Magnetic Navigation of Nanoparticles inside a 3D Carotid Model

Authors : E. G. Karvelas, C. Liosis, A. Theodorakakos, T. E. Karakasidis

Abstract : Magnetic navigation of the drug inside the human vessels is a very important concept since the drug is delivered to the desired area. Consequently, the quantity of the drug required to reach therapeutic levels is being reduced while the drug concentration at targeted sites is increased. Magnetic navigation of drug agents can be achieved with the use of magnetic nanoparticles where anti-tumor agents are loaded on the surface of the nanoparticles. The magnetic field that is required to navigate the particles inside the human arteries is produced by a magnetic resonance imaging (MRI) device. The main factors which influence the efficiency of the usage of magnetic nanoparticles for biomedical applications in magnetic driving are the size and the magnetization of the biocompatible nanoparticles. In this study, a computational platform for the simulation of the optimal gradient magnetic fields for the navigation of magnetic nanoparticles inside a carotid artery is presented. For the propulsion model of the particles, seven major forces are considered, i.e., the magnetic force from MRIs main magnet static field as well as the magnetic field gradient force from the special propulsion gradient coils. The static field is responsible for the aggregation of nanoparticles, while the magnetic gradient contributes to the navigation of the agglomerates that are formed. Moreover, the contact forces among the aggregated nanoparticles and the wall and the Stokes drag force for each particle are considered, while only spherical particles are used in this study. In addition, gravitational forces due to gravity and the force due to buoyancy are included. Finally, Van der Walls force and Brownian motion are taken into account in the simulation. The OpenFoam platform is used for the calculation of the flow field and the uncoupled equations of particles' motion. To verify the optimal gradient magnetic fields, a covariance matrix adaptation evolution strategy (CMAES) is used in order to navigate the particles into the desired area. A desired trajectory is inserted into the computational geometry, which the particles are going to be navigated in. Initially, the CMAES optimization strategy provides the OpenFOAM program with random values of the gradient magnetic field. At the end of each simulation, the computational platform evaluates the distance between the particles and the desired trajectory. The present model can simulate the motion of particles when they are navigated by the magnetic field that is produced by the MRI device. Under the influence of fluid flow, the model investigates the effect of different gradient magnetic fields in order to minimize the distance of particles from the desired trajectory. In addition, the platform can navigate the particles into the desired trajectory with an efficiency between 80-90%. On the other hand, a small number of particles are stuck to the walls and remains there for the rest of the simulation.

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