A fully parameterized 3D computational model of atherosclerotic arteries to simulate balloon angioplasty

Sanne M. B. Kwakman*†[1], Michele Terzano[1], Malte Rolf-Pissarczyk[1], and Gerhard A. Holzapfel[1,2]

[1]Technische Universität Graz – Austria
[2]Norwegian University of Science and Technology (NTNU) – Norway

Abstract

Atherosclerosis is one of the most common cardiovascular diseases, characterized by the gradual accumulation of atherosclerotic plaques in the arteries. This process begins with the infiltration of smooth muscle cells and leukocytes into the intima and contributes to the formation of a lipid-rich core separated from the vessel lumen by a fibrous cap. Balloon angioplasty is a common treatment to restore normal blood flow in coronary or peripheral arteries affected by atherosclerosis. A critical event during balloon deployment is a rupture at the plaque shoulder or at the top of the fibrous cap, depending on the oversizing of the balloon (1,2). The mechanical load that leads to rupture is strongly influenced by various factors, such as the geometrical extension of the fibrous cap, the lipid pool and calcifications. Patient-specific models provide valuable insights; however, they are often limited in their ability to capture the wide variability in morphological features that influence the outcomes of balloon angioplasty. To fill this gap, we developed an efficient computational model of an atherosclerotic artery that includes various geometrical features: a healthy three-layered structure, the fibrotic media, the fibrous cap, the lipid pool, and calcifications of different sizes and locations. This three-dimensional (3D) parameterized computational model is designed to be easily adjustable to tissue- and region-specific mechanical properties to mimic various vessels such as coronary, iliac, and femoral arteries, as well as various stages of atherosclerosis. In the current study, we employed experimental data from several iliac arteries (3) and fitted these data to the anisotropic Gasser-Ogden-Holzapfel model (4). Numerous simulations of balloon angioplasty have been performed in which the morphology of the atherosclerotic artery was altered by varying the dimensions of the lipid pool, calcifications, and fibrous cap. The aim of these simulations is to gain deeper insights into the possible causes of damage and plaque rupture during balloon angioplasty under different morphological conditions.

References:

(1) Falk, E., 2006. Pathogenesis of atherosclerosis. *Journal of the American College of cardiology*, 47(8S), C7-C12.

(2) Holzapfel, G.A., Sommer, G., and Regitnig, P., 2004. Anisotropic mechanical properties of tissue components in human atherosclerotic plaques. *Journal of Biomechanical Engineering*, 126(5), 657-665.

*Speaker

†Corresponding author: sanne.kwakman@tugraz.at

(3) Holzapfel, G.A., Schulze-Bauer, C.A.J., and Stadler M., 2000. Mechanics of angioplasty: Wall, balloon and stent. In *ASME International Mechanical Engineering Congress and Exposition* (Vol. 19173, pp. 141-156). American Society of Mechanical Engineers.
(4) Gasser, T.C., Ogden, R.W., and Holzapfel, G.A., 2006. Hyperelastic modelling of arterial layers with distributed collagen fibre orientations. *Journal of the Royal Society Interface*, 3(6), 15-35.