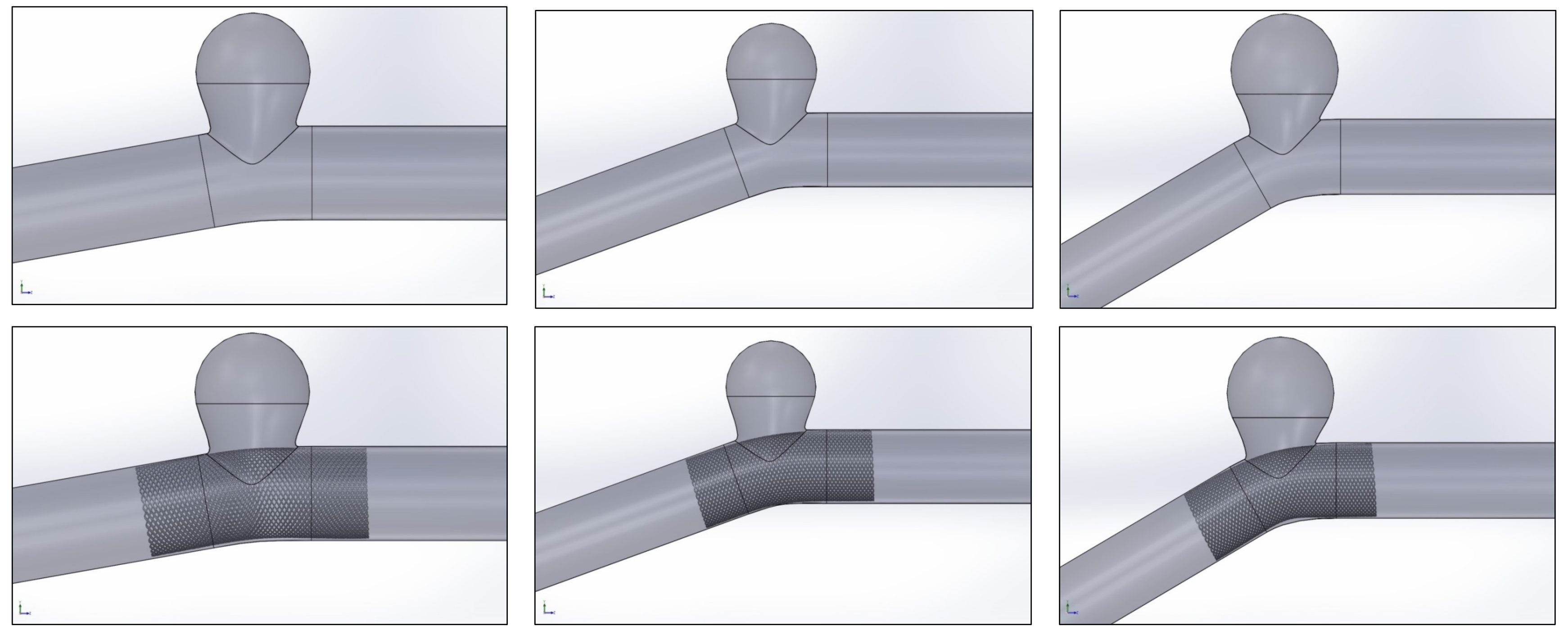
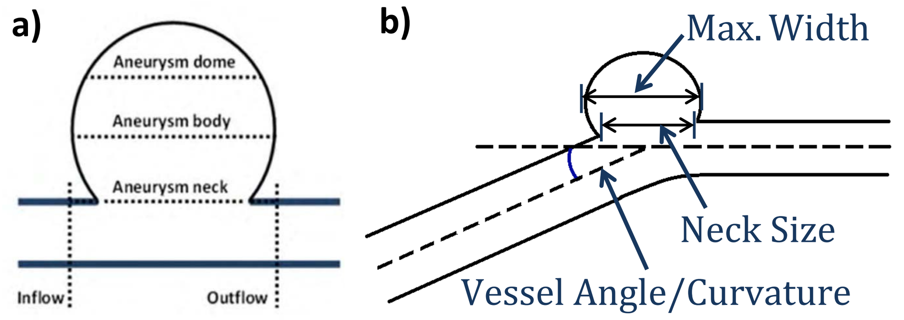


Figure 1. Three of the six models tested, unstented and stented. Shown are 1.2 AR at 10°, 1.2 AR at 20°, and 1.4AR at 30°. Both ARs 1.2 and 1.4 were each tested at 10°, 20°, and 30°.

