Role of flow and mechanical factors on neo-intimal hyperplasia after stenting

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Introduction

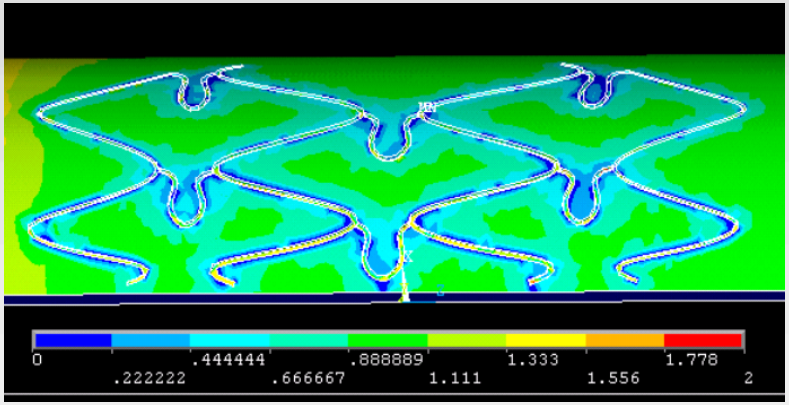
- Fluid wall shear stress (WSS) and intramural circumferential wall stress (CWS) affect endothelial and smooth muscle biology.

- We hypothesize that the perturbation of WSS and CWS affect neo intimal hyperplasia (IH) after stenting.

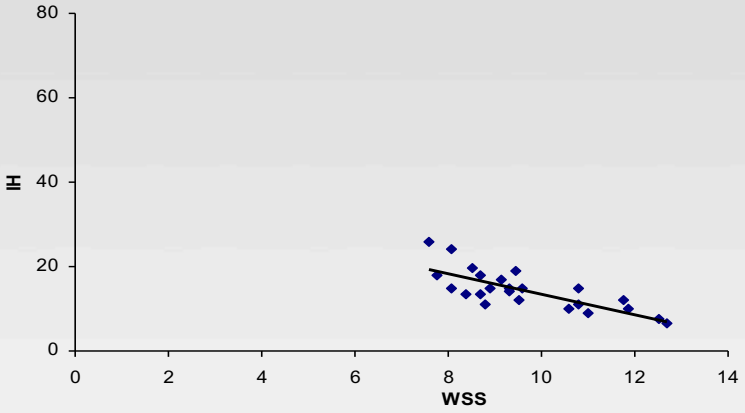
Methods

- To test this hypothesis, we purposely under- and over-sized BMS stents in a normal swine model to measure IH (using IVUS and histology) at 4 weeks post implant.
- We developed computational models of stents and non-Newtonian blood simulations to calculate WSS (WSSG and OSI) and CWS.
- 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.

Results: Correct Size Stent



A



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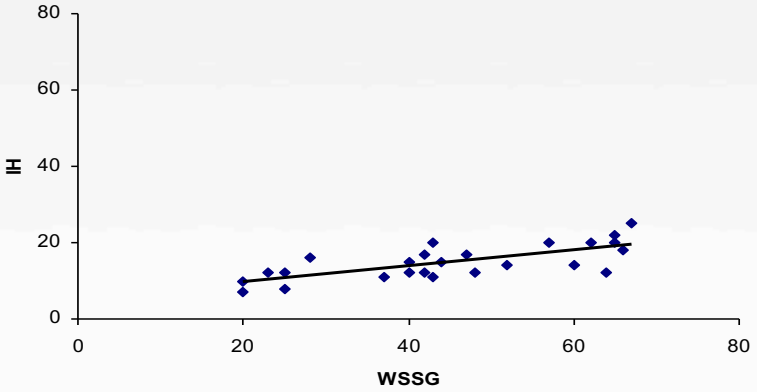

