The Effects of Leg Flexion on the Hemodynamic and Structural Behaviors of the Femoro-popliteal Arterial Tract

The long-term outcomes of endovascular therapy in patients with Peripheral Arterial Disease (PAD) show high restenosis rates, which may be explained by the demanding mechanical environment related to leg movements. Stents that are implanted towards the popliteal artery (PA) can lead to unphysiological arterial deformations during leg flexion, such as arterial kinking. Although the presence of these extreme deformations have been qualitatively linked with restenosis, their effects on either the flow behaviors or structural stress distributions of the PA have only been investigated using idealized arterial geometries and simple material models. Therefore, the objective of this work was to perform Computational Fluid Dynamics (CFD) and Finite Element (FE) analyses on patient-specific models of arteries in straight and flexed positions, in order to investigate the changes in hemodynamic and structural properties of the PAs with leg flexion.

3D patient-specific arterial geometries in straight and flexed positions (hip/knee flexion of 20°/70°) were reconstructed from 2D angiographic images of 5 patients with PAD. The arteries were assumed to have a constant lumen diameter of 5 mm and a wall thickness of 0.5 mm. The stenoses/stents were represented by increasing the stiffness of the artery wall. The FE analyses were performed with Abaqus/Explicit. The arteries were modeled as isotropic, hyperelastic (polynomial). The flexion was simulated by calculating the displacement between the two configurations and applying them to a rigid tool around the straight artery. Thus, there was no risk of over-constraining the artery. The CFD analyses were conducted with Abaqus/CFD. Blood was modeled as a Newtonian fluid and the flow was simulated by applying an MRI measured volumetric flow rate at the inlet of the artery. A zero pressure condition was applied at the outlet and a no-slip condition was prescribed for the artery wall.

The FE analyses showed localized stress distributions distal and proximal to the heavily curved regions; while the CFD analyses resulted in areas of low Wall Shear Stress within the kinked segments. As such, both analyses suggest that arterial kinking due to leg flexion would adversely affect the structural and hemodynamic properties of the arteries and may trigger arterial remodeling.