Terminology Definitions



c)

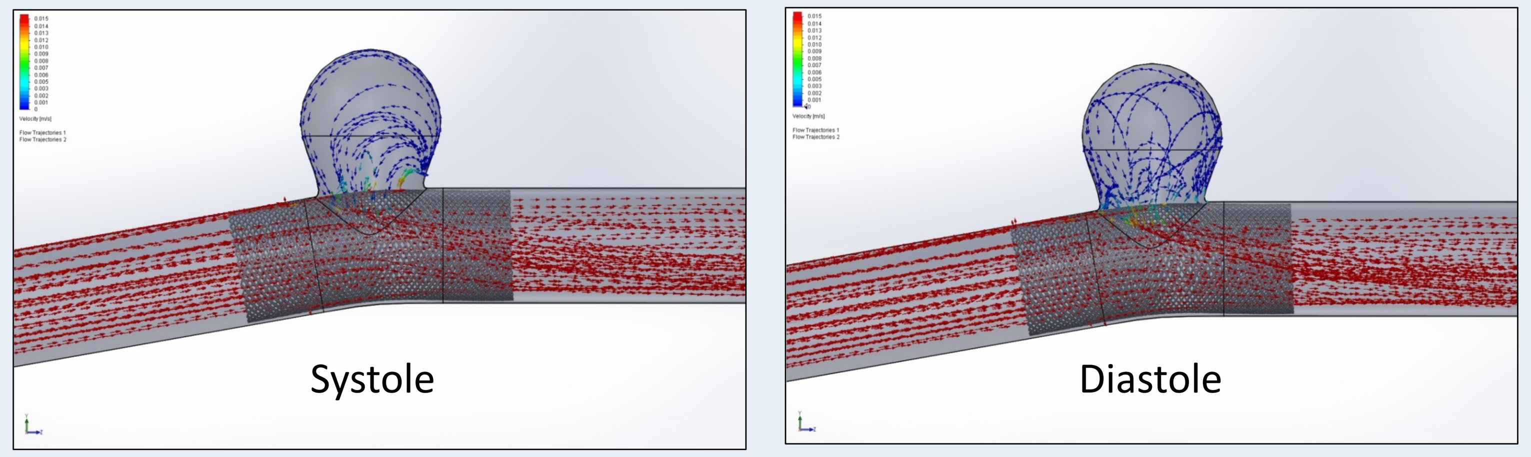
$$\%\ \text{Vel. Reduction} = \frac{|\text{Stented Vel.} - \text{Unstented Vel.}|}{\text{Unstented Vel.}}$$

$$\text{Aspect Ratio (AR)} = \frac{\text{Max. Aneurysm Width}}{\text{Aneurysm Neck Size}}$$

Figure 2. (a) The three aneurysm regions of interest [2], (b) an illustration of the vessel angle/curvature, and (c) the definitions of percent velocity reduction and aspect ratio.

Flow Pattern Changes from Stenting Depend on Vessel Angle and Time Point in Cycle

