LOCAL HEMODYNAMICS OF PATIENT-SPECIFIC DISEASED FEMORAL ARTERIES: ROLE OF THE INFLOW BOUNDARY CONDITION

POLITECNICO MILANO 1863

Fondazione CARIPLO

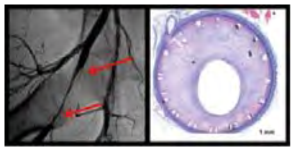
Monika Colombo[1], Marco Bologna[1], José F. Rodríguez Matas[1], Francesco Migliavacca[1], Marc Garbey[3,4], Scott Berceli[5,6], Claudio Chiastra[1]

1. LaBS, Dept. of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Milan, Italy
2. Dept. of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy
3. University of La Rochelle, LASIE UMR CNRS, La Rochelle, France
4. Houston Methodist Hospital Research Institute, Houston, TX, USA
5. Malcom Randall VAMC, Gainesville, FL, USA
6. Department of Surgery, University of Florida, Gainesville, FL, USA

E-mail contact:
monika.colombo@polimi.it

INTRODUCTION

In-stent restenosis is a major drawback of endovascular treatment of diseased **superficial femoral arteries** (**SFAs**), resulting in a stent failure rate of ~35% [1]. Among the different factors responsible for restenosis, the **abnormal hemodynamics** induced by stent presence has been recognized as an important contributor.



In this work, a computational model of **patient-specific** femoral artery reconstructed from computed tomography (CT) images was developed for the investigation of the local **hemodynamics**. Furthermore, the impact of the inlet boundary condition on the hemodynamic results was investigated.

Fig. 1 – Example of restenosis, causing the re-narrowing of the arterial lumen, at 1 year post-intervention follow-up.

MATERIALS AND METHODS

Computational framework

A general computational framework to analyze the local hemodynamics (Fig. 2) was developed to investigate diseased patient-specific SFAs. With the CT-based 3D reconstruction method, validated using 3D printed phantoms, arterial models were created and used to perform computational fluid dynamics (CFD) analyses.

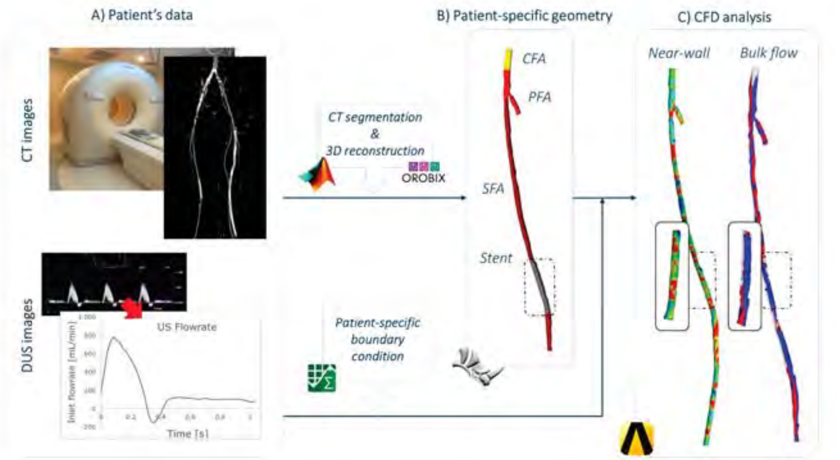


Fig. 2 – Framework for patient-specific CFD of femoral artery. In the pre-processing, the CT images are resized and prepared for the segmentation, which is carried out using user-defined thresholds.

Impact of boundary conditions

To evaluate the impact of the inlet boundary condition on the hemodynamic results, four CFD models of femoral arteries were compared (Fig. 3):

- '**SFA-Flat**': without bifurcation, inlet flat velocity profile and outlet zero pressure;
- '**SFA-Par**': without bifurcation, inlet parabolic velocity profile and outlet zero pressure;
- '**CFA-Flat**': model with common femoral artery (CFA) bifurcation, inlet flat velocity profile and outflow split;
- '**CFA-Par**': model with bifurcation, inlet parabolic velocity profile and outflow split.

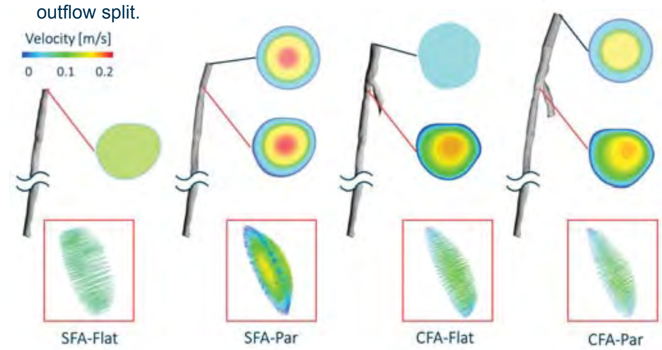


Fig. 3 – Velocity contour at inlet and SFA cross-sections, evaluated for the 4 scenarios. In the boxes, the vectors of velocity magnitude at SFA cross-section are shown.

