Wall shear stress topological skeleton variability predicts plaque growth in human coronary arteries

Giuseppe De Nisco[1], Eline M. Hartman[2], Valentina Mazzi[1], Diego Gallo[1], Claudio Chiastra[1], Joost Daemen[2], Jolanda J. Wentzel[2], Umberto Morbiducci[1]

1. PoliTo^{BIO}Med Lab, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24 - 10129 Turin, Italy
2. Department of Cardiology, Biomedical Engineering, Erasmus MC, P.O. Box 2040, 3000 CA Rotterdam, Netherlands

Authors' e-mail address:

giuseppe.denisco@polito.it

elinehartman@gmail.com

valentina.mazzi@polito.it

diego.gallo@polito.it

claudio.chiastra@polito.it

j.daemen@erasmusmc.nl

j.wentzel@erasmusmc.nl

umberto.morbiducci@polito.it

Introduction

In last decades wall shear stress (WSS) has gained consensus as hemodynamic mechanism for coronary atherosclerosis. However, the exact biomechanical stimulus affecting early atherosclerosis is still undetermined[1]. To bridge this knowledge gap, the WSS topological skeleton (TS) is receiving increasing interest, because of its link with flow disturbances associated to vascular dysfunction[2], and its capability to improve the description of the complex biomechanical stimulus affecting atherosclerosis evolution[3]. The WSS TS consists of fixed points, where WSS vanishes, and unstable/stable manifolds, where WSS exerts a contraction/expansion action on the endothelium, thus dictating intracellular and cell-cell tension definition[4]. Here we test the ability of WSS TS to predict the coronary artery plaque burden (PB) temporal evolution in 49 patient-specific computational models of human coronary arteries.

Methods

The methods workflow is provided in Figure 1. Forty-eight hemodynamically stable patients with acute coronary syndrome and at least one non-culprit coronary segment, were enrolled[5]. Previous coronary bypass graft surgery, renal insufficiency (creatinine clearing<50ml/min), ejection fraction<30%, and atrial fibrillation, were considered as exclusion criteria. After successful percutaneous coronary intervention of culprit vessel, the non-culprit coronary segment was imaged by coronary computed tomography (CCTA) angiography and intravascular ultrasound (IVUS) at intervention time (T1) and at 1 year follow-up (T2).

3D vessel geometries were reconstructed at T1, and computational fluid dynamics simulations were performed prescribing patient-specific boundary conditions. WSS analysis was based on time average WSS (TAWSS), and topological shear variation index (TSVI),[2] quantifying the variability of

the local WSS contraction/expansion action on the endothelium along the cardiac cycle. PB growth was measured on IVUS images as the difference between PB (100*plaque area/total vessel area) at T2 and T1, adjusted to PB at T1 and averaged over 1.5mm/45° luminal sectors. WSS-based quantities were averaged over the same luminal sectors and classified into artery-specific (low, mid, and high) tertiles.

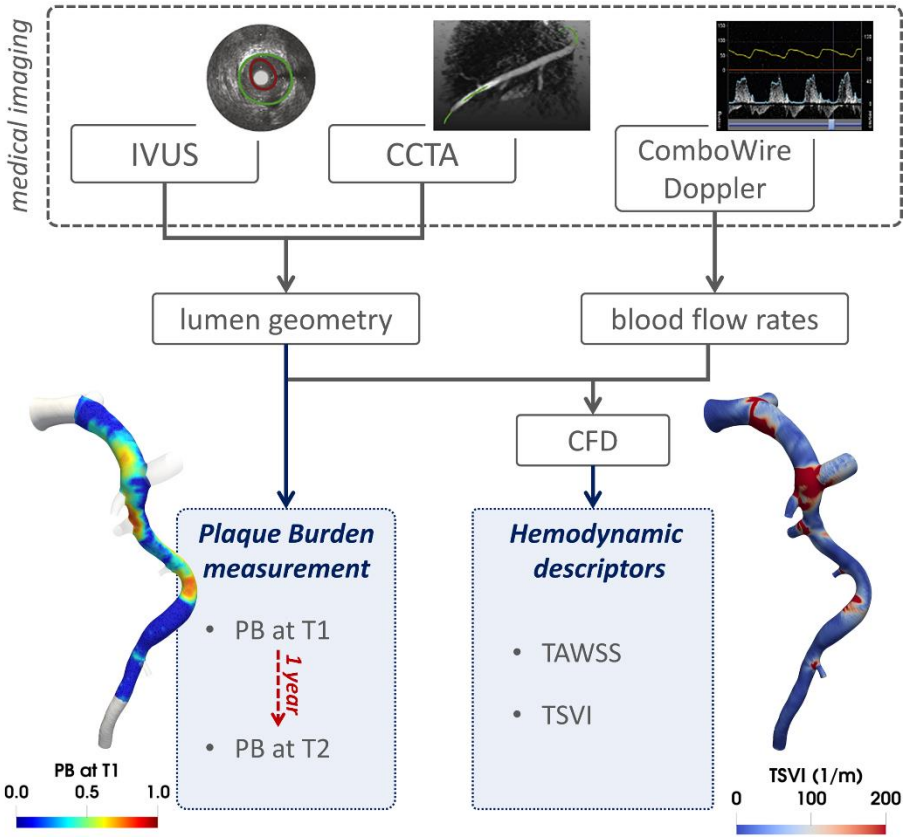

Figure 1. Diagrammatic sketch of the workflow of the study

Results

Figure 2 presents the luminal distributions of T2-T1 PB growth, and TAWSS and TSVI at T1 for six explanatory cases. The luminal sectors-based distribution of adjusted PB growth within low, mid, or high values of TAWSS and TSVI is also reported. Luminal sectors exposed to high TSVI at T1 exhibit T2-T1 PB growth significantly higher than sectors exposed to low ($p<0.05$) or mid ($p<0.01$) TSVI. A clear trend (even if not significant) emerges also for the exposure to low TAWSS at T1 and PB growth, the latter being higher in luminal sectors where TAWSS is low and *vice versa*.

