STENTING IN CORONARY BIFURCATIONS: IMAGE-BASED STRUCTURAL AND HEMODYNAMIC SIMULATIONS OF REAL CLINICAL CASES

POLITECNICO DI MILANO

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Introduction

The majority of current **numerical models** simulates typical stenting procedures in idealized geometries. Consequently, such models can only provide standard guidelines without specific indications for the optimal interventional planning of each patient. The aim of this work is the implementation of **patient-specific** structural and fluid dynamic models that use **image-based reconstructions** of atherosclerotic bifurcations. Particular attention is paid to the plaque identification and the insertion of stents by simulating their advancement in the artery. Two clinical cases involving a coronary bifurcations of the left anterior descending artery have been investigated.

Materials and Methods

Image-based 3D atherosclerotic coronary bifurcation

The **pre-stenting** internal wall surfaces are generated from a combination of conventional coronary angiography and computed tomography angiography (Fig. 1, left) [1]. These surfaces have been used to construct **3D solid models** of the two coronary bifurcations investigated (Fig. 1, right). External wall surfaces were created choosing the diameters in order to respect physiological values of the internal diameter and wall thickness of the arterial branches investigated (LAD). The geometry is discretized using a fully hexahedral mesh (Fig. 2a). Finally, **atherosclerotic plaques** were identified based on the distance between each node and the centerline of the external wall surface (Fig. 2b).

Stent models and preliminary structural analyses

The two clinical cases simulated involve two coronary stents: the **Endeavor Resolute** by Medtronic and the **Multilink Vision** by Abbott Vascular. Their 3D CAD models and discretizations are shown in Fig. 3. To correctly position the stents in the complex arterial geometries, **crimping** and **advancement** (Fig. 4) of the devices are simulated using an internal guide following the vessel centerline.