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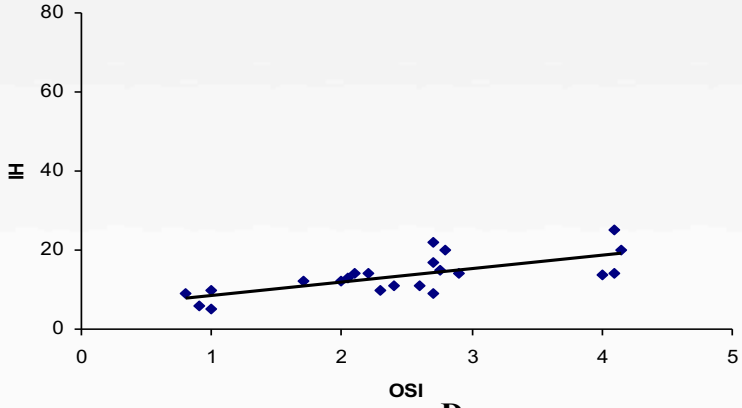
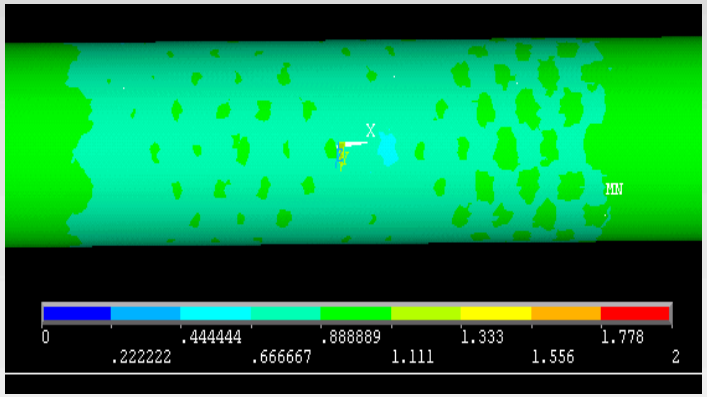


D

A) WSS distribution (1 Pascal = 10 Dynes/cm^2). **B**) A linear least squares fit between WSS (Dynes/cm^2) and IH (% area) ($R^2 = 0.61$, $P < 0.005$). **C**) & **D**) Positive correlations between WSSG (Dynes/cm^3) and OSI (%) and IH (% area). *Am. J. Physiol. Heart Circ. Physiol.*, 301(6):H2254-63, 2011.

Results: -10% Under-Sized Stent



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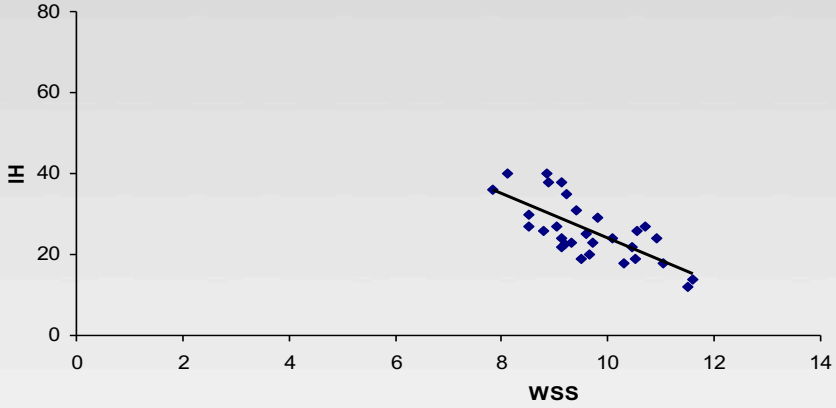

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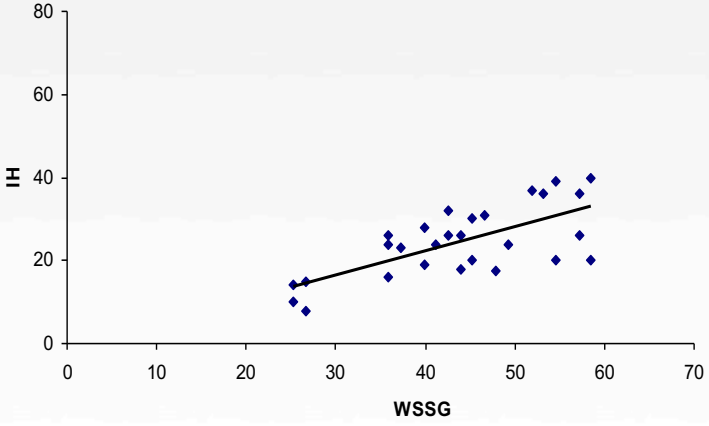