(a) 10° Parent Vessel Angle



(b) 30° Parent Vessel Angle

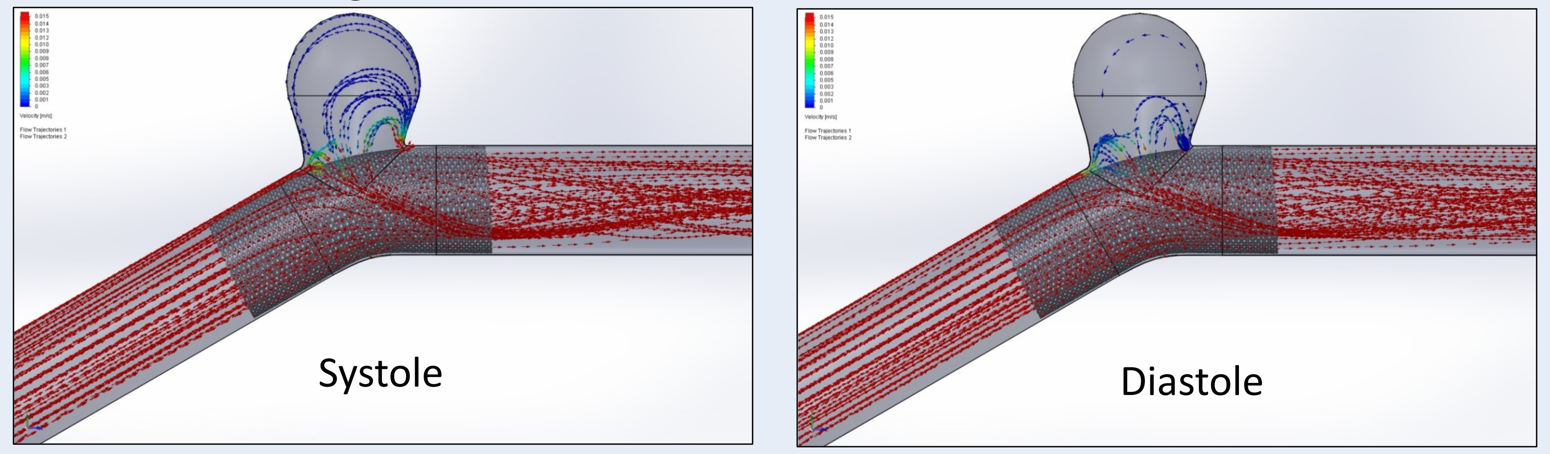
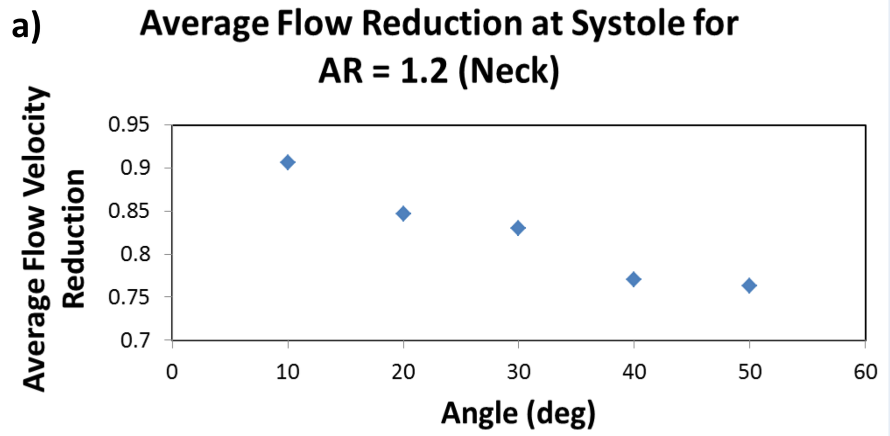


Figure 3. Two stented models for AR 1.2 shown at systole and diastole. The vessel angles shown are (a) 10° and (b) 30°. Color indicates average flow velocity, with denser streamlines indicating higher volume flow rates.

Average Flow Velocity Reduction Decreases with Angle Similarly for Both Aspect Ratios



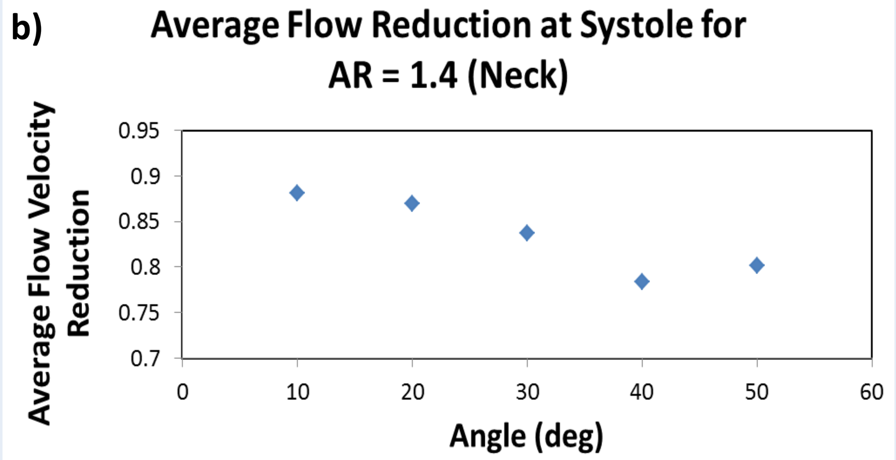


Figure 4. Plots of average flow velocity reduction at peak systole in the neck region of the aneurysm for ARs 1.2 and 1.4, with vessel angles 10° through 50°. Overall, there is a decreasing trend for average flow velocity reduction with increasing vessel angle. Additionally, AR may have a small effect on flow reduction at higher ARs.