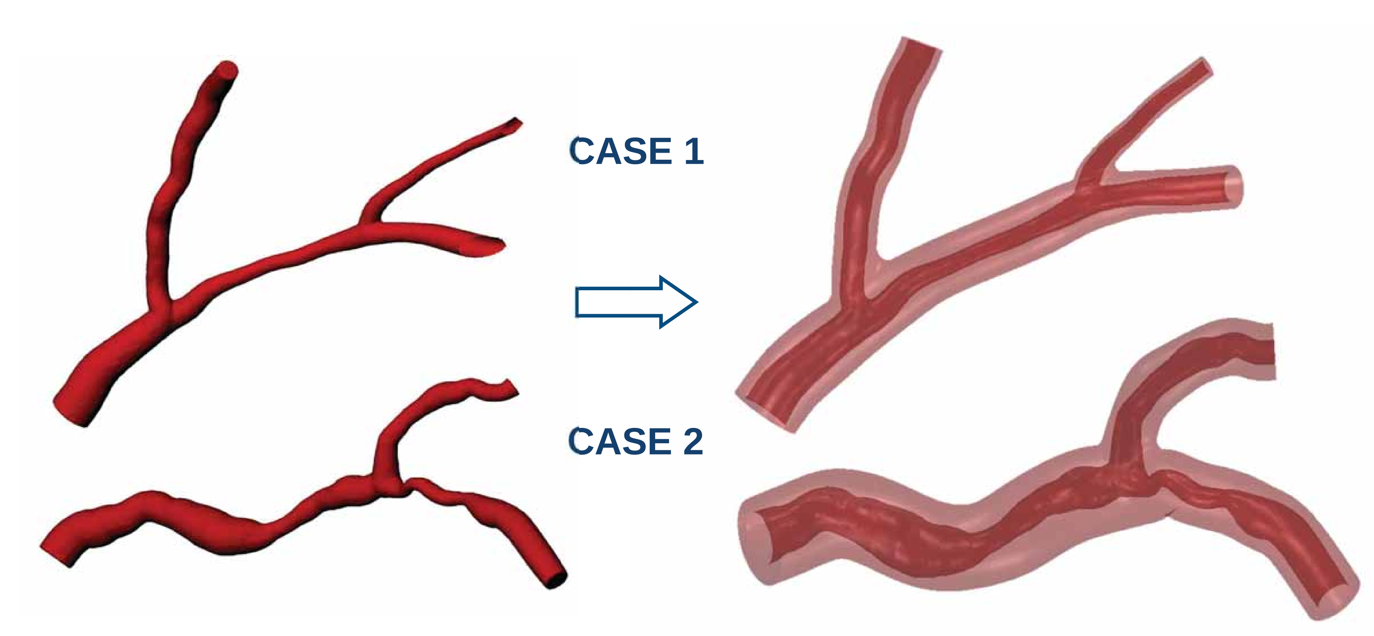

Figure 1. Creation of the 3D geometries (right) of the two left anterior descending coronary arteries investigated. On the left, image-based reconstructions of the pre-stenting internal wall of the vessel created using a combination of conventional angiography and computed tomography.

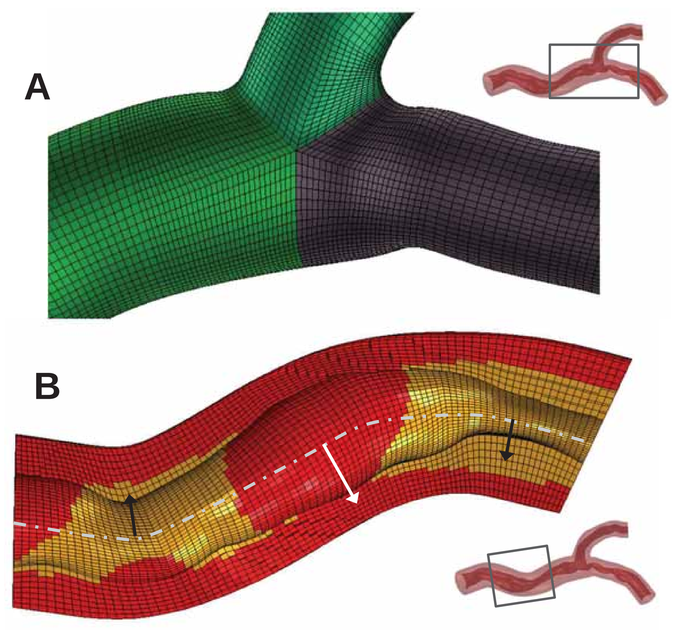

Figure 2. A) Hexahedral mesh of the geometry of case 2. B) Plaque identification is based on the comparison between a typical radius of a healthy LAD and the distance of each node to the centerline. If the distance is lower than the radius (black arrows), the node will be part of the plaque; otherwise (white arrow), it will be part of the arterial wall.

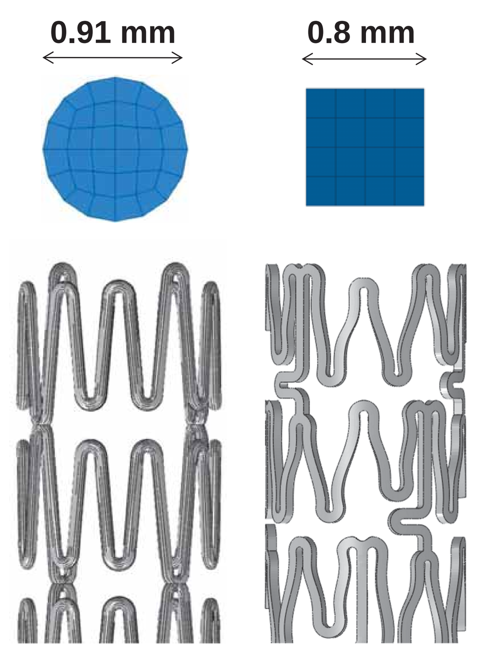

Figure 3. 3D models resembling the two stents used: Endeavor resolute (left) and Multilink Vision (right). Dimensions and discretization of their sections are shown, too.

