Numerical analysis of stent geometry and deployment technique on arterial wall adaptation

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Abstract

Atherosclerosis is characterized as plaque buildup on the inner wall of the artery, and its treatment involves the deployment of a meshed tube known as a stent. Stent deployment expands the narrowed arterial lumen, allowing blood to flow unobstructed. However, it simultaneously increases stress within the arterial wall, which can lead to damage, thrombus formation, or in-stent restenosis (re-narrowing of the artery). The stress induced by stent deployment triggers growth and remodeling processes within the arterial wall. Stress levels depend, among other factors, on the stent's geometry and deployment technique used.
Stents are generally made of metal and traditionally have a cylindrical shape due to the manufacturing process, and their geometry does not conform to the natural curvature of an artery. Metallic stents are usually expanded using a balloon, which deforms the metal beyond its elastic limit. Most modern carotid artery stents are made from nickel-titanium alloy. This material can elastically recover from significant strain caused by stress-induced deformation, allowing self-expanding deployment method (1). However, the metallic, thrombogenic stent surface increases the risk of stent thrombosis, which can lead to myocardial infarction or even cardiac death (2).

On the other hand, a promising alternative to traditional stents are polymer-based stents, which can be produced using additive manufacturing techniques such as 3D printing. This approach enables the creation of patient-specific stents tailored to follow the unique curvature of a patient specific individual arteries (3). These stents can be made from shape memory polymers (SMPs), advanced materials that can revert from a temporary, deformed state to their original, permanent shape when activated by an external stimulus, making SMP stents suitable for self-expanding deployment. Triggers for shape recovery include heat, hydration, magnetic fields, or light. Additionally, SMP stents have been shown to reduce the risk of restenosis (4).

Numerical analysis is a valuable tool for studying the effects of stent deployment on arteries. Soft tissues can be modeled using growth and remodeling (G&R) framework and this approach has greatly advanced our understanding of the biochemical and biomechanical processes and has improved predictions of disease progression over time (5).

This study simulates stent deployment and the adaptation of the carotid artery to the stent implantation, incorporating a growth and remodeling model for the arterial wall. Various stent geometries and deployment techniques are analyzed and compared. Simulations are carried out to study the effects of standard cylindrical stents versus curved designs, as well as

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balloon deployment versus self-expansion methods. For all scenarios, the impact on arterial stresses and the production of arterial wall constituents-key factors influencing the occurrence of in-stent restenosis-is evaluated. Additionally, the adequacy of stent expansion is assessed.

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