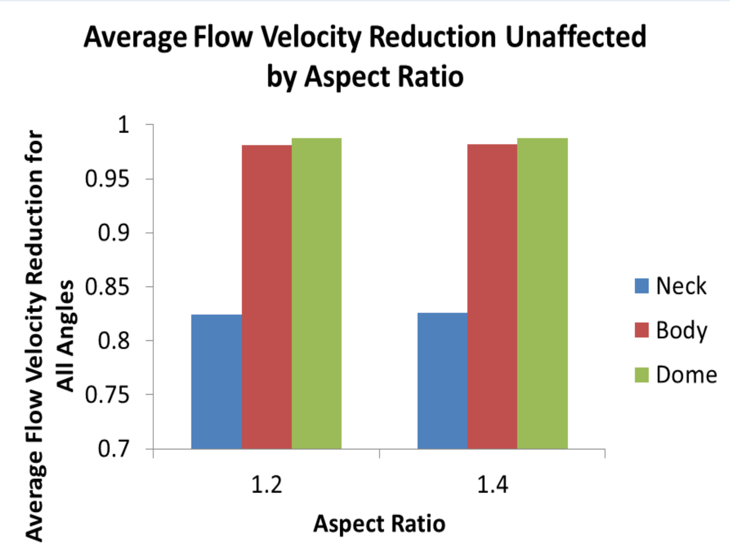
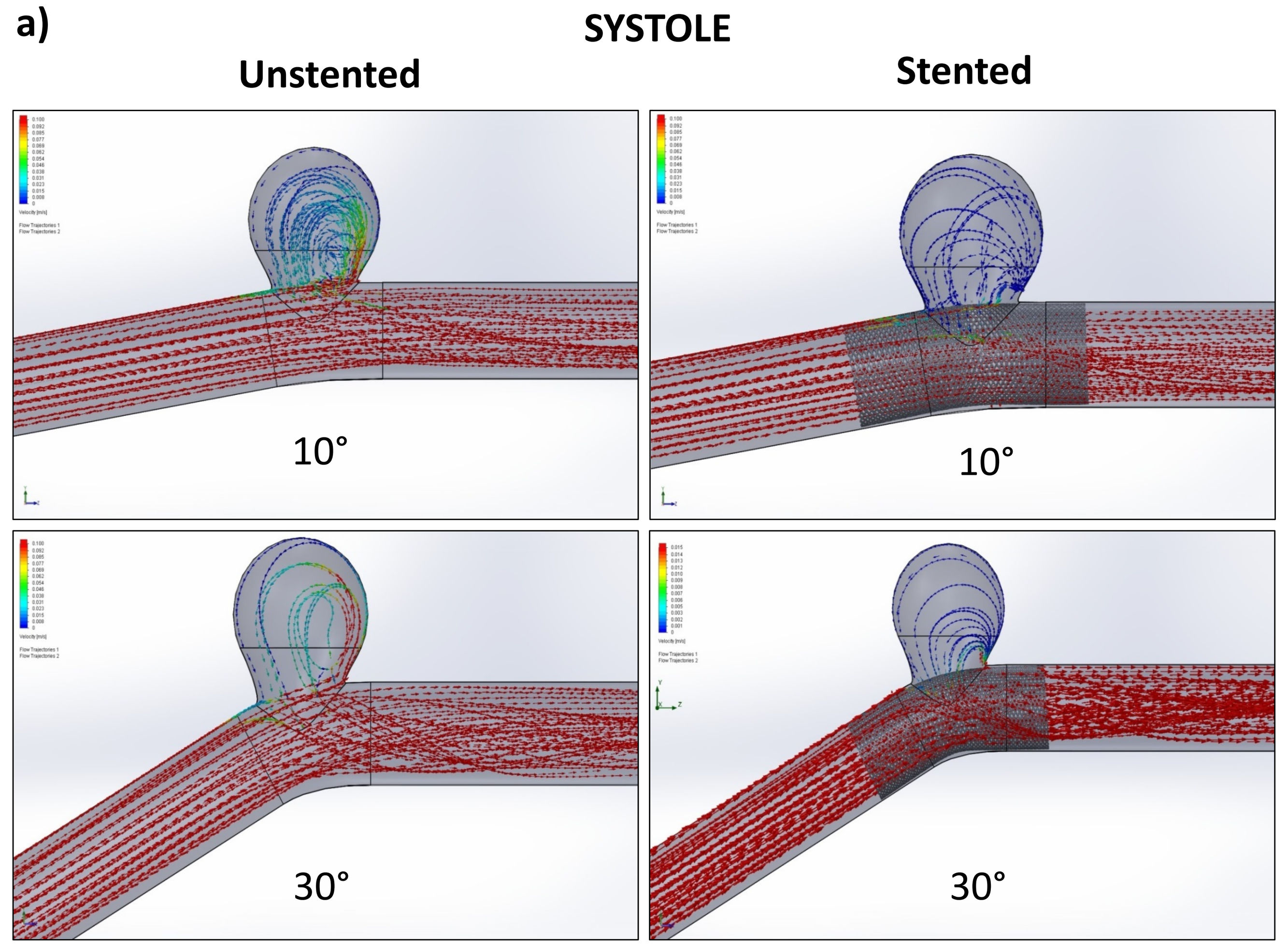