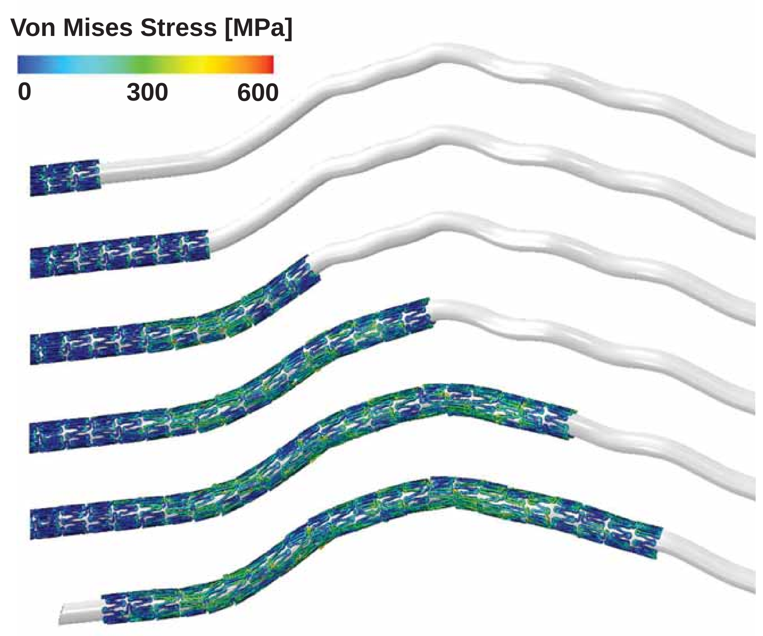

Figure 4. Structural simulation of the stent advancement along a cylindrical guide constructed following the post-angioplasty vessel centerline. Final stresses and geometrical configurations have been used as a starting point for the final simulations.

Results

Simulated procedures

Numerical simulations of stent deployment were performed using a commercial code as quasi-static processes. Two simulations are carried out following the **clinical indications** provided by the physician who performed the treatments at the Hospital Doctor Peset in Valencia (Fig. 5 and 6). Initial stressed configurations of the devices are imported from the preliminary analyses to guarantee a correct positioning and accurate mechanical results. More information on the materials and modeling details can be found in [2] and [3].

