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Short communication

Non-uniform shrinkage for obtaining computational start shape for in-vivo MRI-based plaque vulnerability assessment

Yuan Huang [a], Zhongzhao Teng [a,b,*], Umar Sadat [a,c], Sarah Hilborne [a], Victoria E. Young [a], Martin J. Graves [a], Jonathan H. Gillard [a]

[a] University Department of Radiology, University of Cambridge, Cambridge, UK
[b] Department of Engineering, University of Cambridge, Cambridge, UK
[c] Cambridge Vascular Unit, Addenbrooke's Hospital, Cambridge, Cambridge, UK

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ABSTRACT

Background: Critical mechanical conditions, such as stress within the structure and shear stress due to blood flow, predicted from in-vivo magnetic resonance image (MRI)-based computational simulations have shown to be potential in assessing carotid plaque vulnerability. Plaque contours obtained from in-vivo MRI are a result of a pressurized configuration due to physiological loading. However, in order to make accurate predictions, the computational model must be based on the loading-free geometry. A shrinkage procedure can be used to obtain the computational start shape.

Method: In this study, electrocardiograph (ECG)-gated MR-images of carotid plaques were obtained from 28 patients. The contours of each plaque were segmented manually. Additional to a uniform shrinkage procedure, a non-uniform shrinkage refinement procedure was used. This procedure was repeated until the pressurized lumen contour and fibrous cap thickness had the best match with the in-vivo image.

Results: Compared to the uniform shrinkage procedure, the non-uniform shrinkage significantly reduced the difference in lumen shape and in cap thickness at the thinnest site. Results indicate that uniform shrinkage would underestimate the critical stress in the structure by 20.5 ± 10.7%.

Conclusion: For slices with an irregular lumen shape (the ratio of the maximum width to the minimum width is more than 1.05), the non-uniform shrinkage procedure is needed to get an accurate stress profile for mechanics and MRI-based carotid plaque vulnerability assessment.

1. Introduction

High-resolution multi-sequence in-vivo magnetic resonance imaging (MRI) is capable of quantifying the embedded atherosclerotic components, such as the lipid core and calcification, in the carotid plaque with good accuracy and reproducibility (Cai et al., 2002; Sadat et al., 2009). It has been widely used for computational modeling to predict critical mechanical conditions in plaque vulnerability assessment (Groen et al. 2007; Sadat et al., 2011, 2010a; Tang et al., 2009b). Under physiological condition the artery and plaque are pressurized, therefore, the segmented contours need to be processed to get the computational start shape.

Several techniques have been employed for this purpose. Inverse design analysis has been used in relevant studies (Gee et al., 2009; Govindjee and Mihalic, 1996; Lu et al., 2007) to determine a truly stress-free configuration. A backward incremental method which is a modified updated Lagrangian formulation has also been applied to get the computational start shape in studies of abdominal aortic aneurysms (de Putter et al., 2007; Gee et al., 2009; Merkx et al., 2009; Speelman et al., 2009). This approach leads to a good recovery of vessel geometry with reasonable computational load. The uniform shrinkage method proposed by Huang et al. (2009) and Tang et al. (2009a) is another approach. It involves uniform shrinkage of the lumen contour about its geometric center before external loading is applied. The shrinkage rate, which is the extent of circumferential contraction of lumen contour, is obtained either by registering in-vivo and ex-vivo vessel circumferences, or by studying the most circular slice from the vessel. The shrinkage is verified by comparing the pressurized geometry with the in-vivo contour. This technique has been employed in various studies (Sadat et al., 2011, 2010a; Tang et al., 2009b; Zhu et al., 2010) to assess the carotid plaque vulnerability. Being a phenomenon-based technique, this is relatively easy to apply with, but it might fail to recover the in-vivo configuration well if lumen shape is irregular and it has never been investigated in detail.

In this study, the shrinkage procedure was adopted with modifications. Based on artery composition and in-vivo geometry, slices of the vessel were shrunk non-uniformly using an iterative approach to overcome the difficulty of irregularity in lumen

* Corresponding author at: Level 5, Box 218, Hills Road, Addenbrooke's Hospital, Cambridge CB2 0QQ, UK. Tel.: +44 1223 762 772; fax: +44 1223 330915.
E-mail address: zt215@cam.ac.uk (Z. Teng).

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