ASSESSEMENT OF THROMBUS FORMATION IN ARTERIAL STENTS

Mohammad Rezaeimoghaddam (1), Frans van de Vosse (1), Carlijn Bouten (1,2), Sandra Loerakker (1,2)

1. Department of Biomedical Engineering, Eindhoven University of Technology, The Netherlands;
2. Institute for Complex Molecular Systems, Eindhoven University of Technology, The Netherlands.

Introduction

After balloon angioplasty in arteries, stents are implanted to maintain the vessel's dilation and ensure its patency. However, stent geometry, including the inter-strut spacing, length, and strut cross-section, affects stent-vessel interactions and alter blood flow patterns. In addition, poor stent design can increase particles residence time, create low wall shear stress and promote coagulation [1]. Furthermore, the struts could bring the risk of inflammation due to endothelial damage, intimal thickening, and thrombus formation. Assessing high risk geometrical features for thrombus formation and evaluating strategies for preventing thrombosis are essential in designing effective stents. Platelets play a crucial role in haemostasis and clot formation. They bind to the damaged endothelial cells through the processes of aggregation, activation, and adhesion. Additionally, in high shear flows von Willebrand factor (vWF), a protein that is sensitive to mechanical stress and hemodynamic forces, undergoes a conformational change to bind to collagen and platelets through A1 and A3 binding domains, respectively [2]. Thus, the combined effect of platelet activation due to collagen exposure and unfolding vWF due to hemodynamic alteration could start the thrombus formation. The aim of the current study is to quantify the mechanisms, underlie thrombus formation in stents in order to find means to prevent serious complications and maintain long-term patency.

Methods

The thrombus formation model can be described by the convection, diffusion, and reaction of biochemical agonists into a series of a coupled equations,

$$\frac{\partial[C_i]}{\partial t} + (\boldsymbol{V}.\nabla)C_i = D_i \Delta C_i + S_i(C_j). \qquad (1)$$

Where $[C_i]$ is the concentration of species i, $\boldsymbol{V}$ is the velocity vector, D_i is the diffusivity of species, and $S_i(C_j)$, are the source terms, production/consumption, for the i species. The current model of platelet-fibrin kinetics includes the features of our previously deposited bounded platelet model [3]. Concentration of un-activated platelets, activated platelets, ADP, thromboxane, prothrombin, thrombin, antithrombin, fibrinogen , fibrin, VWF folding/stretched and deposited bounded platelets are solved at each time step. Two different mechanisms for platelet activation, and adhesion are used. The gap between struts serve as a surface flux boundary condition representing a collagen surface to initiate thrombus formation. In addition, a combined effect of stretched vWF concentration and residence time on the struts are added to the model. The blood is considered as a Newtonian fluid, and thrombus considered as a porous medium. The model is implemented into FLUENT 2021 R1 (ANSYS Inc. PA) Computational Fluid Dynamics software. The computational domain consists of a 2D channel with a height of 3 mm and length of 250 mm. The simplified stent's architecture is denoted by eight unconnected squares in the model which represents cross sectional of the struts.

Results

The results of thrombus shape from our numerical 2D cartesian symmetric domain model with a parabolic velocity inlet profile, is shown in Figure 1.

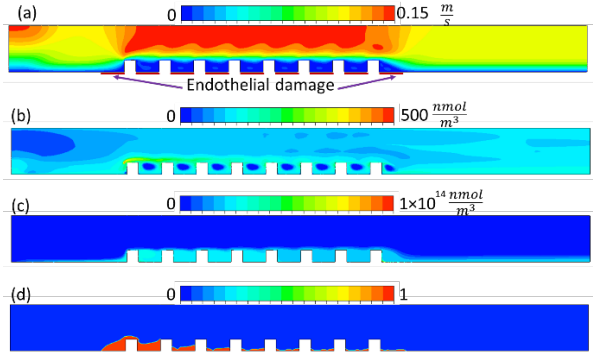

Figure 1: Visualization of velocity magnitude and the concentration of biomolecules. a) Velocity magnitude at 10 sec, b) vWF concentration at 10 sec, c) activated platelets at 10 sec, d) deposited thrombus at 200 sec.

The results indicate a strong correlation between a high concentration of stretched vWF and thrombus formation at the first strut.

Conclusion

This computational model will enable identification of key factors associated with thrombus formation, resulting in new insights that are critical for guidelines to ensure patency of stents. This model accurately describes the interactions between the regulatory network of the coagulation cascade and dynamics of platelet deposition due to endothelial damage and hemodynamics.

References

1. Jiménez et al, Ann Biomed Eng, 37: 1483-1484, 2009.
2. Zhussupbekov et al, Ann Biomed Eng, 49:2646-58, 2021.
3. Rezaeimoghaddam et al, J Biomech, 132:110915, 2022.

Acknowledgements

This research was financially supported by the Gravitation Program “Materials Driven Regeneration”, funded by the Netherlands Organization for Scientific Research (024.003.013).