Robust Multiobjective Optimization of Coronary Stents

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Introduction

A coronary stent is a medical device used to unblock clogged arteries. The stent is a cylindrical mesh-like structure which is expanded via elasto-plastic deformation by the use of an expandable balloon catheter. As the stent is expanded, it opens up the clogged artery and restores the proper blood flow. When the balloon catheter is deflated and retracted, the plastic deformation allows the stent to stay in place of the blood vessel and act as a scaffold.

During the stent manufacturing and deployment inside the patient, there are some factors that may be out of the control by the manufacturer and cardiologist, which may impact adversely upon the stent expansion behaviour. These factors may include the slight movement of the stent upon the balloon catheter as the stent is being deployed, or the light variation in material properties between stents. These uncontrolled factors lead to uncertainties, which have not been considered in any previous study concerning the structural optimization of stents. This study aims to quantify these uncertainties and observe their impact on stent expansion, thereby conducting multiobjective optimization for the stent structure in a robust (in a manner that reduces the stent's sensitivity to uncertainties) way.

Methods and Materials

The new generation ring-link type MAC-Plus stent was used in this study. Its thickness, strut width and link width were the three key control variables. The noise variables used were the balloon position relative to the stent and Young's modulus of the stent material. Using Optimal Latin Hypercube sampling, 21 points were taken in the control variable space and 4 points in the noise variable space for each of the 21 control points giving a total of 21x4=84 sample points, and the finite element analyses were performed at each of these points.

The analysis was a quasi-static expansion of the stent via a tri-folded balloon expansion inside a tri-layered artery. Based on the displacement and stress results from the FEA, two objective functions were sought to be minimized: (1) average arterial stress induced by the stent deployment; and (2) elastic recoil of the stent due to balloon deflation at the end. The optimization is also subjected to a constraint on the dog-boning of the stent being non-negative (as negative dog-boning referred to as "dog-barrelling") is usually rectified easily during surgery if it occurs. For these objective and constraint functions, the mean and standard deviation responses are constructed using the response surface methodology (RSM). These objectives were simultaneously minimized using the Multi-objective Particle Swarm Optimization (MOPSO) algorithm.

Results

The study showed that when the standard deviation was stressed more heavily than the mean response in the objective functions, the design became more robust yet less optimal. The Pareto plots show the sensitivity of the Pareto fronts as the standard deviation response is weighted higher than the mean responses.