RESULTS

Near-wall hemodynamics

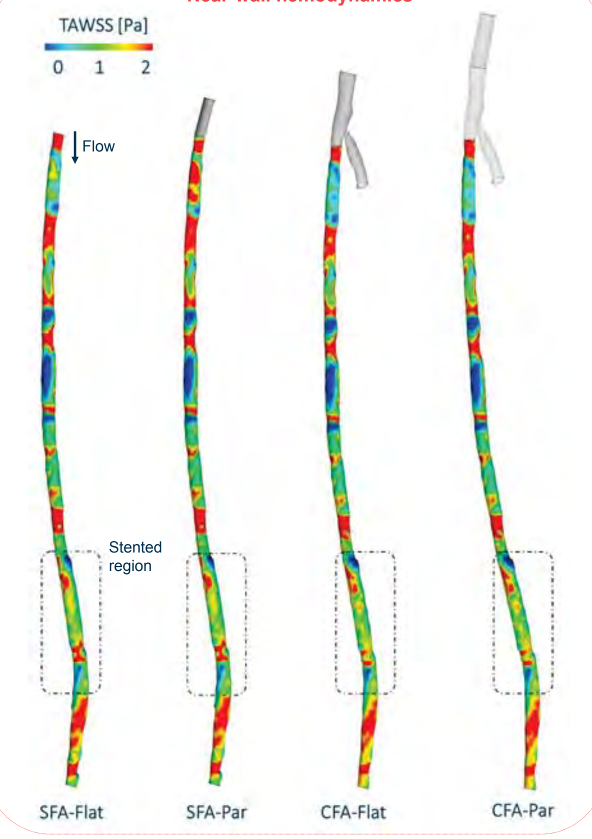


Fig. 4 – Near-wall hemodynamics in the four scenarios: contour maps of TAWSS..

The four CFD scenarios were compared in terms of **near wall hemodynamics** (time-averaged wall shear stress – TAWSS, Fig. 4) and **bulk hemodynamics** (local normalized helicity – LNH, Fig. 5). The first one shows the effect of the flowing blood along the vessel wall, while the second one shows the spiral flow patterns.

From a **qualitative** analysis, non-noticeable differences were found. However, a **quantitative** analysis with respect to the most **complex** model (i.e. 'CFA-Par') highlighted non-negligible differences both in near-wall and bulk hemodynamics in the **stented** region. In particular, while the difference of TAWSS was < 1% in each scenario, the difference to 'CFA-Par' of percentage area with TAWSS < 0.4 Pa was > 2%, except for the 'CFA-Flat' model.

Bulk hemodynamics

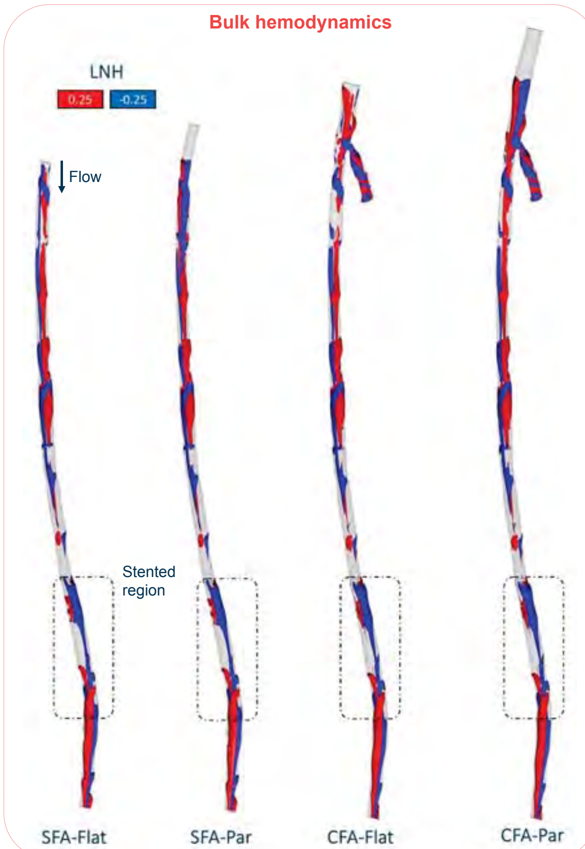


Fig. 5 – Bulk hemodynamics in the four scenarios: iso-surfaces of LNH at peak flow-rate time instant. Positive (red) and negative (blue) LNH values correspond to right-handed and left-handed rotating fluid structures along the main flow direction.

CONCLUSIONS

In the current work, reliable geometrical models of **patient-specific femoral arteries** were created from CT images with a validated reconstruction method. Numerical comparison of the results highlighted the difference in terms of local hemodynamics by moving from a **simpler** to a more **complex** CFD model. The inclusion of the upstream bifurcation with a parabolic velocity profile at the inlet guarantees more reliable patient-specific **CFD results**.

References: [1] Dick P et al. Catheter Cardiovasc Interv. 2009;74:1090–5.