Impact of Intramural Stresses on NIH in Bifurcation Stenting

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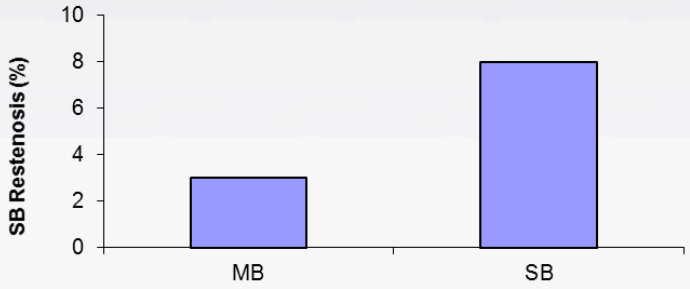
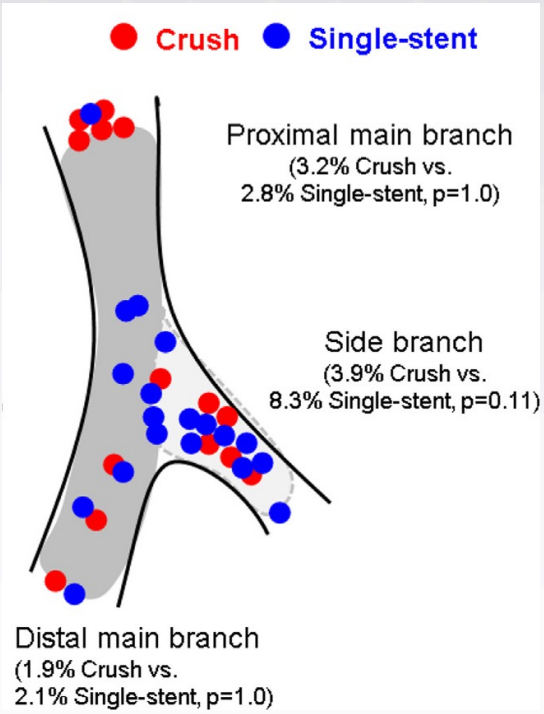
Introduction

Although the fluid shear stresses have been well investigated in bifurcations, the same is not true of intramural stresses.

We hypothesized that the perturbation of intramural stresses at the bifurcation in provisional stenting are greater than the fluid stresses and hence lead to higher restenosis rates.

Re-stenosis Rates: MB vs. SB





[Kim et al, JACC 2015;8:550–60]

Higher restenosis rate at SB was found clinically [Kim et al, JACC 2015].

