Relevance of Mesh Dimension Optimization, Geometry Simplification and Discretization Accuracy in the Study of Mechanical Behaviour of Bare Metal Stents

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ABSTRACT

In this paper, a set of analyses on the deployment of coronary stents by using a nonlinear finite element method is proposed. The author proposes a convergence test able to select the appropriate mesh dimension and a methodology to perform the simplification of structures composed of cyclically repeated units to reduce the number of degree of freedom and the analysis run time. A systematic study, based on the analysis of seven meshes for each model, is performed, gradually reducing the element dimension. In addition, geometric models are simplified considering symmetries; adequate boundary conditions are applied and verified based on the results obtained from analysis of the whole model.

Keywords: Bare Coronary Stent Deployment, Convergence Test, Finite Element Method, Geometry Simplification, Mesh Dimension Optimization

INTRODUCTION

The implantation of a coronary stent in human patients in the treatment of the stenosis is a common clinical procedure (El-Menyr et al., 2007; Goodney & Powell, 2008; Zeller, 2007). Stents are metallic cylindrical structures constituted of a cell-repeated pattern. Basing on cell pattern, stents can be classified as slotted tubes, coil or mesh types (Xia et al., 2007). These devices are rigid scaffolds used to maintain a diseased artery open after the implantation (Timmins, 2007). In order to foresee the mechanical behaviour of the structure and to quantify stresses and strains in the device after the application, computer simulations began to receive attention in the last years, when a number of software tools, based on the Finite Element Method (FEM) were developed. In mechanics, the FEM is the
most diffused simulation method, employed to study and predict the physical behaviour of bodies undergoing various external forces that involve complex phenomena like great displacements, large deformation or plasticity.

A large number of studies in literature reports the analysis of the mechanical behaviour of stent devices (Chua et al., 2002; Chua et al., 2004; Etave et al., 2001). Finite Element (FE) models of the whole structure of the stent (Migliavacca et al., 2005; Lally et al., 2005), the half structure or a significant part were analyzed (Chua et al., 2002; Kajzer et al., 2005), taking or not into account the presence of the arterial wall. In addition, other computational models analysed effects of the stent on the blood flow (Lam et al., 2008; LaDisa et al., 2005; LaDisa et al., 2006; Fung et al., 2008).

FE computational analyses employ a mathematical model to describe the real behaviour of the structure being analyzed and a discrete model of the real structure by the use of finite elements. A FE analysis allows determining only an approximate numerical solution of the problem. In order to verify quality and reliability of the computational solution, the gathering of experimental and analytical data is required. However, FE packages generally report a great amount of warnings and errors that help the operator in the adjustment of the modelling process.

The choice of the mathematical model fulfilling to describe the object of the analysis depends on a theory that, in turn, is selected on object geometry, material properties constituting the object, as well as constraints and loads applied to the body. The accurate selection of the mathematical model minimizes the modeling error, or rather the error due to the difference between the mathematical function used to describe the theoretical behaviour and the physical property of the analyzed body. During the modelling process, a series of choices are generally made about, for example, the choice to model a thin structures with shell elements, to simplify a body considering symmetries and to delete features unessential with respect of the whole structure. In addition, a predefined structural model, based on a small number of parameters, can schematize the mechanical behaviour of the employed materials. Furthermore, another important factor concerning the modelling procedure is the schematization of constraints and loads. The modelling error depends on these factors but is independent from the FE dimensions.

Finite elements are little but finite entities, with one, two or three dimensions, used to fill a structure with greater size. Discretisations (meshes) are coarse or fine basing on element size, furnishing solutions with different degrees of precision. From the degree of precision of the mesh arises the finite-element discretization error. Generally, a finer mesh allows obtaining results that are more accurate but decreasing the element dimensions an important increase in run time and hardware resource occurs. For this reason, the selection of the best element dimension is important in the optimization of a FE analysis. The selection of the element dimension derives from a systematic procedure that analyse the same problem by using different mesh dimensions and monitoring the trend of one or more interesting parameters in one or more nodal points. This systematic procedure is generally indicated as convergence test.

After the optimisation of the mesh size, it is suitable to simplify the problem and limit the number of degree of freedom in order to reduce the analysis time. The reduction of the geometry of the body represents one method of simplification. This procedure depends on the presence of symmetries of the whole structure and is not possible in all cases. When the simplification of the geometry can be performed, a fundamental step is represented by the identification of the symmetries and the choice of appropriate boundary conditions. This simplification procedure appears particularly important in problems where the whole structure being analyzed is composed of cyclically repeated units. In these cases, simplifications allow appreciably reducing the degrees of freedom of the analysis and then the calculation time.

The present work analyses both the optimization of the mesh dimension and the sim-
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