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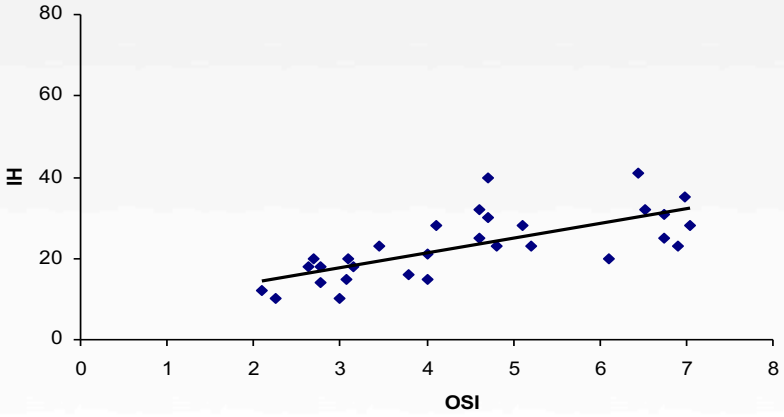
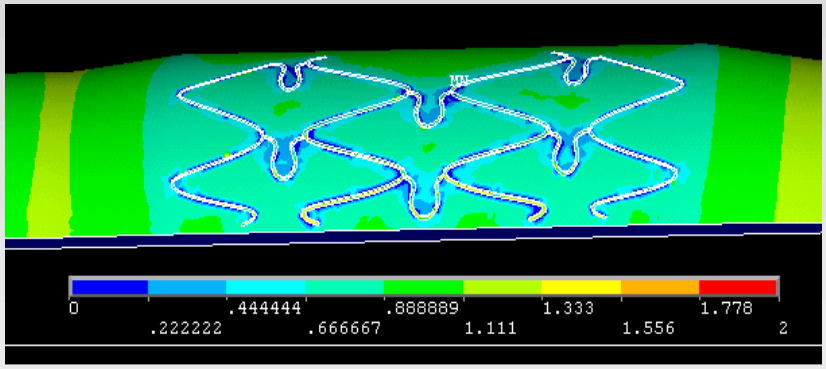


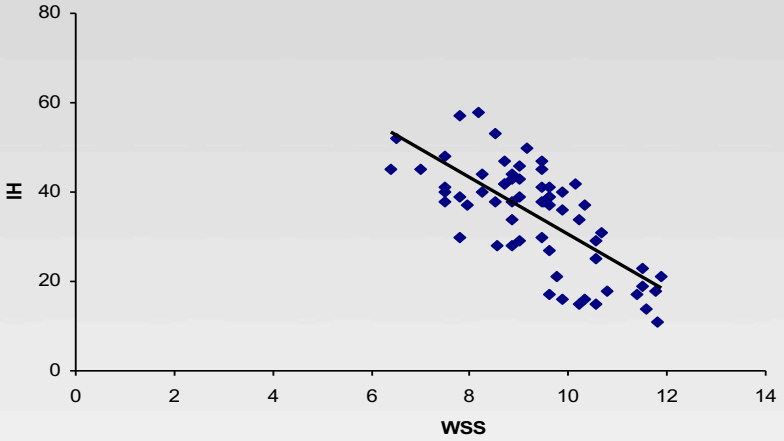
D

A) WSS Distribution (Pa). **B**) An inverse correlation between the WSS (Dynes/cm^2) and IH (% area). **C**) & **D**) Positive correlations between WSSG and OSI and IH.