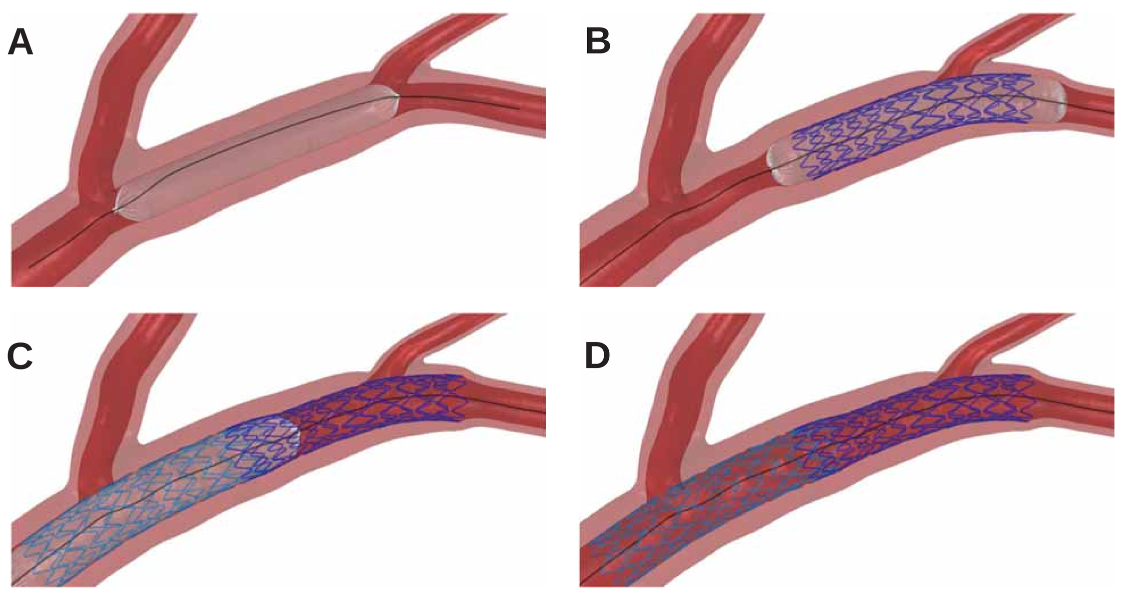

Figure 5. - Steps of the procedure performed in Case 1: A) pre-dilatation with a semi-compliant 15 mm long angioplasty balloon with a diameter of 2.5 mm; B) deployment of the 15 mm long Endeavor stent across the distal bifurcation inflating a 2.75 mm balloon at 12 atm; C) positioning and dilatation at 14 atm of the second 15 mm long Endeavor stent across the proximal bifurcation with a 3.0 mm balloon; D) final configuration after recoil.

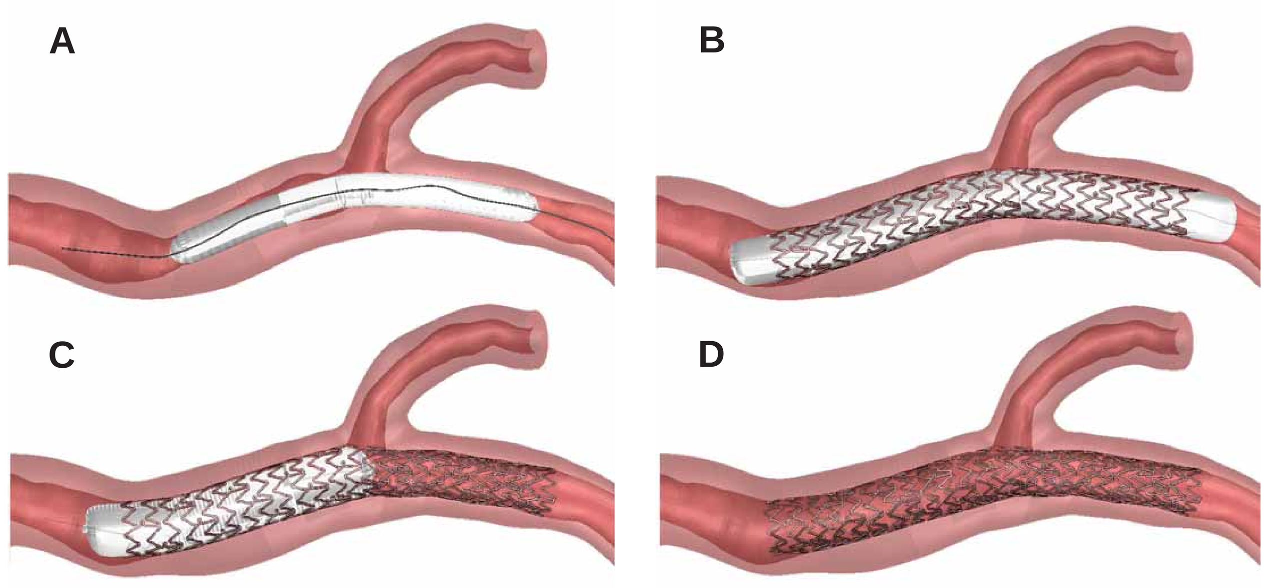

Figure 6. - Steps of the technique performed for Case 2: A) pre-dilatation performed with a 2.0 mm balloon expanded at 12 atm; B) a 28 mm long Multilink Vision stent with nominal diameter of 3 mm is deployed at 14 atm across the bifurcation between the LAD and its first diagonal branch; C) the procedure is ended with a post-dilatation at 18 atm in the proximal part of the main branch using a 3 mm balloon; D) final configuration after recoil.

