Association between helical blood flow and atherosclerotic plaque progression in coronary arteries: an animal-specific study.

Giuseppe De Nisco[1], Ayla Hoogendoorn[2], Annette M. Kok[2], Claudio Chiastra[1], Diego Gallo[1], Umberto Morbiducci[1], Jolanda J. Wentzel[2]
[1]PoliTo[BIO]Med Lab, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy
E-mail: *giuseppe.denisco@polito.it, claudio.chiastra@polito.it, diego.gallo@polito.it, umberto.morbiducci@polito.it*

[2] Department of Biomedical Engineering, ErasmusMC, Rotterdam, The Netherlands
E-mail: *a.hoodendoorn@erasmusmc.nl, a.m.kok@erasmusmc.nl, j.wentzel@erasmusmc.nl*

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INTRODUCTION

Findings from recent studies suggested that helical flow (HF) (1) protects from atherosclerosis by suppressing flow disturbances in human arteries [1], and (2) is inversely associated with atherosclerosis at the early stage [2]. However, a gap in knowledge still exist on the significance of HF in coronary arteries, a prominent site of atherosclerotic plaque formation. Here we investigate the possible link between HF and disturbed shear, and HF and wall thickness (WT), in a representative sample of swine-specific computational models of coronary arteries.

MATERIALS AND METHODS

The three main coronary arteries, the left anterior descending (LAD), the left circumflex (LCX), and the right coronary artery (RCA) of 5 adult hypercholesterolemic pigs on a high fat diet were imaged by computed tomography (CT) angiography and intravascular ultrasound (IVUS) at two time points (baseline - after 3 months since start of the diet; T2 - after 9.4±1.9 months). The baseline geometry of the 15 imaged coronary arteries was reconstructed [3]. The finite volume method was used to numerically solve Navier-Stokes equations, by prescribing personalized boundary conditions derived from Doppler flow velocity measurements [4]. Three descriptors of low/oscillatory wall shear stress (WSS), i.e. time-averaged WSS (TAWSS), oscillatory shear index (OSI), and relative residence time (RRT) were computed. Additionally, WSS multidirectionality was further evaluated using the transverse WSS (transWSS), representing the time-averaged WSS component orthogonal to the cicle-averaged direction of WSS vector [5]. Objective thresholds for ‘disturbed flow’ were defined as the upper (lower) 33th percentile of pooled data for OSI, RRT, and transWSS (TAWSS). The percentage of luminal area exposed to ‘disturbed flow’ was quantified and labeled as TAWSS33, OSI66, RRT66, and transWSS66. Intravascular hemodynamics was investigated in terms of cycle-average helicity intensity (h_2), as proposed elsewhere [2]. Additionally, local normalized helicity (LNH) was used to visualize intravascular HF structures [1]. Wall thickness was evaluated by subtracting the distance from the lumen centre of the outer and inner (segmented) wall boundaries. The difference between T2 and baseline WT measurements at each sector was normalized to follow-up time (ΔWT/month). As for WT *vs.* HF analysis, each IVUS imaged arterial segment was divided into 3mm/45° sector. Helicity intensity was evaluated over the same sectors as WT, both in the whole luminal volume and in the near-wall region (outer 10% of the local radius), and h_2 data were divided into artery-specific tertiles (low, mid and high) to perform a statistical analysis

RESULTS

HF patterns visualization by cycle-average LNH isosurfaces revealed that all 15 coronary artery models present two distinguishable counter-rotating HF structures distributed all along the length of the artery, although with different intensity (Figure 1A). Baseline h_2 was associated with the percentage of surface area exposed to unfavourable shear conditions. In particular, h_2 was negatively associated (r = -0.93, $p < 0.01$) with TAWSS33 and RRT66 (i.e. lower helicity intensity implies larger lumen area exposed to low WSS and high RRT).

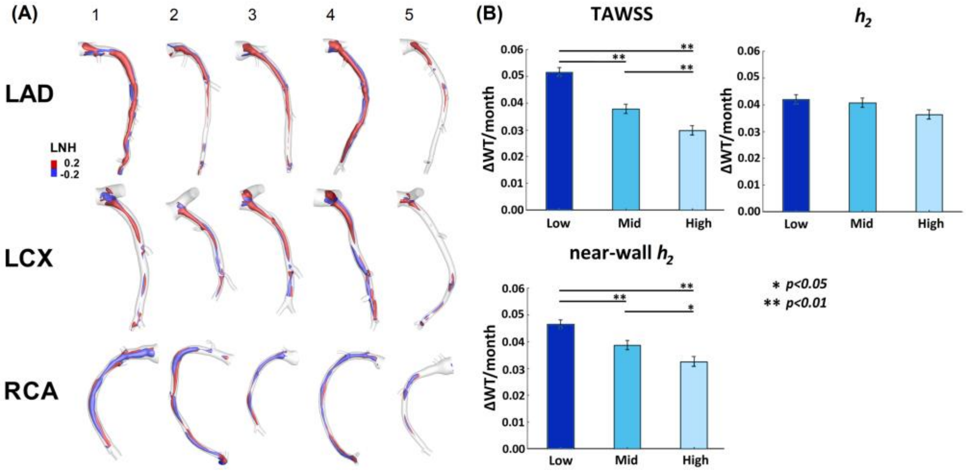

Figure 1. (A) Cycle-averaged LNH isosurfaces for the 15 investigated coronary arteries: right (red) and left-handed (blue) rotating helical structures; (B) TAWSS, h_2 and near-wall h_2 *vs*. estimated plaque growth.

From the analysis of WT, it emerged that a low plaque growth per month was associated with high baseline levels of TAWSS and near-wall h_2 (Figure 1B).

CONCLUSION

Results from this study suggest that: (1) counter-rotating HF patterns naturally develop in coronary arteries and are negatively associated with descriptors of disturbed shear stress, suggesting an atheroprotective role for HF in coronary arteries; (2) helicity intensity (h_2) is protective against WT and has a potential in predicting atherosclerotic plaque growth.

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