Results: 10% Over-Sized stent



A



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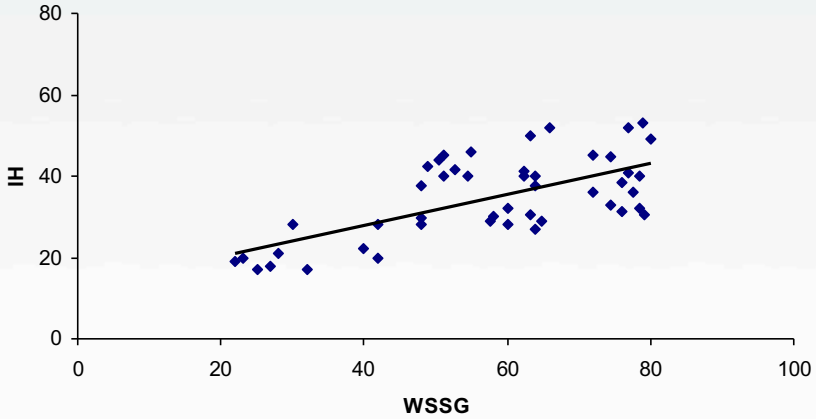

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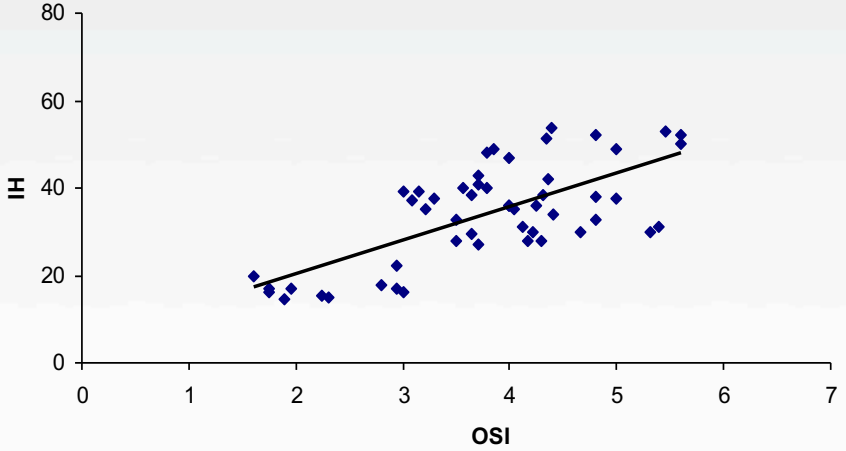
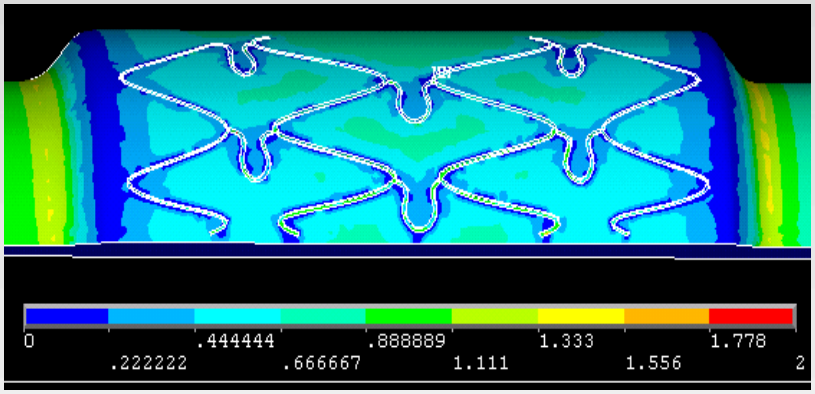


