Comparison of computational methods for simulating stent deployment

K. Spranger[1], **J. M. T. Penrose**[2], **A. Chiarini** [3], **P. N. Watton**[1], **Y. Ventikos**[1]

[1]Institute of Biomedical Engineering, Department of Engineering Science
University of Oxford, Oxford, UK
kateryna.spranger@eng.ox.ac.uk

[2]Bio-Computing Competence Centre, SCS, Italy

[3]ANSYS UK, Milton Park, Abingdon, UK

ABSTRACT

Currently, minimally invasive vascular interventions with stent[1] deployment constitute a compelling choice in the treatment of vascular disorders for an increasing number of patients, as compared to conventional open surgery (Kulcsar et al., 2011). Such endovascular repair involves small incisions made to expose the arteries, from where, under fluoroscopic guidance and with the help of specially designed introducer systems, a stent is deployed inside the diseased vessel. It is known that the effectiveness of stenting procedure depends on a number of factors such as the released position and configuration of the stent, alteration of the vessel haemodynamics after the intervention, incidence of an arterial injury during the procedure, etc. (Pierot, 2011); however, there is currently no means for a clinician to obtain this vital information prior or during the intervention for a given clinical case.

The aim of this study is to develop a computational methodology allowing the simulation of the deployment procedure of implantable endovascular stents. Since two major key players in these interventions are the vessel and the stent, both of them have to be accounted for with a sufficient sophistication, in order for the model to be able to assist clinical decision-making. Hence, our efforts concentrated on modelling the stent expansion process in a mechanically feasible manner, as well as considering the specificity of stent design parameters (snapshots of stent deployment simulation by the treatment of a cerebral aneurysm in Fig. 1). The mechanics of the self-expanding prostheses was approximated with three different methods depending on the stent design: lineal spring analogy (Blom, 2000), semi-torsional spring analogy (Zeng and Ethier, 2005) and the Direct Stiffness Method (DSM; Felippa, 2004); while plastic deformation of ballon-expandable stents was modelled by the application of the outwards-acting radial force. Furthermore, the pivotal element of the model is deformable vasculature. The vascular wall was treated as an elastic structure rather than a rigid body, which enables the possibility of vessel deformation under stresses induced by the introduced prosthesis together with the subsequent alterations in the post-interventional haemodynamic environment of the vessel.

In order to validate the model, comparison of its results is performed with the outcome of detailed Finite Element Analysis. Due to the high precision, the FEA results can serve as a benchmark in assessing the accuracy of the developed model. FEA simulations are performed

[1]For the sake of conciseness, "stent" will be used in the sequel to denote stents, stent-grafts and flow diverters.

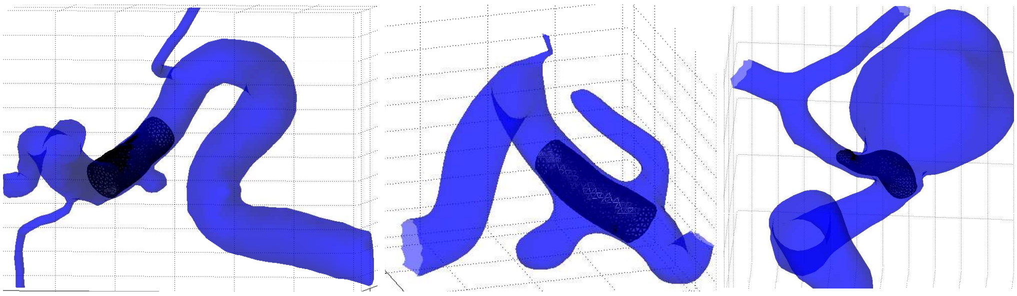

Figure 1: Placement of a flow diverter over an aneurysmal neck.

by means of the commercial codes ABAQUS (Simulia Corp, Providence, RI, USA) and ANSYS Mechanical (ANSYS Inc., Canonsburg, PA). Stents are deployed in simplified vessel geometries (bent cylinders) and the differences between methods are assessed by measuring the stent released configurations by means of comparing, e.g. the distance between corresponding nodes in the two models, predictions of remaining forces in structs of deployed stents.

We investigate: (i) the deployment of two commercially available stents on 10 clinical cases depicting intra-cranial aneurysm; (ii) the deployment of a stent-graft on 2 clinical cases of aortic dissection. In all scenarios, we perform a Computational Fluid Dynamics (CFD) analysis before and after the virtual deployment of a stent. To set-up the CFD simulations we utilise the software suite AIMA (see www.biomedtown.org), which incorporates a 1D model of the arterial tree and enables flow and pressure boundary conditions to be automatically prescribed; links with ANSYS ICEM to automatically mesh the volumetric domain, set-up and solve the CFD simulation. The impact of stent deployment on the haemodynamics is explored. From the comparisons with FEA results, we conclude that different stent designs are best modelled with different methods in order to achieve fast computational times without sacrificing accuracy. For example, flow diverters that have a high porosity and coverage, can be well approximated by a generic mesh of lineal springs. On the other hand, prostheses with a very pronounced struts architecture should be modelled with methods explicitly taking the struts mechanics into account, such as the torsional springs or DSM, and be as precise as possible.

References

Blom, F. (2000). Considerations on the spring analogy. *International Journal for Numerical Methods in Fluids*, 32(6):647–668.

Felippa, C. (2004). Introduction to finite element methods. *Department of Aerospace Engineering Sciences and Center for Aerospace Structures*.

Kulcsar, Z., Houdart, E., Bonafe, A., Parker, G., Millar, J., Goddard, A., Renowden, S., Gal, G., Turowski, B., Mitchell, K., et al. (2011). Intra-aneurysmal thrombosis as a possible cause of delayed aneurysm rupture after flow-diversion treatment. *American Journal of Neuroradiology*, 32(1):20.

Pierot, L. (2011). Flow diverter stents in the treatment of intracranial aneurysms: Where are we? *Journal of Neuroradiology*, 38:40–46.

Zeng, D. and Ethier, C. (2005). A semi-torsional spring analogy model for updating unstructured meshes in 3d moving domains. *Finite Elements in Analysis and Design*, 41(11-12):1118–1139.