Coronary Stent Strut Optimization Using Parametric 3D Finite Element Models

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Abstract

Development of new polymer based bioabsorbable drug-eluting scaffolds (BVS) requires a new geometry of the device which is made of material characterized by a substantially lower stiffness than the stiffness of the metallic alloy. It is essential to provide sufficient radial strength of the stent. The optimization procedure based on 3D parametric FE model generation script, numerical analysis and genetic algorithms is performed to obtain optimal geometrical parameters of the structure. The radial force of the implemented stent is maximized considering the plastic strain limit. The developed procedure is very efficient, due to the stent segment model simplicity, therefore a large number of sampling points can be analysed in a reasonable time.

Keywords: stent, coronary, optimization, finite element analysis

1. Introduction

Percutaneous coronary intervention (PCI) is one of the most common treatment techniques of ischemic heart diseases. In the method, the balloon catheter with the stent mounted is inserted into the artery until it reaches the site of blockage. At the blockage, the balloon is inflated to open the artery, allowing blood to flow. The balloon is finally deflated leaving the stent permanently secured in the vessel to avoid restenosis [1].

Nowadays, an alternative and promising therapeutic approach for the treatment of coronary artery disease is bioresorbable technology. A temporary vascular stent could offer transient radial strength to resist acute vessel recoil, and at a later stage would be fully resorbed, leading to restoration of the vessel's biological properties. However, the mechanical properties of polymer based scaffolds substantially differ from those of metal stents and providing sufficient radial strength is problematic. Therefore, the development of a new stent design is necessary to compensate lower material stiffness.

Finite element analysis (FEA) has been proven as a valid and efficient method to investigate and optimize the mechanical behaviour of medical devices such as stents and angioplasty balloons [2-3,8]. A considerable amount of publications pertaining to the computational optimization within this field was released in recent years [4-7,9-10]. However, the literature review carried out by the authors suggests that there are no papers in which genetic optimization based on FE analysis including all stages (crimping, deploy and radial force assessment) with parametrically generated 3D solid models is presented.

2. Methodology

The stent implant made of polymer bioresorbable material was taken into consideration. To assess a stress development and deformations of the stent Finite Element Method was applied. The solution was obtained using nonlinear static analysis (Newton-Raphson scheme). To represent the stent material an elasto-plastic model was adopted.

The authors decided to use optimisation algorithms coupled with computational mechanics to estimate the optimal stent strut shape. The main goal of this study was to maximize the expanded stent radial force $F_{objective}$ *[N]* with respect to strut' fillets radius r_1, r_2, r_3 *[μm]*, strut' width b *[μm]* and strut' segment length l *[μm]*. Total length of stent was assumed to be equal to *8.2 mm*. The constrain was adopted as maximum plastic strain for investigated stent after implantation. The problem can be described in the following form:

$$\max F_{objective}(r_1, r_2, r_3, b, l) \text{ subjected to } \varepsilon_{pl}^{max} \le 90\% \quad (1)$$

where r_1=<70;250>, r_2=<70;250>, r_3=<100;300>, b=<70;250>, $l=(8200-(n_{segm}-1)*l_{gap})/n_{segm}$, n_{segm} – number of segments per length of stent structure n_{segm}=<5,6,7,8,9>, $l_{gap}=50\ \mu m$ – gap between segments.

To solve this task the direct optimization based on genetic algorithms was used. The population size was 50 and 20 generations were considered (Fig. 1).

3. Results and conclusions

As a result of the optimization procedure, 983 stent models with different shape parameters were generated. The FE analysis performed for each sampling point provided responses presented as a set of points in radial force-plastic strain chart (Fig. 1). The maximum radial force of feasible solutions (satisfying the plastic strain constrain) was obtained for the following set of parameters: $r_1=75\ \mu m$, $r_2=115\ \mu m$, $r_3=101\ \mu m$, $b=102\ \mu m$ and $l=1129\ \mu m$. It is worth pointing out that the optimized stent struts form a circle after the expansion process, which highly increases radial force and reduce recoil.

Genetic algorithms together with computational mechanics are very powerful tool for determining optimal geometric parameters of the stent structure. Moreover, 3D models based on thick shell elements gave a high possibility to obtain more realistic behaviour than plain analyses using shell and beam based models.