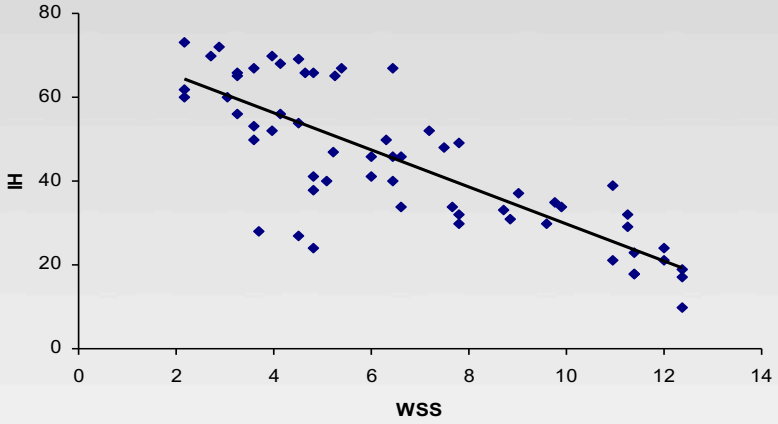
D

A) WSS distribution (Pa). **B**) A linear least squares fit between WSS and IH (R^2= 0.56, P < 0.005). **C**) & **D**) Positive correlations between WSSG and OSI and IH.

Results: 30% Over-Sized stent



A



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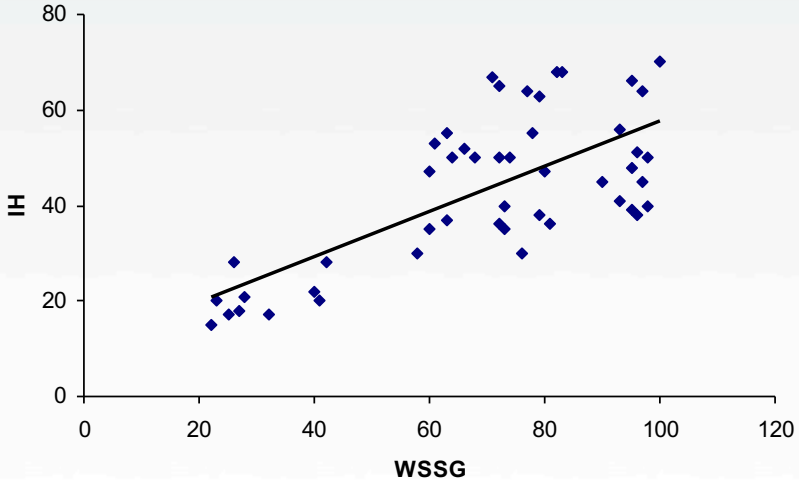

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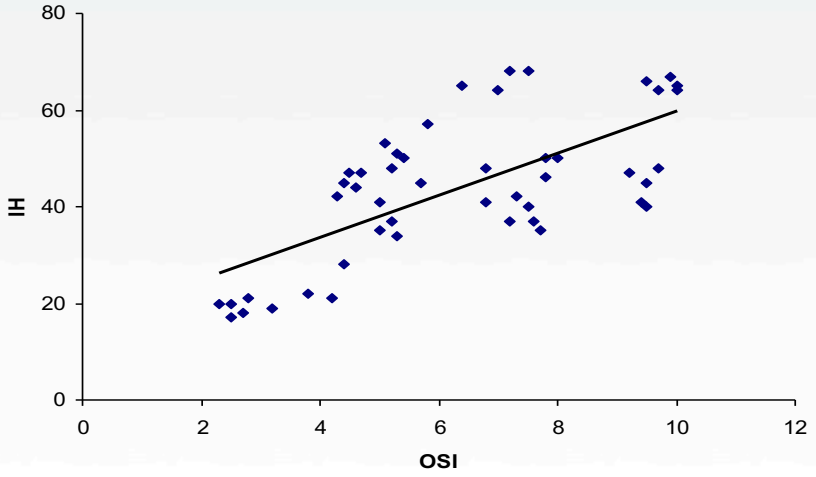
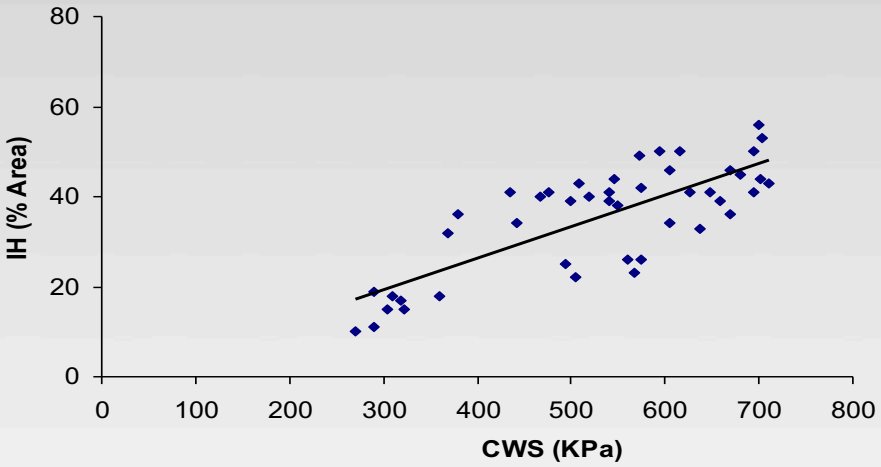