Fluid dynamic simulations

The final geometrical configurations obtained are then used to perform steady fluid dynamic analyses [5]. Preliminary results (Fig. 10) highlight the criticism of the overlapping region.

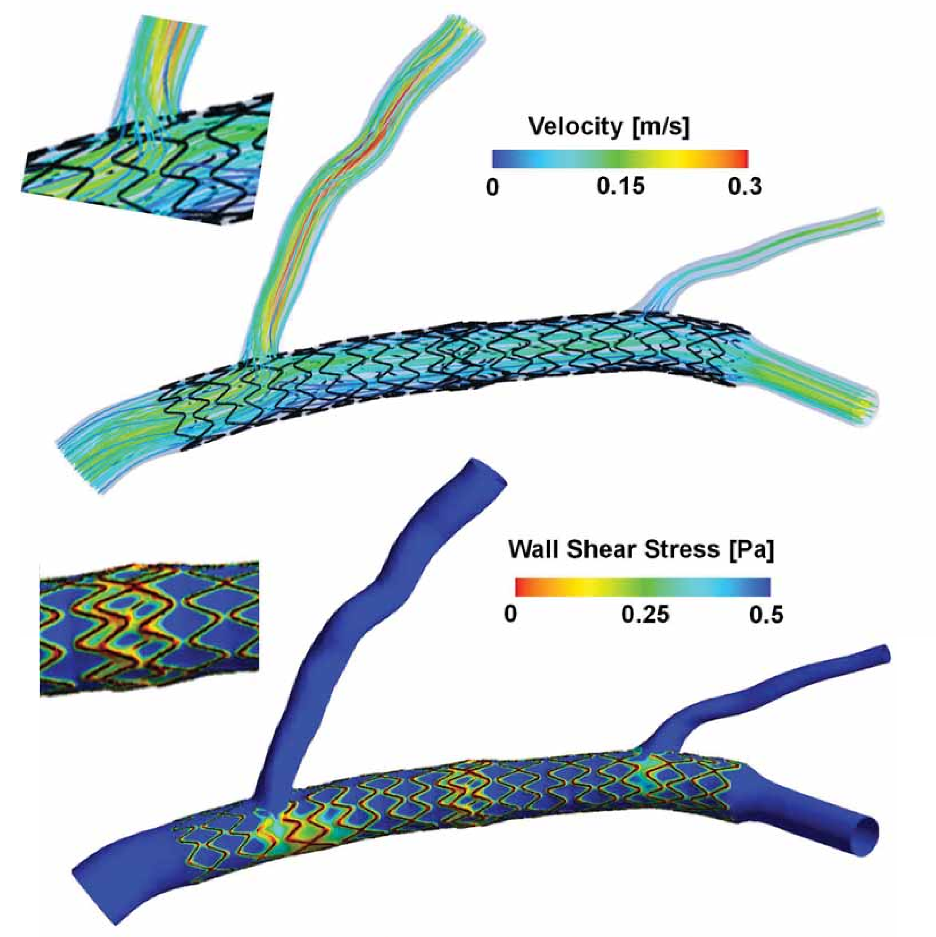

Figure 10. Velocity field (top) and wall shear stress magnitude (bottom) contour maps for a steady state simulation. Preliminary results prove that the overlapping area and the walls opposite to the bifurcations are affected by wall shear stresses lower than 0.5 Pa that is a critical value.

Biomechanical analysis: overlapping stents and straightening of the artery

Main biomechanical results are shown in Figs. 7, 8 and 9 in terms of stresses in the arterial walls, stresses in the stents and final geometrical configurations. **Overlapping of stents** is proved to be a critical area due to higher stresses and metal-to-artery ratios. Moreover, in both cases, a **straightening** of the artery is found at the end of the procedure, in accordance to *in vivo* measurements found in literature.