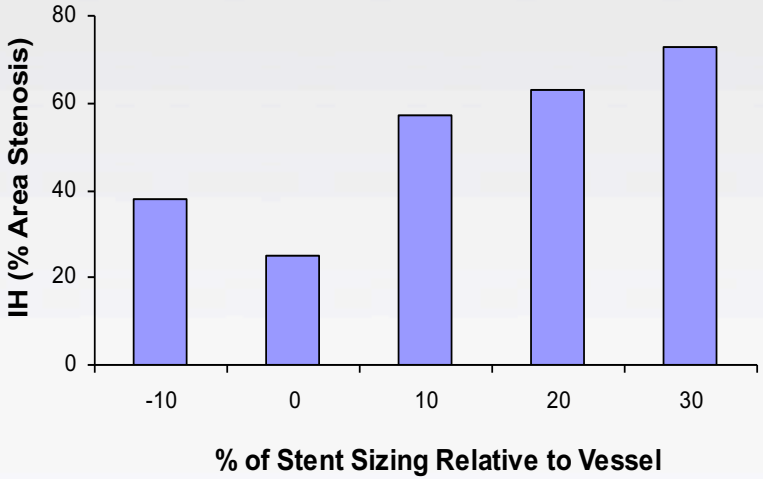
Methods

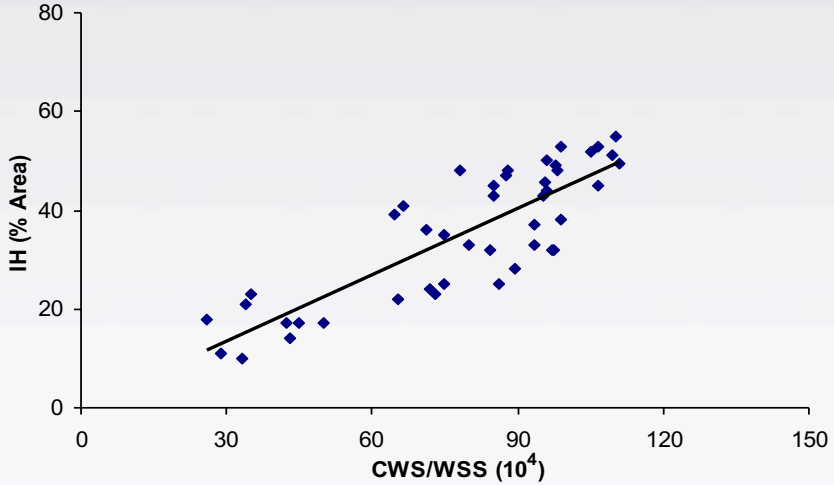
- To test this hypothesis, we developed computational models of stents and non-Newtonian blood simulations.
- The models were then interfaced, meshed and solved in a validated finite element package.
- The blood was modeled with flow waveform based on human left coronary artery pulsatile velocity measurements applied at the inlet of vessel.
- To model the interaction of stent with vessel wall, multi-body interaction was simulated via the Augmented Lagrange algorithm.
- Nonlinear hyper-elastic material model was used for the coronary artery wall.
- Penetrations between the stent and vessel elements were not allowed by the contact algorithm.

Methods: Solids vs. Fluids

- The interactions of stent and vessel wall often cause convergence problems which make it more challenging to perform structural simulations. The meshes consisted of structured and refined elements to ensure convergence and accuracy of simulation results.
- Nonlinear material model for the coronary artery is needed for wall stress analysis which may vary depending on the degree of disease (unlike the standard blood models for flow simulations).
- To evaluate both the solid and fluid effects, we used a stress ratio defined as: Solid CWS/Fluid WSS; CWS-circumferential wall stress, WSS-wall shear stress.
- This stress ratio was previously validated for evaluation of mechanical disturbances caused by a coronary artery stent [Chen et al, and G.S. Kassab, 2011].

