Introduction

Percutaneous intervention through stent deployment of the left main (LM) coronary bifurcation has difficult clinical aspects. Currently, new stenting techniques are under investigation to improve clinical outcomes. In this study, numerical simulations are performed to compare the biomechanical influence of a standard technique (i.e. simultaneous kissing stenting - SKS) with a new one (i.e. new simultaneous kissing stenting – NSKS). A sequential numerical strategy is implemented. In particular, the deformed geometry of the artery, obtained from structural analysis of stent deployment, is used to extract the fluid domain for subsequent fluid dynamics simulations.

Materials and methods

Structural simulations

A three-layered hyperelastic idealized coronary bifurcation was created with an angle of 60° and internal diameters based on the mean values of a human LM (Fig. 1). Elastic angioplasty balloons were built to simulate the stent expansion. Stent geometries resembled the Resolute Integrity stent (Medtronic Inc., USA) with a cobalt-chromium alloy material. The simulations of the SKS and NSKS stenting techniques (Fig. 2) were performed using ABAQUS/explicit (Dassault Systems Simulia Corp) as quasi-static processes.

Fluid dynamic simulations

The fluid domains were created starting from the final geometrical configurations of the structural simulations (Fig. 3a). A tetrahedral mesh was computed with a refinement of the elements at the stent struts and at stented bifurcation region (Fig. 3b). Transient simulations were carried out using ANSYS Fluent (ANSYS, Inc., USA). Physiological boundary conditions were applied at the inlet and the outlets (Fig. 4).

Results

Structural simulations

Geometrical configurations after stenting with SKS and NSKS techniques were compared by evaluating the position of the stent struts and the wall stress. In particular, malapposition (i.e. struts not in contact with the lumen surface) was higher in SKS than NSKS (Fig. 5), due to the long metallic carina in the LM branch. The evaluation of the wall stress gave a measure of the damage on the inner surface of bifurcation. Contour maps of maximum principal stress after stent recoil showed that the area with high stress was higher in the NSKS than SKS (Fig. 6), due to the overexpansion of the proximal main branch stent.

Fluid dynamic simulations

The presence of a long metallic carina in the SKS model caused flow separation in the proximal main branch with the creation of two inner channels with an increase of the flow velocity (Fig. 7-left). Recirculation regions are also present in the SKS model. In both cases there blood stagnation areas were located near metallic struts. In particular, in NSKS model the LM stent caused a wider stagnation region close to the LM wall (Fig. 7b). Hemodynamic forces on the inner surface of the bifurcations were evaluated by calculating time-averaged wall shear stress (TAWSS). Results showed a larger area with low TAWSS in NSKS than SKS (Fig. 8), which is caused by the presence of fewer malaposed struts (especially in the LM branch).

Conclusions

In this study, structural and fluid dynamic models were implemented to compare two different stenting techniques in an idealized model of the LM bifurcation. NSKS resulted in better outcomes in terms of malapposition than SKS, with a better coverage of each branches. This aspect induced a better velocity distribution, smaller blood stagnation areas and no blood recirculation. The main disadvantages of the NSKS were the larger area with higher wall stress and the larger area with low TAWSS at the lumen surface.