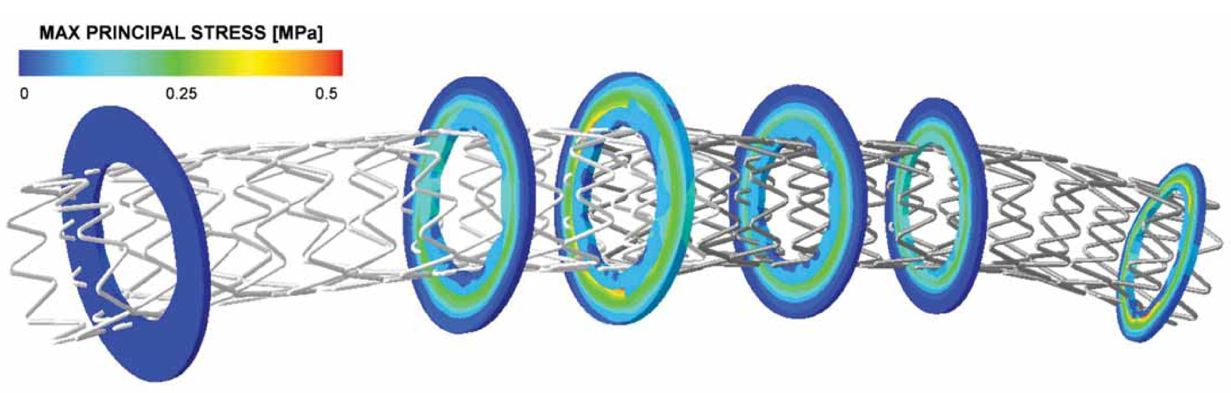

Figure 7. Maximum principal stresses contour maps of several sections along the main branch of the coronary tree investigated in Case 1. Results are taken at the end of the whole procedure. Absence of plaque and minimal expansion of the artery results in very low stresses in the proximal area (left) while higher stress values can be found in the distal part of the main branch and, particularly, in the overlapping area.

