11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

A finite element model of coil insertion in cerebral aneurysms

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Key Words: *Cerebral aneurysm, Coil embolization, Finite element method, 3D beam theory, contact dynamics.*

INTRODUCTION

Coil embolization is one of the popular clinical methods for the cerebral aneurysm. In this method, metallic coils are inserted into the aneurysm to stagnate blood flow and induce embolization. It is known that the effect of the treatment of the coil embolization depends on an amount of coils and uniformity of them in the aneurysms [1]. Computational fluid dynamics (CFD) studies are expected to evaluate the effect of these factors on the blood flow in the aneurysms [2]-[4]. Since it is difficult to obtain the real configuration of the geometrically-tangled coils in the aneurysm from medical images, several numerical models e. g., porous media model [2], [3] and virtual coil model [4], [5], have been proposed. The authors have revealed that the global flow patterns and the degree of stagnation of blood flow in the aneurysm do not change between those models but the local flow patterns in the space between coils are significantly different, especially in the entrance region of the aneurysm [5], due to the presence or absence of the exact coil surface which imposes no-slip boundary conditions. Therefore, to represent the realistic configuration of the coils in the aneurysm is sure to promote understanding the characteristics of the blood flow in detail. The purpose of the present study is to develop a finite element model of the coil insertion in the cerebral aneurysm which enables to describe the realistic configuration of the coils in the aneurysms.

METHODS

The coil is discretized by a set of three-dimensional beam elements based on Timoshenko's beam theory, e. g., [6]. The beam element is constituted of the nodes, each of which has six degrees of freedom of translation and rotation. To treat the contact of coil-coil and coil-aneurysm, a frictionless contact model is introduced based on Signorini condition [7] which is given by $g\lambda = 0$, where g is the minimum distance between two materials and λ is the magnitude of the compressive force being understood as the Lagrange multiplier [7]. The minimum distance between two beam elements is searched by means of the algorism proposed by Wriggers and Zavarise [8]. The Galerkin finite element method is applied for solving the equation of motion for the coil with an energy function; $\Pi = W + g\lambda$, where W is the potential energy of the beam elements.

RESULTS AND DISCUSSION

For the validation of the proposed coil model, coil insertion simulation is performed using a patient-specific geometry of the aneurysm with a radius of approximately 3.5 mm. The 3D geometry of the aneurysm including the parent artery is constructed from clinical CT images using imaging software, Amira 5.4 (Visual Imaging, Inc.). For simplicity, the reference state of the coil is set to be a straight line. The configurations of the coils inserted in the aneurysm are shown in Fig. 1. Two coils with the length of 300 mm and 150 mm are inserted in the aneurysms and the packing density of the coil, which is the volumetric ratio of the coil to the aneurysm, is approximately 15%. The coils are curved and tangled around the aneurysmal wall during insertion and finally the complex configurations are constructed. Figure 2 shows the radial distribution of the coils in the aneurysm with a radial thickness of 0.25 mm. The coils mainly distribute between 2.5 mm to 3.5 mm from the center of the aneurysm. It shows that the proposed coil model distributes around the aneurysmal wall to minimalize the curvature of the coil according to the reference state of the coil set as the straight line. In addition, there are no penetration of the aneurysmal wall by the coil and overlap between coils. Thus it indicates that the proposed coil model enables to treat the multiple contacts precisely. The proposed coil model is expected to describe the realistic configuration of the coils in the aneurysms in clinical practice. Moreover, the CFD studies using proposed coil model enable to reveal the effects of the coil distribution on the blood flow in cerebral aneurysms.

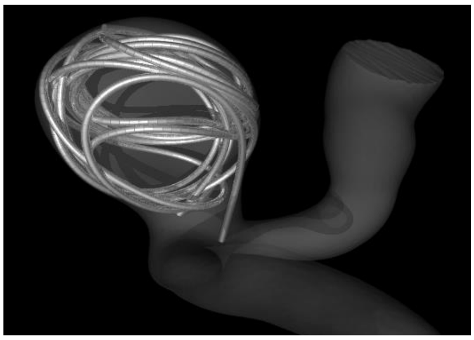

Fig. 1 Configuration of the embolization coils placed in the aneurysm at the packing density is approximately 15%.

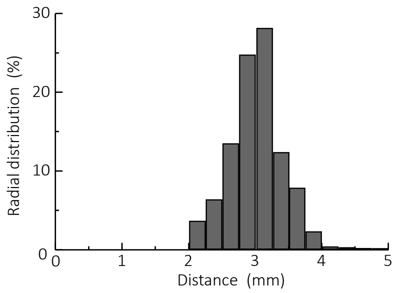

Fig. 2 The radial distribution of the coils in the aneurysm with a radial thickness of 2.5×10^{-4} m.

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