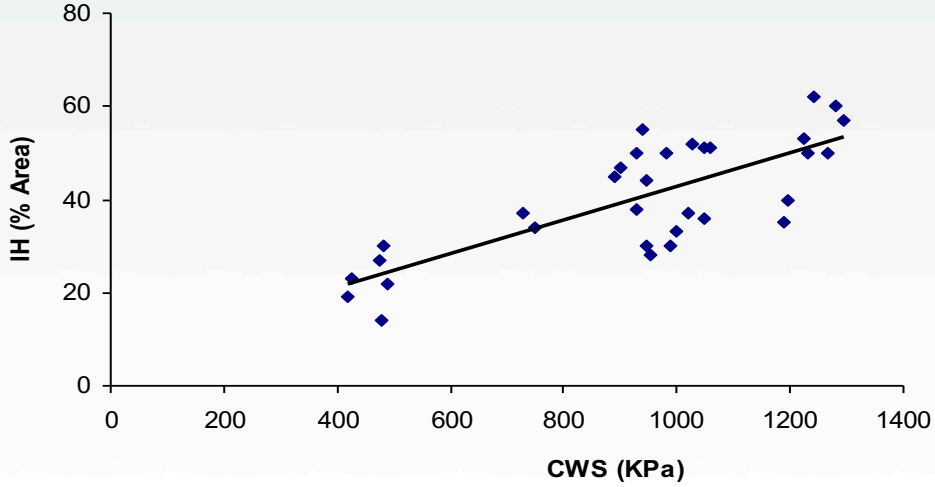
D

A) WSS distribution. **B**) A linear least squares fit between WSS and IH ($R^2 = 0.62$, $P < 0.005$). **C**) & **D**) Positive correlations between WSSG and OSI and IH.

Results: 10% vs. 20% Over-Sized stent



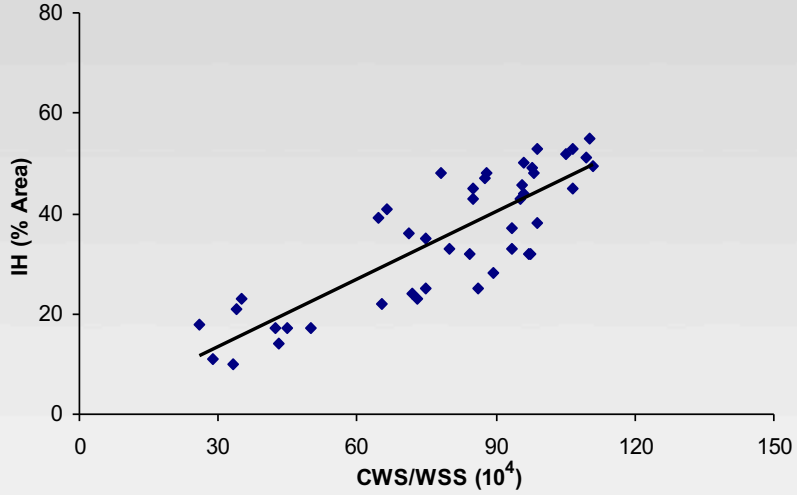
A



B

Positive correlation between solid wall stress (CWS) and intimal hyperplasia (IH) in **A**) the +10% sizing case: $R^2 = 0.61$, $P < 0.005$; **B**) in the +20% sizing case: $R^2 = 0.56$, $P < 0.005$.

