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HOMOGENIZATION OF A NITINOL STENT-GRAFT TO SIMULATE ITS DEPLOYMENT IN AN ABDOMINAL AORTIC ANEURYSM

C. Dupont (1,2), A. Bel-Brunon (1), A. Combescure (1)

1. LaMCoS (CNRS UMR5259), INSA-Lyon, 18-20 rue des sciences, 69100 Villeurbanne, France;
2. INSAVALOR, 66 Boulevard Neils Bohr, 69100 Villeurbanne, France

Introduction

The endovascular aneurysms repair is a technique used to avoid the rupture of abdominal aortic aneurysms. During the surgery, the vascular structure undergoes deformations due to the insertion of guidewires through femoral arteries [1] and the deployment of stent-graft in the aneurysm sac. Nevertheless, surgeons rarely take into account these deformations to choose the stent-graft during the preoperative planning phase and it can lead to some complications. Finite element simulations could help them to choose the appropriate stent-graft by predicting these deformations.

A stent-graft is composed of a textile, called graft, and several Nitinol stents, typically with a sinusoidal shape. The computational cost of the simulation of its deployment is very large if a realistic description of its geometry is used [2]. Therefore such a simulate cannot be proposed to surgeons so far.

Our objective is to develop a new model of the stent-graft, using a homogenization process to reduce the computational cost of the deployment simulation.

Methods

The realistic reference model for the stent-graft is composed of shell elements to represent the graft and beam elements for the stent [3]. The homogenization process consists in developing a homogeneous model that generates the same strain energy for a given external loading than the reference model. The stent geometry can be approximated by two periodic segments, called stiffeners, oriented with an angle $+\alpha$ (or $-\alpha$) with the vertical axis, and junctions between two stiffeners.

The homogenized model is a cylinder with the same dimensions as the reference model and meshed with shell elements, which satisfy the Kirschoff-Love assumption (no transverse shear). The stent geometry is "virtually" represented on the cylinder to take into account its contribution to the overall behavior of the stent-graft. Four types of elements are therefore considered: elements with graft only, elements reinforced by a stiffener tilted of $+\alpha$ (or $-\alpha$), elements reinforced by a junction. The behavior matrix of each element equals to the one of the graft, modelled as an orthotropic material, and the behavior matrix of the stiffeners (or the junctions) can be added according to the element type. These two behavior matrices are computed respectively using the theory of stiffened shells [4] and the theory of curved beams.

Results

We consider only a section of a stent-graft, composed of a stent with 8 patterns. This section is subjected to 4 mechanical tests: traction, internal pressure, pinching and bending. We show that the error on the strain energy between the two models decreases, when the mesh size h decreases. For $h = 1$, the maximum error equals 20%, regardless the mechanical test. For a given mesh size, we consider a section of a stent-graft with 6 and 12 patterns. The error remains inferior to 30%.

We compare also the computational cost of the reference and of the homogenized model for a given mechanical test and a given mesh size. For a section of stent-graft with 8 patterns, we gain 40% in computational cost for $h = 1$. The decrease of the computational cost increases when the mesh size decreases and when the number of patterns increases.

Discussion

In the reference model, when submitted to an external loading, the graft wrinkles, so most of the total strain energy is contained in the graft deformation. The only way to form wrinkles at the surface of a homogenized model would be to consider variable mechanical properties along the circumference.

Our homogenization process gives promising results. Even if we commit an error of about 30% on the strain energy with the homogenized model, this error is acceptable for the simulation of the deployment of a stent-graft by surgeons. Besides it is directly applicable to different stent-graft geometries; accounting for the various geometries available on the market is therefore straightforward.

The other important point for surgeons is to perform the simulation rapidly. We show that our homogenization process allows to reduce significantly the computational cost for a section of stent-graft.

References

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