Figure 5. Bar graph showing the average flow reduction across all angles for each aspect ratio at systole. The results indicate that aspect ratio may have only small role in FD effectiveness. However, based on the two aspect ratios examined, this difference only appears at higher vessel angles.

Flow Diverter Decreased Flow Volume into Aneurysm and Altered Overall Flow Patterns at Systole and Diastole



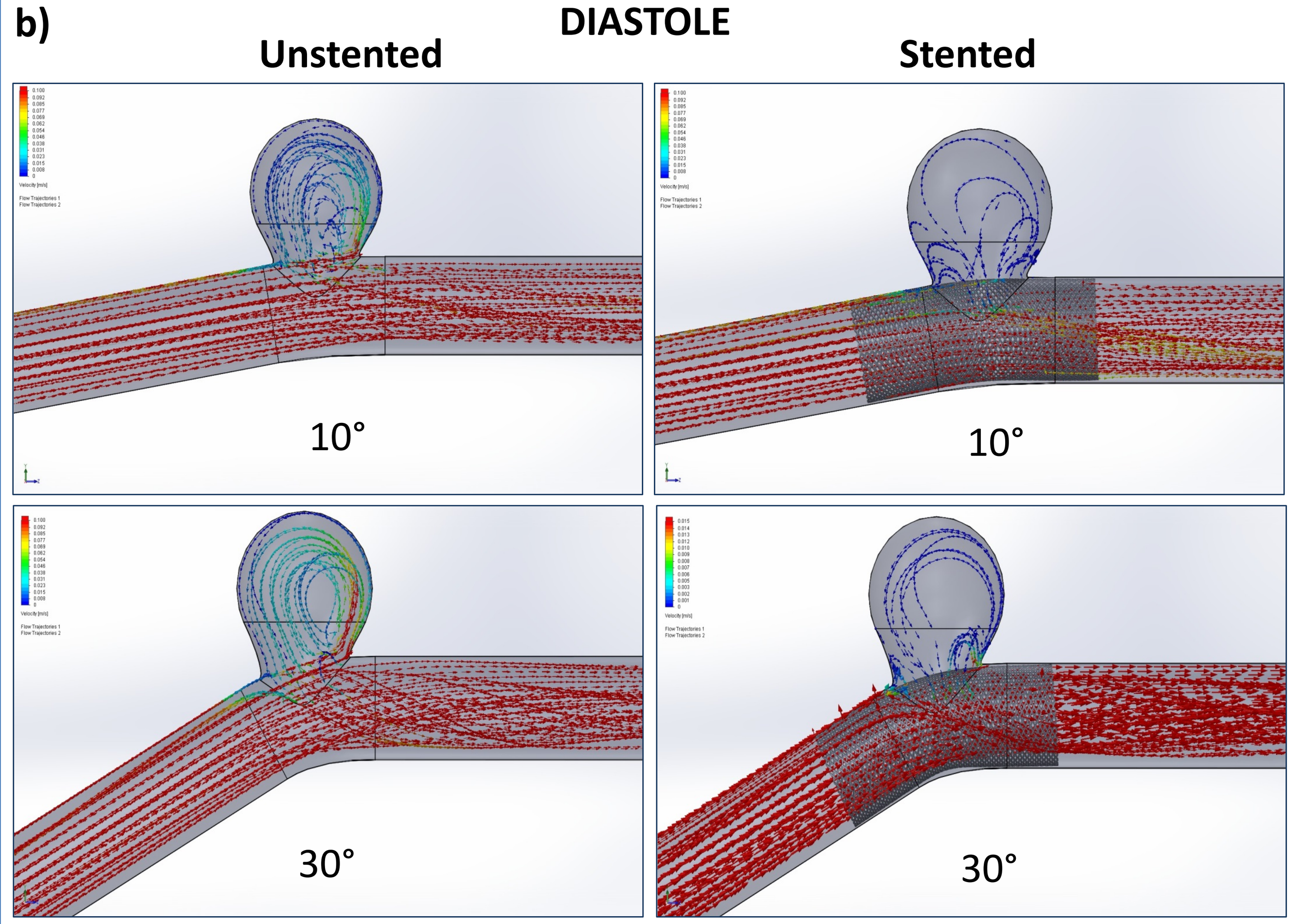
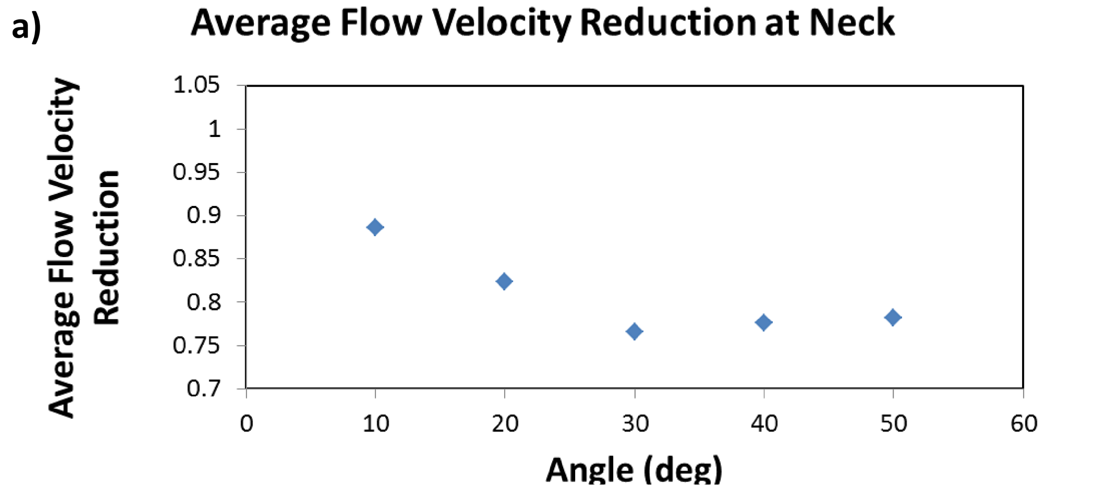
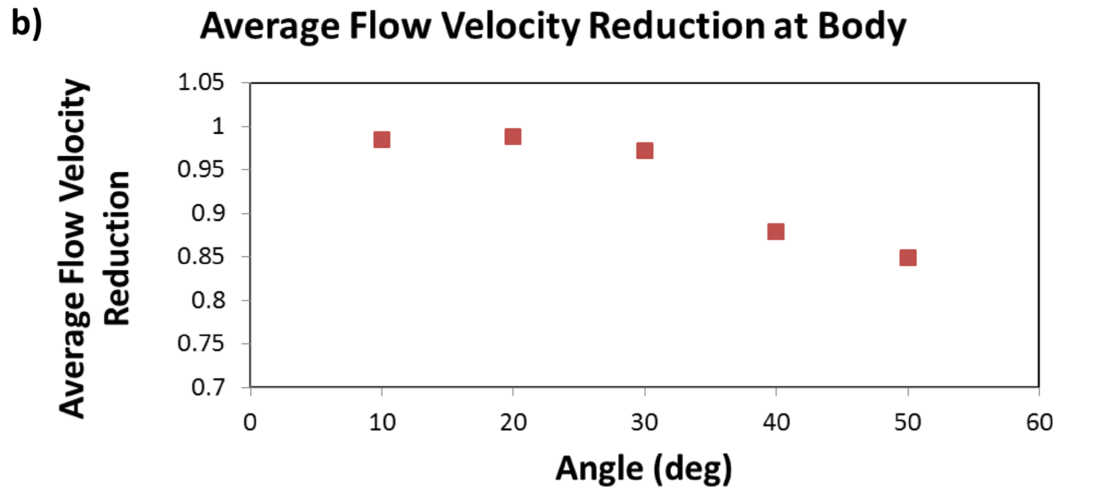