The study was supported by the NCBiR within project "Apollo" (STRATEGMED) and the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM) University of Warsaw under grant no GB65-19. This support is gratefully acknowledged.

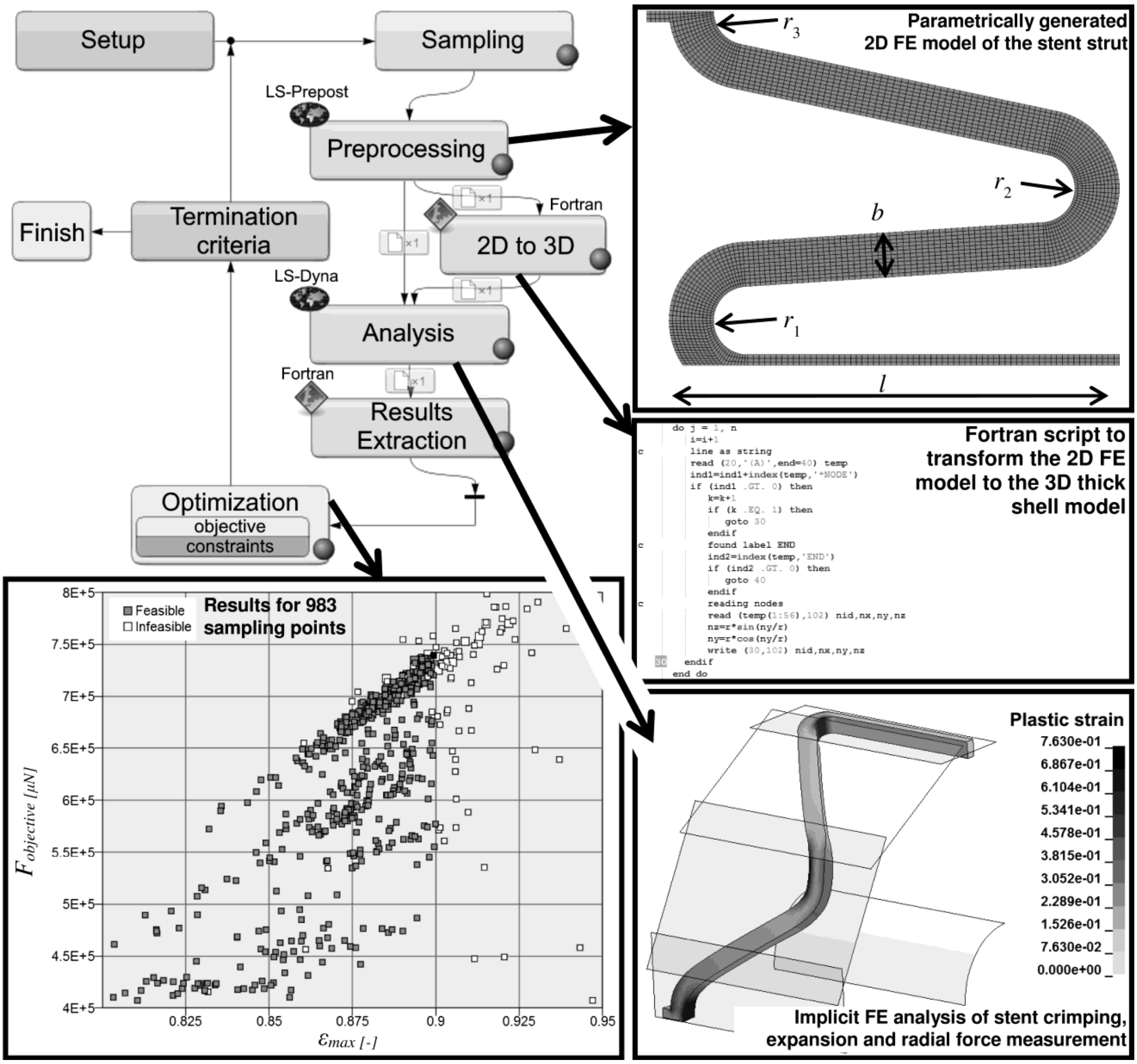

Figure 1: Scheme of the optimization procedure

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