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Robust Multiobjective Optimization of Coronary Stents

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Abstract

When optimizing stents, there are uncertainties associated with stent delivery and expansions which have not been considered in any study, such as slight movement of the crimped stent on the balloon during the stent deployment leading to lopsided expansion of the stent, or slight variations in material properties. Taking these noise factors into account is of primary importance to ensure that the Pareto optimal front is robust under such uncertainties. This paper aims to take these uncertainties into account when performing a Taguchi type multi-objective optimization of stents.

The new generation ring-link type MAC-Plus stent was used. 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. These sample points were meshed together in a Taguchi type inner and outer loop, and a finite element analysis was 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 minimised: (1) average arterial stress induced 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.

The study showed that when the standard deviation was stressed more 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.