Multiobjective Shape Optimization of a Balloon Expandable Coronary Stent

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ABSTRACT

One of the most common and widely used treatments for coronary artery disease is the deployment of intravascular stents. These are cylindrical, mesh-like and normally balloon expandable prostheses implanted into blood vessels to act as a structural support in the place of stenosis, holding the artery open so that blood flow is improved. However, in-stent restenosis (re-occlusion of the implanted site) remains the principal problem of stenting procedures. Clinical evidence shows that restenosis is largely related with the vascular injury originated by stent-artery interaction. One of the key determinants of restenosis rates is the stent design [1]. Indeed, modifying stent design may improve the biological response of the body towards restenosis. Taking this into account, the aim of this work was to develop an optimization model in order to obtain a stent optimal geometry with an improved clinical performance.

A shape optimization model was developed and applied to a three-dimensional model of a generic, non-commercial stent [2]. The goal is to obtain stents that are less likely to provoke restenosis. To avoid that outcome is essential to reduce the stress change in the arterial wall caused by stent placement. So, the optimization model was set up to minimize artery stresses induced by stent placement and to maximize stent flexibility. The latter objective is extremely important because easy stent manoeuvrability during deployment is crucial to reach the target site and flexibility is also largely influenced by stent design. The objective functions were calculated using finite element procedures representative of stent deployment and stent bending. The multiobjective optimization problem was solved using the direct multisearch algorithm [3], which is based on a derivative-free methodology which does not combine the objective functions into a single one. Its framework is inspired in direct-search methods of directional type through the search/poll paradigm. A list of nondominated points is generated and maintained using the Pareto dominance concept.

The Pareto front obtained exhibited a trade-off between the two objectives. Comparing with the initial point, designs that favor artery stresses presented curves with increased width (upper bound value) and decreased amplitude and links with decreased length and width. Concerning flexibility, the only difference to artery stresses was the curve width, which converged to the lower bound. An adequate compromise solution of the Pareto front exhibited the same values for all parameters comparing with the optimized design for stress and flexibility except for curve width, where its value remained near the mean of the admissible interval. Therefore, one can conclude that the curve width was the design variable that had the higher impact on the Pareto front. As future work, additional objective functions related with the stent mechanical behaviour will be added like stent radial strength and stent radial recoil.

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