Figure 6. The two representative models shown are AR 1.4 models with parent artery angles of 10° and 30°. The flow patterns are shown at (a) systole and (b) diastole. Relative to the unstented flow streamlines, the stented 10° model showed greater average flow velocity reduction than the stented 30° model at the aneurysm neck at peak systole, as indicated by the streamline density. The same is true at diastole, though at diastole, the post-stented flow patterns are markedly different compared to the flow pattern changes at systole.

Across 20 Models, Aneurysm Neck Experienced Least Flow Velocity Reduction with Increasing Angle





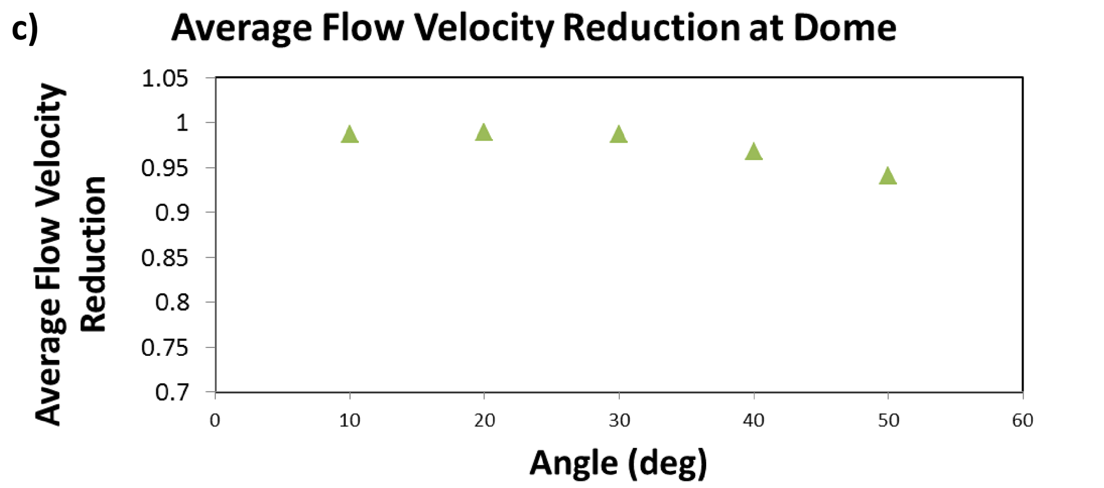


Figure 7. Plots of average flow velocity reduction at systole in each of the three aneurysm regions at peak systole for parent vessel angles of 10°, 20°, 30°, 40°, and 50°. The values for each region were obtained by averaging the values for the corresponding 1.2- and 1.4-aspect ratio models.

References:

[1] Wu Yong-Fa, Yang Peng-Fei, Shen Jie, et al. "A comparison of the hemodynamic effects of flow diverters on wide-necked and narrow-necked cerebral aneurysms". J Clin Neurosci. 2012 Nov 19(11):1520-4.

[2] A Chien, J Sayre, F Vinuela, "Hemodynamic Differences Found in Ruptured and Unruptured Aneurysms - Quantitative Comparison of 41 Cases from a Single Location," Stroke, 44:89, 2013.