XXIII International Conference on Mechanics in Medicine and Biology – ICMMB
Bruxelles, Belgium, September 11-13, 2024

Category: Oral presentation

Mechanical stress in coronary atherosclerotic plaques: Comparison of 2D *vs.* 3D computational strategies

Sara Zambon[1*], Aikaterini Tziotziou[2], Eline MJ Hartman[2], Claudio Chiastra[1], Joost Damen[2], Umberto Morbiducci[1], Jolanda J. Wentzel[2], Diego Gallo[1]

[1]Polito^{BIO}Med Lab, Politecnico di Torino, Turin, Italy;

[2] Cardiology Department, Erasmus MC, Rotterdam, The Netherlands;

[*]Corresponding author; e-mail address: sara.zambon@polito.it

Abstract

Background: Biomechanical factors play a fundamental role in the initiation and progression of coronary atherosclerotic plaques. Recent evidence demonstrated the association of high mechanical wall stress (MWS) with wall thickness progression in coronary wall plaque-free regions and reduction in lipid-rich necrotic core (LRNC) size in plaque regions [1]. Moreover, high MWS hot spot values have been suggested as potential trigger for plaque rupture [2]. However, most of the emerging findings rely on finite element (FE)-based 2D structural analyses, an approach that may oversimplify the 3D nature of the atherosclerotic arterial wall structure. Expanding the current approach, here we analyze the effect of 2D *vs.* 3D FE-based modelling of MWS in atherosclerotic coronary lesions with LRNC using patient-specific imaging data.

Methods: Three acute coronary syndrome patients, enrolled at the Erasmus MC (Rotterdam, NL), underwent invasive pressure measurement, computed tomography angiography (CTA), optical coherence tomography (OCT) and intravascular ultrasound (IVUS) imaging of a non-culprit coronary artery (two left anterior descending coronary artery, LAD1 and LAD2, and one right coronary artery, RCA) [1]. Combining co-registered IVUS and OCT frames, a total of 57 (2 containing LRNC), 29 (3 containing LRNC), and 37 (4 containing LRNC) 2D cross-sections were obtained for LAD1, LAD 2, and RCA, respectively. Lumen and external elastic lamina were segmented from IVUS images. The adventitia was assumed to have constant thickness [1]. The LRNC inner edge was segmented on OCT images, while the outer edge was reconstructed adopting a previously validated approach [3]. The 3D geometry was reconstructed combining IVUS lumen segmented contours and the vessel centerline extracted from CTA images. FE-based structural simulations were carried out in Abaqus/Standard (Dassault Systèmes), assuming intima and media, adventitia, and LRNC components as nonlinear hyperelastic materials [1]. The backward incremental method [4] was applied to obtain the initial diastolic stress distribution before prescribing the patient-specific systolic blood pressure. The 2D *vs.* 3D comparison was carried out in terms of von Mises stress (VMS) distribution and shortest distance along the lumen perimeter between the locations of 2D and 3D peak VMS values, expressed as fraction of the total lumen cross-sectional perimeter.

Results: Comparable MWS distributions were obtained in 2D *vs.* 3D simulations. In general, 2D simulations overestimated the maximum MWS values obtained from 3D simulations at the corresponding slice location. On average, peak lumen VMS absolute differences were 56.6 [interquartile range, IQR: 27.8-110.2] kPa, 91.0 [49.3-204.6] kPa, 43.7 [23.6-138.5] kPa for LAD1, LAD2 and RCA, respectively. The average distance between 2D and 3D peak lumen MVS values was 2.2 [0.8-11.2] %, 1.9 [0.8-4.4] %, 2.2 [1.1-20.8] % of the total lumen cross-sectional perimeter for cases LAD1, LAD2, and RCA, respectively, but in half of the investigated cross-sections the distance was less than 2%. Considering sections presenting with LRNC, mean absolute differences of 2D *vs.* 3D peak VMS values on the LRNC border were 351.6±142.3 kPa (LAD1), 284.8±168.8 kPa (LAD2), and 126.0±75.2 kPa (RCA). Distributions of MWS in the cap region were qualitatively comparable, with mean absolute differences in peak VMS of 345.4±142.1 kPa (LAD1), 258.7±176.6 kPa (LAD2), and 32.1±24.2 kPa (RCA).

Conclusions: The biomechanical assessment of the MWS in coronary plaques based on 2D *vs.* 3D FE simulations highlighted that the 2D strategy could overestimate peak VMS at both the cap and the lumen, although adequately capturing the location of peak VMS in most of the cross-sections. Future advancements will include the implementation of fluid-structure interaction to consider the synergistic action between MWS and hemodynamic stresses on disease initiation and evolution.

[1] Tziotziou A, et al., *Atherosclerosis*, 387:117387, 2023. [2] Pedrigi R, et al., *Arterioscler Thromb Vasc Biol*, 34(10):2224-31, 2014. [3] Kok A, et al., *Biomed Eng Online*, 15:48, 2016. [4] Akyildiz A, et al., *Comput Methods Biomech Biomed Engin*, 19(7):771-9, 2016.

Keywords: Coronary atherosclerosis, Arterial wall stresses, Finite element analysis.