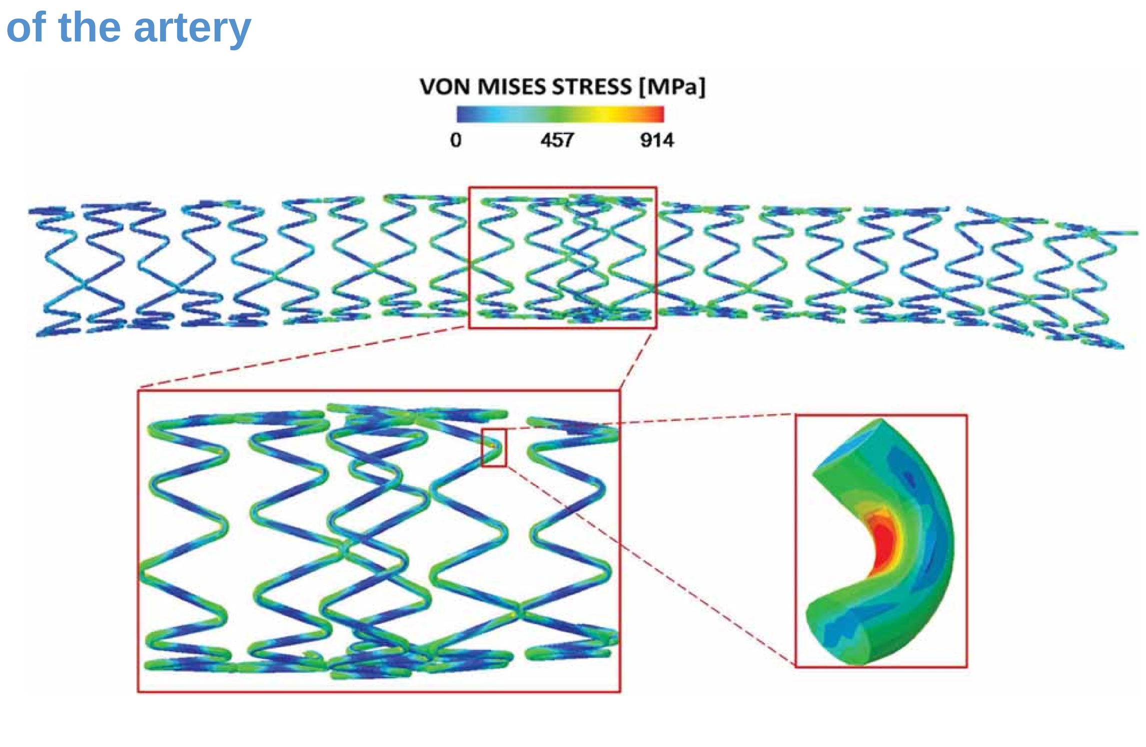

Figure 8. Von Mises stresses contour maps of the devices at the end of the procedure simulated in Case 1. Higher stresses are found in the struts of the stent close to the overlapping area. Expansion with a 3.0 mm balloon of the second stent results in an overexpansion of the first device that was deployed with a 2.5 mm balloon. The close-ups highlight the overlapping area and the most stressed strut.

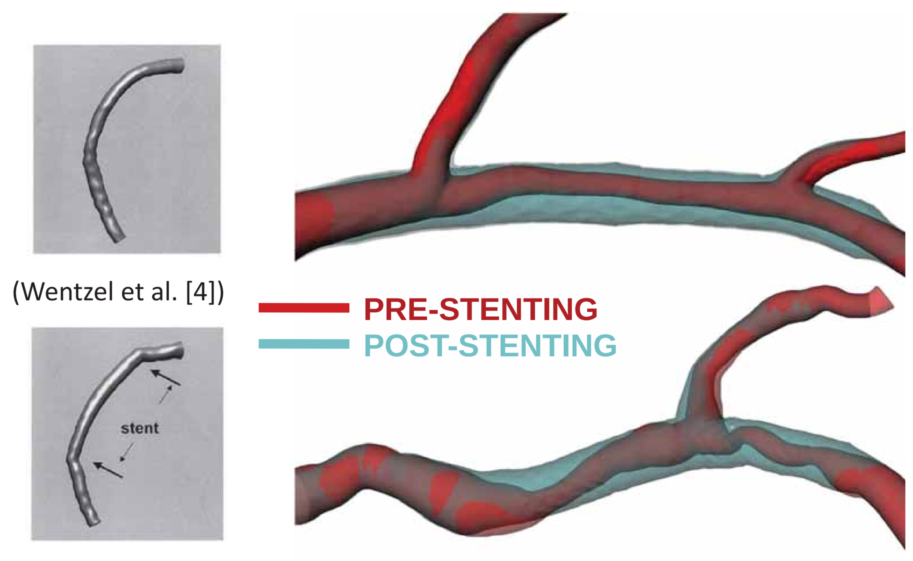

Figure 9. Red and light blue shapes correspond to the pre-stenting surface and the post-stenting geometrical configuration obtained with numerical simulation. Straightening of the arterial wall is found in both cases. This occurrence is in accordance to the cited publication where stented arteries are reconstructed using a combination of angiography and IVUS.

Conclusions

This work shows the feasibility of implementing a **patient-specific** virtual model replicating actual clinical cases. Standard medical images (CCA and CTA) were used to create the 3D pre-stenting geometry and the intervention was simulated following the clinical indications provided. Moreover, simulations of crimping and insertion were necessary to find the correct positioning of the devices in complex image-based geometries. From a biomechanical point of view, **overlapping of stents** has been recognized as a critical occurrence due to modified hemodynamic and structural variables both in the artery and the devices.

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