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FINITE ELEMENT SIMULATION OF STENT DEPLOYMENT INSIDE A STENOTIC ARTERY

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Since the first coronary stent was developed about three decades ago, a variety of designs have been produced by medical device companies, especially the revolutionary drug eluting stents [1]. To reduce the risk of clinical complications, it is important to implant the most suitable stent for the patient, for which it is imperative to have a thorough understanding of the biomechanical behaviour of stents with different designs, materials and coatings. This is the motivation behind this research paper.

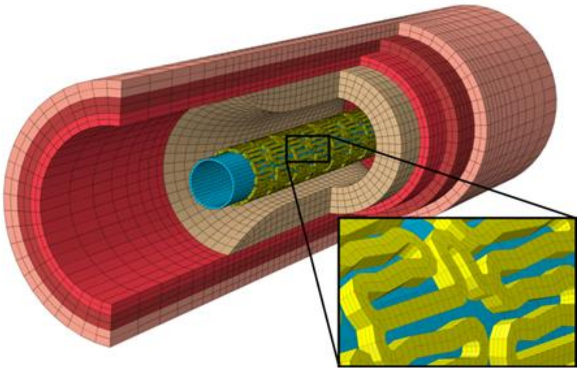

Figure 1, Finite element mesh for the stent, the stenotic artery and the balloon.

In this work, finite element analyses have been carried out to simulate the deployment of stent inside a stenotic artery (40% of stenosis). The essential performances (e.g. expansion, dogboning and recoiling) of stent were evaluated, including the effects of material choice and stent coating. Effect of different designs on stent expansion was investigated through a comparative study of four typical balloon expandable stents, Palmaz-Schatz, Cypher, Xience and Endeavor, representing the stents of four generations. This paper also investigated the stresses on the artery/plaque system caused by stenting, which contribute to in-stent restenosis by facilitating the proliferation of vascular smooth muscle cells. Finite element models of all stent designs were produced using Abaqus CAE according to the geometries reported in open resources (Fig.1). The stents were modelled using the elastic-plastic constitutive relationship with nonlinear hardening behaviour. The polymer coating was simulated as a bilinear elastic-plastic material. The balloon was modelled using a Mooney-Rivlin hyperelastic strain energy potential while the blood vessel and stenotic plaque were described by Ogden hyperelastic strain energy potential [2]. Also the blood vessel was considered to consist of three tissue layers, i.e., intima, media and adventitia (Fig.1).

Results showed that stents made of magnesium (Mg) alloy and 316L stainless steel (SS316L) tend to experience more severe deformation and stronger dogboning/recoiling effects, compared to cobalt-chromium L605 (Co-Cr L605) stent, indicating less radial stiffness for

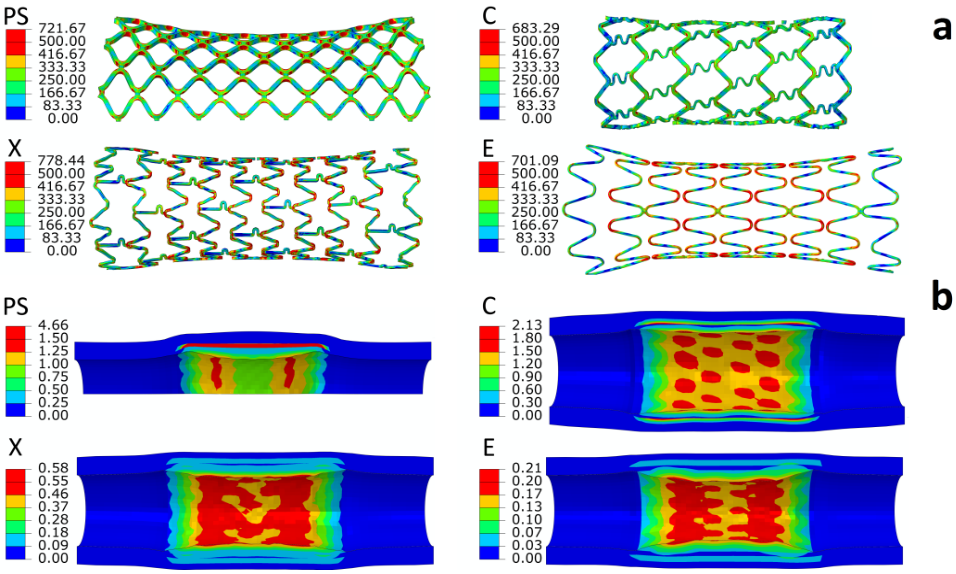

Figure 2, Residual stresses (von Mises) on Palmaz-Schatz (PS), Cypher (C), Xience (X), Endeavor (E) stents and respective stenotic arteries following the deployment.

stents made of metallic materials with lower yield stress and strain hardening. Stent made of Mg alloy has much lower residual stress than those made of SS316L and Co-Cr L605. Drug eluting coatings have little effect on stent expansion (i.e. radial stiffness), but reduce recoil effect and increase dogboning effect slightly. Also the coated stent had a slightly higher residual stress compared to the bare metal one, due to property mismatch between the stent and the coating. The stent diameter change is mainly controlled by the radial stiffness of the stent which is closely associated with the stent design. In particular open-cell design (e.g. Endeavor) tends to have easier expansion than closed-cell design (e.g. Cypher). Recoil effect is lower for the closed-cell design (i.e. Palmaz-Schatz and Cypher) and higher for open-cell sinusoidal designs (i.e. Endeavor and Xience). Dogboning effect was stronger for slotted tube design (e.g. Palmaz-Schatz) and open-cell sinusoidal design (e.g. Endeavor), but reduced significantly for designs strengthened with longitudinal connective struts (e.g. Xience and Cypher). After deployment, the maximum von Mises stress appear to locate at the bending or turning points of stent struts, with varying magnitude that depends on the materials and severity of plastic deformation (Fig.2a). For artery-plaque system, the von Mises stresses appear to be distinctly different for different stent materials and designs, in terms of both distribution and magnitude (Fig.2b). In most cases, the stress concentration tends to occur on the plaque due to the direct contact of the plaque with the expanded stent. For the artery under severe stretch (e.g. Palmaz-Schatz stent), a significant amount of stress was transferred to the intima layer of the artery due to its high stiffness and strong constraints imposed by surrounding tissues (Fig.2b).

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