Results: 10% vs. 20% Over-Sized stent



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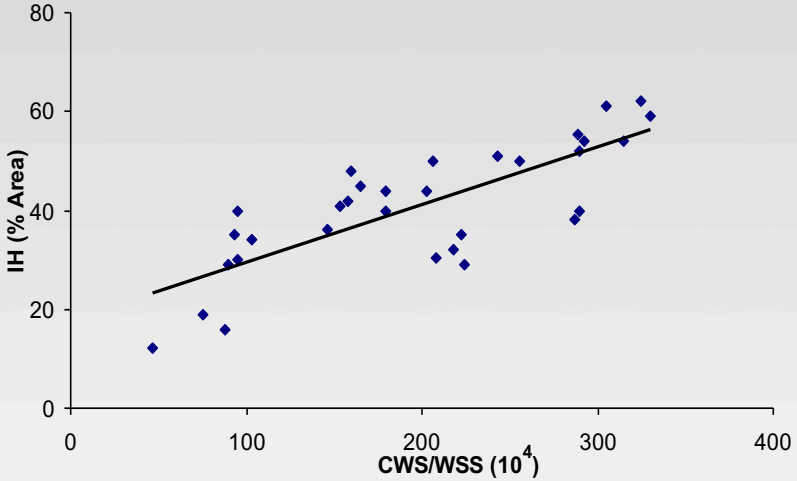

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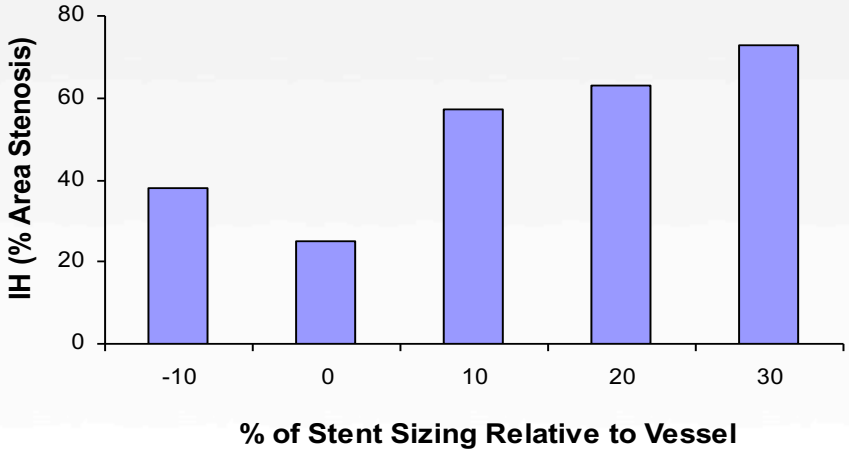

C

Positive correlation between CWS/WSS and IH is shown in the **A**) +10% sizing case ($R^2 = 0.68$, $P < 0.005$); and the **B**) +20% sizing case: $R^2 = 0.64$, $P < 0.005$. **C**) Effect of stent sizing on extent of IH as the maximum %area stenosis in the stented region for all the data.

Conclusions

- Significant linear relations were found between solid (vessel wall) CWS and fluid WSSG, OSI and IH, while an inverse relations were found between fluid WSS and IH.

- Even more highly significant linear relations were found between the ratio CWS/WSS and products CWS*WSSG, CWS*OSI and IH.

- These findings suggest that the effects of both strut flow disturbances and radial wall force on IH are synergistic and should be considered to fully understand the effect of stenting.