TOPOLOGY OPTIMIZATION FOR THE DESIGN OF NOVEL FEMORAL ARTERY STENTS

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Introduction

Self-expandable femoral stents are employed in diseased femoropopliteal arteries to provide mural support and prevent vessel obstruction after intervention [1]. The state-of-the-art in femoral stents design is represented by contributions that rely on minimum modifications of a limited number of stent geometries. This results in high costs due to the conventional trial-and-error design pipeline. In order to overcome the limitations of such approaches, we propose a novel computational framework for designing from scratch innovative self-expandable femoral stents by resorting to mathematically sound optimization techniques.

Methods

A stent can be considered as a hollow cylindrical device whose exterior surface is generated through the repetition of a 2D unit cell. Stents typically present differences in such a unitary geometry, which, in turn, characterizes the devices with diverse physical properties.

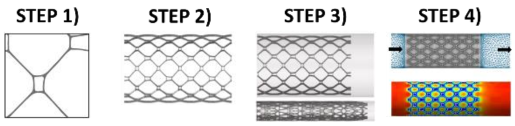

Figure 1: Stent design workflow.

The workflow in Fig. 1 follows 4 steps, namely:

1) the use of an *ad hoc* inverse homogenization topology optimization enhanced by an anisotropic mesh adaptation procedure [2]. This phase drives the design of customized 2D unit cells that retain some desired mechanical properties, while imposing the minimization of the contact area between the stent and the vessel;
2) the generation of a 3D stent geometry starting from the optimized 2D unit cell;
3) the evaluation of structural mechanics performance of the new stent in terms of peak maximum principal strain, radial force, foreshortening and crimpability into the catheter [3];
4) the assessment of the stent hemodynamics performance, by quantifying the blood flow disturbances induced by the stent inside the vessel in terms of Time-Averaged Wall Shear Stress and Topological Shear Variation Index [3].

Results

The design workflow is tested onto five proof-of-concept stent designs. The obtained layouts in Fig. 1 are characterized by high heterogeneity in the topology of the unit cells and differ from the state-of-the-art shapes employed in stenting clinical practice.

Figure 2: Optimized unit cells for stent design.

All the generated stents feature a desirable low contact area between stent and vessel, and are characterized by diverse structural and fluid dynamics properties.

Discussion

By a critical examination of the results, we conclude that the new computational workflow is disruptive, cost- and time-effective and capable of generating novel and functional stent designs. In more detail, the finite element analyses suggest that only two designs meet the minimum requirements for usability in terms of device crimpability into the catheter, although they differ in terms of mechanical and fluid dynamics features. In particular, the first design (see Fig. 2, left) exhibits: a low value of the peak maximum principal strain at the catheter diameter, corresponding to high safety in terms of structural integrity; high radial force; an adequate foreshortening at the implantation diameter. Conversely, the fluid dynamics simulations highlight that the last design (see Fig. 2, right) is subject to a low risk of in-stent restenosis. As a consequence, these two stents turn out to be promising, yet some further explorations are needed in order to determine the best candidate. With this regard, it is possible to pave the way to future enhancements, such as the inclusion of structural and fluid dynamics criteria directly in the design step 1), the introduction of manufacturability constraints for production purposes, as well as the optimization of the material employed for the subsequent production phase.

References

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