IMPACT OF CORONARY STENT SHAPE AND THICKNESS ON THE HEMODYNAMIC-RELATED RISK OF IN-STENT RESTENOSIS

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Introduction

Despite continuous advancements in stent technology for the treatment of diseased coronary arteries, major complications still affect the long-term postoperative outcomes [1]. Coronary stent implantation can induce flow disturbances, altering hemodynamic profiles at the strut level. This plays a major role in the pathophysiological mechanisms leading to in-stent restenosis (ISR) [1]. In detail, stent design, struts shape and thickness might modulate flow disturbances, impacting postoperative outcomes. In this study, the largest dataset to date of coronary stent models available on the market is built and computational fluid dynamics (CFD) is applied to investigate the impact of different stent designs on the hemodynamic-related risk of ISR.

Methods

The 3D geometries of 12 coronary stents (10 drug eluting stent-DES and 2 bare metal stent-BMS, Figure 1) were reconstructed. Two stents (models D and H) presented a closed-cell design. A uniform strut thickness of 80 µm was considered for all models (U-models), to focus the analysis on the hemodynamic impact of stent shape. Additionally, 12 models with the real stent thickness were created (R-models). Twenty-four unsteady-state CFD simulations were performed in idealized stented coronary arteries, under the same conditions at boundaries [2]. The hemodynamic-related risk of ISR was evaluated in terms of canonical wall shear stress (WSS)-based quantities (i.e., TAWSS, OSI, and RRT). Based on recent evidence [2], the amount of variation in WSS contraction/expansion action exerted on the endothelium along the cardiac cycle T was also quantified in terms of topological shear variation index (TSVI) [3]:

$$\mathrm{TSVI} = \left\{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} [\mathrm{DIV_{WSS}} - \overline{\mathrm{DIV_{WSS}}}]^2 dt\right\}^{1/2} \qquad (1)$$

where $\mathrm{DIV_{WSS}}$ is the divergence of normalized WSS vector field. Luminal surface areas exposed to flow disturbances (low shear area, LSA; high oscillatory shear area, OSA; high residence time area: RTA; high topological shear variation area, TSVA) were identified, based on objective thresholds on pooled luminal distributions: the 20th percentile of TAWSS; the 80th percentile of OSI, RRT, and TSVI.

Results

Independent of stent design, LSAs were mainly located nearby struts and links (Figure 1, R-models), with design J characterized by the largest LSA (>36%). Similar results emerged for OSA, RTA and TSVA.

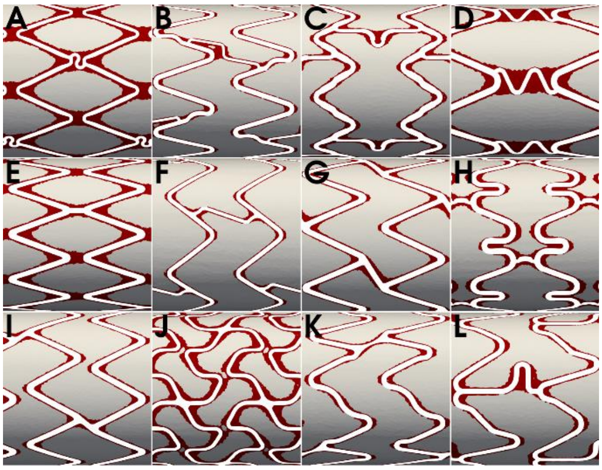

Figure 1: Low shear areas at stent elemental unit.

Boxplots of TAWSS and TSVI distributions (Figure 2) show that, independent of stent shape and thickness, design J exhibited the worst hemodynamic performance (lowest TAWSS and highest TSVI values). Conversely, model F had the best hemodynamic performances. Overall, stent hemodynamic performance was inversely related to strut thickness.

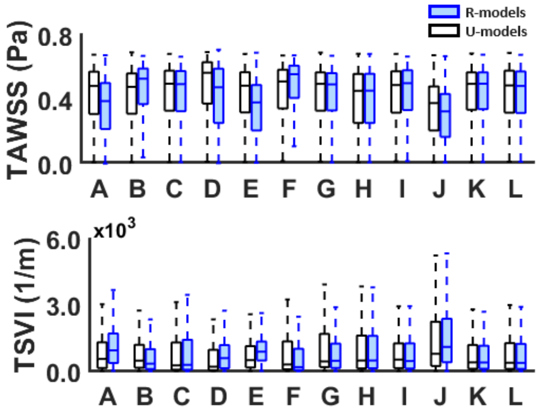

Figure 2: Interquartile range and median value of TAWSS and TSVI for all the investigated stent designs.

Discussion

Here we compared the hemodynamic-related risk of ISR for 12 coronary stent designs available on the market using idealized CFD models. A major impact emerged for stent shape, unexpectedly independent of closed- or open-cell configuration. In the future, the presented stent dataset could be useful for (i) benchmarking purposes in the development of innovative stent designs and (ii) assessing patient-specific ISR risks.

References

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