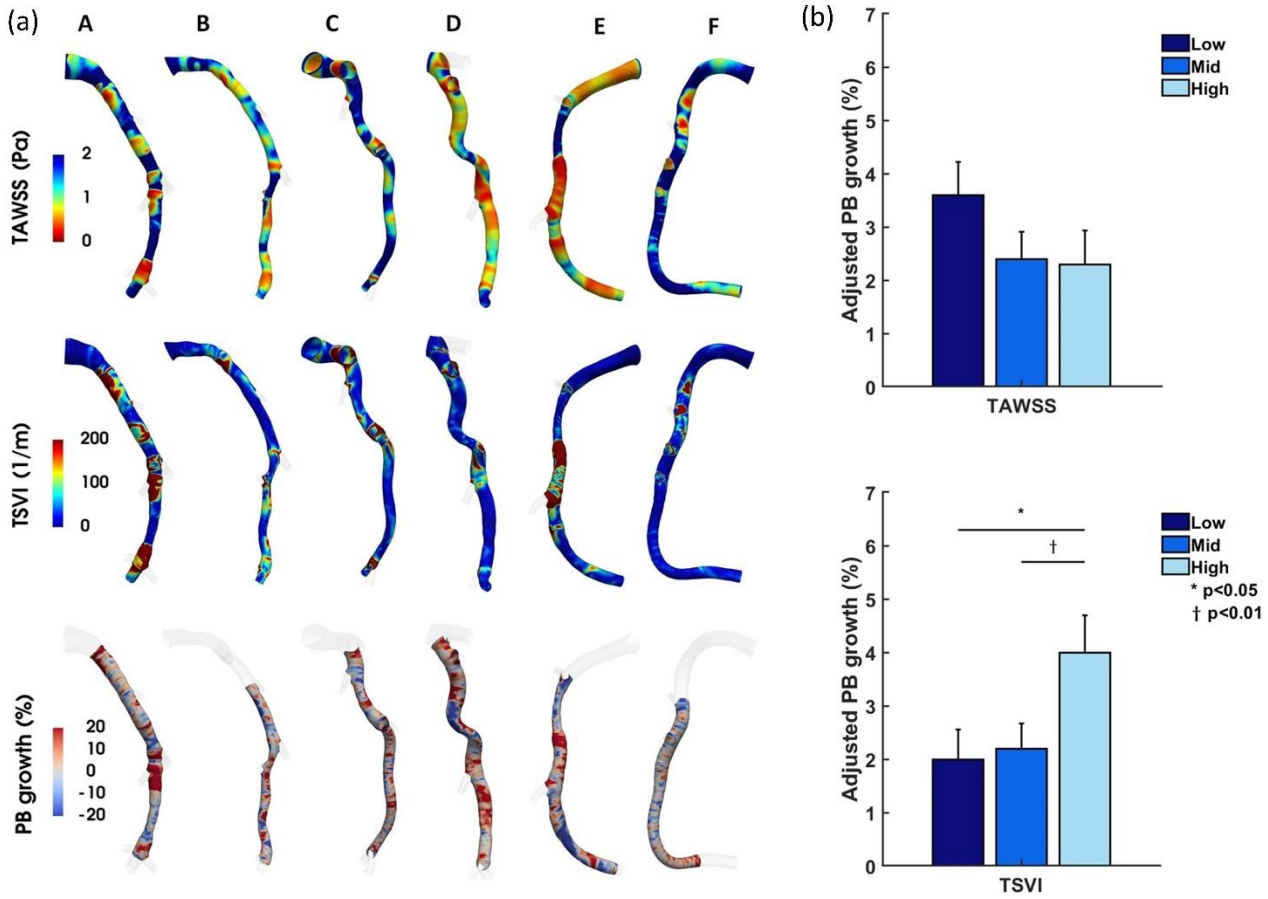

Figure 2. (a) Luminal distribution of TAWSS (top), TSVI (mid), and PB growth (bottom) for six explanatory coronary models. (b) TAWSS and TSVI vs. estimated PB growth (mean ± sem).

Conclusion

Overall, the findings of this study support the hypothesis that WSS is involved in human coronary atherosclerosis development at early stage. In detail, it emerges that luminal exposure to high TSVI is associated with PB growth, a hallmark of early atherosclerosis. A clear inverse trend emerges between PB growth and TAWSS. Physically, TSVI quantifies the variability of WSS contraction/expansion action on the endothelium, describing a different hemodynamic stimulus with respect to low TAWSS. This study confirms recent findings on TSVI as biomechanical marker of vascular disease, encouraging further clinical trials for a clinical translation of this concept.

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