INTRODUCTION
Heart valve failure represents a considerable contribute to cardiovascular disease (CVD) which is the leading cause of death in Western countries [1]. Until recently, such a severe pathology has been treated adopting open-heart surgery techniques and cardiopulmonary bypass. However, over the last decade, minimally-invasive procedures have been developed to avoid large risks associated with conventional open-chest valve replacement techniques. For this purpose, percutaneous valves are adopted to restore valve functionality: a heart valve, sewn inside a stent, is crimped and properly placed in the patient’s heart by means of a catheter. Such a recent and innovative procedure represents an optimal field in order to investigation through virtual computer-based simulations: nowadays, in fact, computational engineering is widely used to deepen many problems belonging to the biomedical field of cardiovascular mechanics [2,3] and, in particular, minimally-invasive procedures [4,5]. In this study we focus on the Edwards SAPIEN trans-catheter aortic valve and we reproduce its implantation by means of computational tools. In particular, Finite Element Analysis (FEA) is performed to simulate the surgical procedure moving from a patient-specific aortic root model obtained by processing medical images.

METHODS
The framework of our study may be resumed by three main steps: (i) creation of the Edwards SAPIEN stent model; (ii) coupling of stent and valve leaflets; (iii) simulation of the deployment of the percutaneous valve under investigation into a patient-specific aortic root model.

Step 1: a straight model of the Edwards SAPIEN stent is created using Rhinoceros v.4.0 (Figure 1a) and then imported in Abaqus (v. 6.10, Dassult Systèmes, Providence, RI) and meshed with C3D8R hexahedral elements. A linear isotropic material (E = 206000 MPa; v = 0.3) is considered to reproduce the material behavior. Simulations of both the crimping and re-enlargement procedure are performed to reproduce the realistic behavior of the stent.

Step 2: the geometrical model of the trileaflet valve is realized within Abaqus by means of a lofting procedure and properly linked with the stent model. A hyperelastic Mooney-Rivlin material model (C_{10} = 0.5516 MPa, C_{01} = 0.1379 MPa, density = 1000 kg/dm^3)[6] is taken into consideration for the valve. Membrane elements, M3D4R, are adopted for the mesh.

Step 3: a patient-specific geometrical model of the aortic root is obtained directly from CT-A images. The stent is crimped and re-enlarged so that expands against the aortic root walls. Then, the comissures of the prosthetic valve are mapped onto the stent and, finally, the diastolic phase is simulated applying an 80 mmHg uniform pressure on the leaflets to evaluate the post-operative performance.

RESULTS AND DISCUSSION
The implant of trans-catheter percutaneous valves is a relatively recent surgical technique avoiding open-heart surgery and cardiopulmonary bypass and FEA represents a powerful tool to deepen the post-operative behavior and performance of such innovative cardiovascular devices. In this work we firstly simulate the crimping (see Figure 1b) and deployment of a realistic geometry of the Edwards SAPIEN stent. Secondly, we couple the valve model to the stent to reproduce the diastolic closure of the prosthetic device highlighting the stress/strain patterns on both leaflets and stent structure (Figure 2).

These two steps, in addition to the creation of a patient-specific aortic root model based on CT-A scan (Figure 3), represent the ingredients to simulate the surgical procedure of
the Edwards SAPIEN prosthesis implant in a patient-specific aortic morphology. Up to now, this final step is a development in progress.

Figure 3: a patient-specific aortic root geometry is obtained by processing CT-A images.

CONCLUSIONS
Besides the intrinsic limitation related to the complex system under investigation, we conclude that the proposed methodology offers a useful tool to evaluate the Edwards SAPIEN valve implant aiming at anticipating surgical operation outcomes.

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