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Development of an Element Based Material Property Model and Its Applications on Arterial Plaque Stress Analysis

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Summary

Atherosclerotic cardiovascular disease is one of the leading causes of death in western countries. Although the precise mechanism of the plaque rupture is not yet fully understood, the stress analysis on the diseased artery suggests that the high stress concentration on the fibrous cap could be the trigger of the plaque rupture(1).

In conventional finite element method (FEM) stress analysis models, usually several geometrical components were defined such as normal arterial wall, fibrous plaque, and lipid pools. Specific material properties were assigned to different components. Here, it is called Region Based FEM or RB_FEM. However, the arterial wall is a hybrid fibrous material containing ground substance, smooth muscle cells, and also fibers of different stiffness. Therefore, the arterial wall is heterogeneous in material properties. In this study, an element based material property model was developed based on the conventional FEM, called Element Based FEM or EB_FEM. In the EB_FME, the idea of defining regions in a geometry model was abandoned all together. It assigned the material property to each numerical element automatically from a material property map obtained from other sources such as histology images.

In the study, EB_FEM was applied to a realistic arterial plaque image obtained from a histology section of a carotid endarterectomy specimen (Fig.1(a)). Four cases were generated to demonstrate the ability of EB_FEM on dealing with heterogeneous material properties. They are Case1: baseline case with uniformly distributed material properties; Case2 and Case 3 represent the material property varied on the fibrous cap along circumferential direction in which case2 has a stiffer collagen layer in the middle while in Case 3 the fibrous cap is much softer at the middle; and Case 4: the material property in the fibrous cap decreased gradually from fibrous cap to lipids (radial direction).

Stress distributions(Von Mises stress) for the above four cases are shown in Fig.1(b,c,d,e) with different legends. Different material property in the fibrous cap could affect the stress distribution and stress level in the fibrous cap. A stiffer fibrous cap may introduce a higher stress level as in case2, while the stiffer fibrous cap can also bear a higher stress without rupture; the stress in a softer fibrous cap

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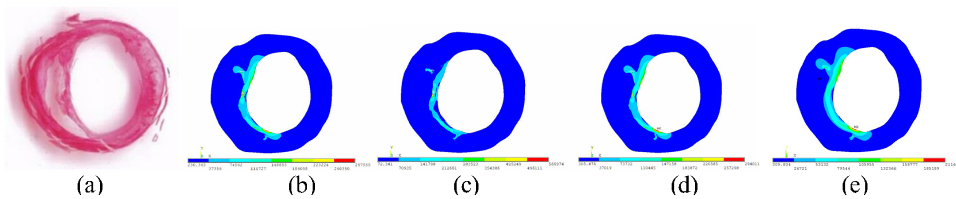

Figure 1: (a) histology image of the plaque sample, (b) to (e) represent stress distributions for case1 to case 4

is similar to the case1, however the softer fibrous cap is prone to rupture under the same stress level as case1. For case4, the stress level is lower than case1, and more smoothed in the fibrous cap, the stress concentration region near lipids disappears. With EB_FEM, more information could be incorporated into FEM model, and a more detailed mechanical environment can be obtained regarding to the local structure in the arterial wall.

References

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