Mis-sizing of stents in swine coronary arteries

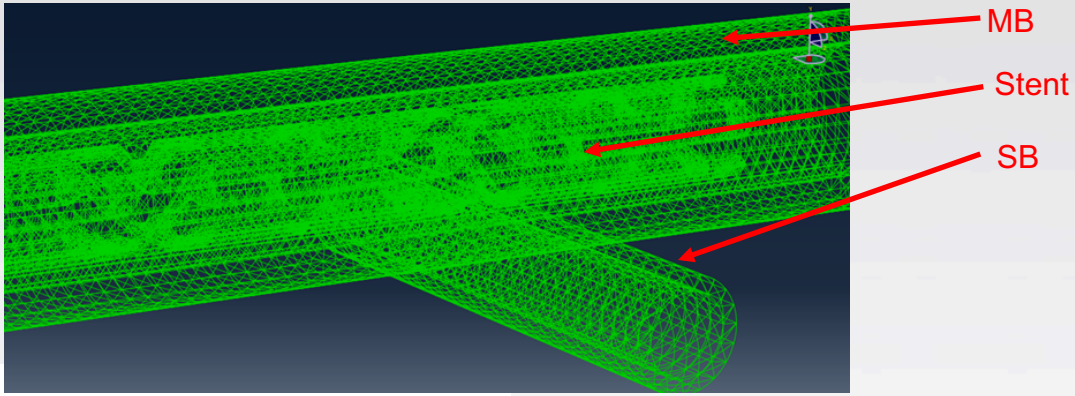


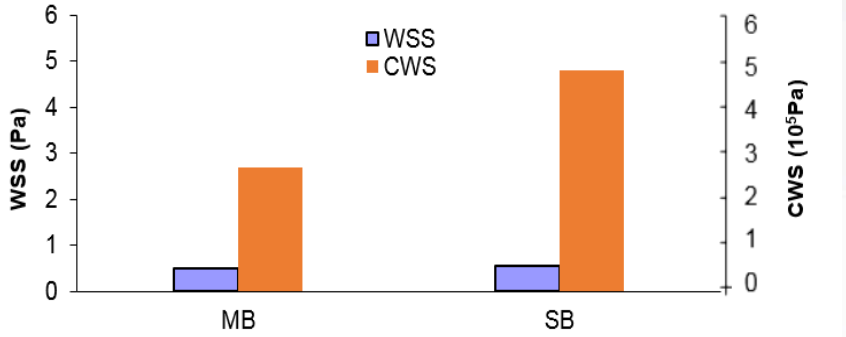


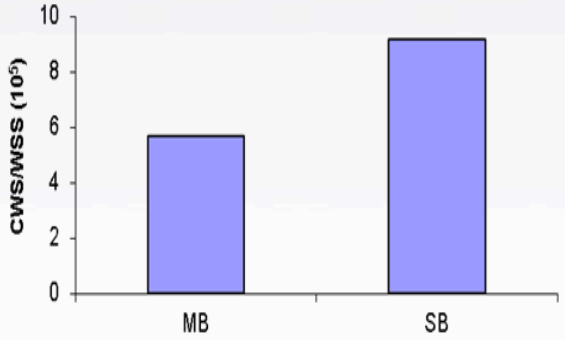
CWS: Circumferential wall stress; WSS: Wall shear stress

Chen, et al, and G.S. Kassab. Mis-Sizing of Stent Promotes Intimal Hyperplasia: Impact of Endothelial Shear and Intramural Stress. *Am. J. Physiol.*, 301(6):H2254-63, 2011.

Biomechanical Comparisons: MB vs. SB



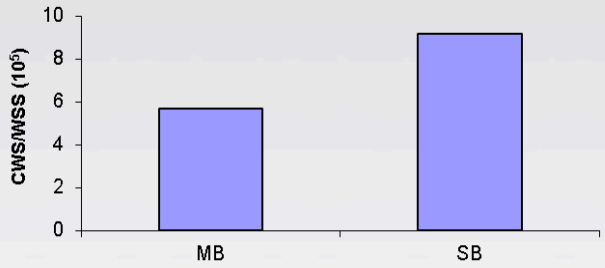


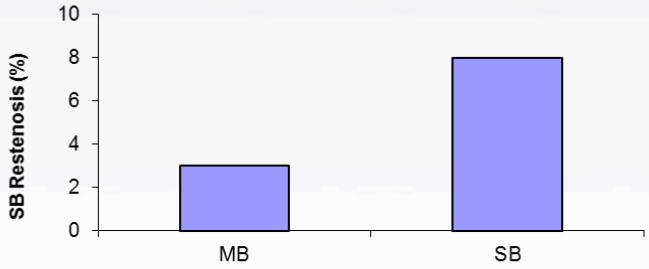


CWS: Circumferential wall stress; WSS: Wall shear stress
Cost Function = CWS/WSS

The simulations predict the SB to have a larger stress ratio than the MB.

Biomechanical/Clinical Correlations





The simulations predict the SB to have a larger stress ratio than the MB, which is consistent with clinical findings [Kim et al, JACC 2015].

Conclusions

- The increase in intramural stresses is higher at SB than MB with provisional stenting.
- The simulations predict the SB to have a larger stress ratio than the MB. This correlates with the higher restenosis rate at SB [Kim et al, JACC 2015].
- The fluid and solids simulations will be further developed to evaluate final kissing balloon (FKB) of SB which appears to reduce re-stenosis rate at SB.