Phenomenological prediction of false lumen thrombosis in type B aortic dissection

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Introduction

Aortic dissection (AD) is a fatal condition caused by a tear in the aortic wall. This tear allows blood to flow between the layers of the aortic wall creating a secondary blood flow channel, known as the false lumen (FL). AD is classified into two types based on Stanford Classification System: type A, which originates in the ascending aorta, and type B, which occurs in the descending aorta. The level of thrombosis in the FL is a significant factor in determining the patient's chances of survival. Clinical studies have shown that the dilation and rupture of the FL are related to the absence of a thrombus in the FL. Complete thrombosis of the FL leads to improved outcomes for patients with type B AD, whereas partial thrombosis is a significant predictor of late dissection-related deaths. Therefore, understanding the conditions under which complete thrombosis of the FL occurs is important for assessing the risk of type B AD patients. In Type B AD, FL thrombosis is governed by local hemodynamic conditions, enhanced in low shear rate zones in the FL. This study presents a novel model for predicting FL thrombosis based on hemodynamic conditions in the FL. The new model is developed based on the findings of Menichini et al. [1] and Melito et al. [2].

Methods

The new model controls the thrombus growth only by considering the local shear rate and shear stress in the FL through a single equation known as the coagulant equation. The coagulant equation is a convection-diffusion-reaction equation that models the effect of all the biochemical reactions in the coagulation cascade. The degree of FL thrombosis is defined based on the coagulant concentration. Additionally, the effect of thrombus growth on blood flow is modeled through a fictitious force incorporated in the Navier-stokes equations. The blood is modeled as a non-Newtonian incompressible fluid.

Results

The new model was applied to a post-TEVAR Type B AD patient-specific case to compare the model prediction with the computer tomography (CT) scans. CT scans were taken one month and three years after TEVAR, shown in Figures 1A and B. The 1-month post-TEVAR geometry was considered a starting morphology to implement the thrombus model, and the computational fluid dynamics (CFD) simulation was run until the thrombus growth stopped. The final simulated FL thrombosis for this patient was compared with the 3-year follow-up scan (Figure 1B and C). The results show that the model can predict FL thrombosis in a patient-specific geometry and the predicted FL status is in excellent agreement with the 3-year follow-up scan.

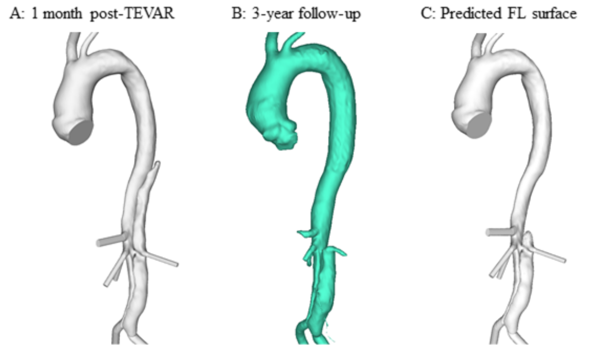

Figure 1: Reconstructed aorta from (A) 1-month post-TEVAR and (B) 3-year follow-up CT scan. (C) Predicted FL surface after thrombus growth over 20 cardiac cycles using the model in this study [3].

Discussion

Understanding FL thrombosis is critical in monitoring and treating type B AD patients. Also, in a clinical setting, fast prediction of the extent and location of FL thrombosis is very beneficial. The computational cost of the new model is significantly lower than the previous thrombus model in [1], with an approximate 65% reduction in computational time. Such improvement means the new model is a significant step toward clinical applicability. The high computational efficiency of the model equips us with a tool to assist clinicians in prognosis and decision-making.

References

1. Menichini et al., J Math Biol, 66:3643, 2018.
2. Melito et al, J Biosci Bioeng, 7:31-40, 2020.
3. Jafarinia et al, Front Bioeng Biotechnol, 10:1033450, 2022.

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