An Adaptive Magnetic Field Source for Magnetic Drug Fixation

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ABSTRACT

Magnetic drug targeting (MDT) therapy is usually controlled through the magnetic field produced by a permanent magnet; the solution proposed and assessed here considers a planar spiral coil (PSC) or a system of such coils, as an equally effective magnetic field source. The PSC may be designed to provide proper configurations of the magnetic field gradients, required for the generation of high magnetic body forces and to limit, in the same time, unwanted side effects affecting adjacent tissue (heating, excitable tissue stimulation). Simplified numerical models (2D projections) and more realistic structures (3D representations) are shown and analyzed in the paper; the electromagnetic and heat transfer problems are solved for different powering schemes applied to the coils.

Keywords: *Heat Transfer, Hemodynamic Flow, Magnetic Drug Targeting (MDT), Magnetic Field Interaction, Mathematical Modeling, Numerical Simulation, Planar Spiral Coil (PSC)*

INTRODUCTION

A notable trend in modern medical therapeutic technologies is represented by minimally invasive interventions as replacement of, or in completion to surgical solutions. Among modern medical treatment methods, Magnetic Drug Targeting (MDT) may play a significant role (Berry & Curtis, 2003; Lübbe et al., 2001; Schütt et al., 1997). This promising therapeutic technology is continuously improving in precision, efficiency, and level of patient tolerance. The therapeutic agent (a chemical substance acting as drug) is bound to super-paramagnetic nanoparticles, injected in the bloodstream and dragged into circulation through the arterial tree, to the region of interest. External control of substance transport inside the body is performed through applied magnetic fields of high gradients. The interactions between the magnetic field and the hemodynamic flow trigger body forces, able to direct the super-paramagnetic particles to precise regions inside the body. The magnetic forces are supposed to guide the

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medication to the Region Of Interest (ROI) and to help delivering it to specific spots, fixing the drug (Alexiou et al., 2003; Arruebo et al., 2007; Shapiro, 2009; Voltairas et al., 2002). Successful MDT is intended to destroy the affected tissues only, while avoiding the spreading of toxic drug to unharmed cells. The therapy is suitable for locally concentrated treatment with aggressive chemical agents (such as in solid tumor destruction, stroke treatment by dispersing blood clots, fighting against local infection) because it favors highly localized chemical concentrations, while keeping whole body dose at a low level.

As with all inside body phenomena and procedures, MDT may be studied and optimized in a harmless and economical manner, by numerical modeling; simulation is able to prospect new methods and technologies for the improvement of magnetic targeting technique. Modeling is also preferred as an initial stage in medical research, for its convenient and accurate post processing facilities, notably visualization and demonstration of physical interactions. Grief and Richardson (2005) for example, demonstrate, by numerical simulation, the limitations in drug inner manipulation, only by exterior control of the magnetic field.

Realistic computational domains based on imagistic reconstruction may be required for simulation of anatomical structures exposed to the action of the electromagnetic field (Dobre et al., 2010; Morega et al., 2010; Riegel et al., 2011). It is however preferable to set the premises of the numerical models on economical grounds and to gradually sophisticating the model, when higher accuracy is needed. For this reason our study started with simpler, 2D numerical representations and then continued with more realistic, 3D models, obtained by reconstruction from medical image-based anatomical data.

Magnetic field source and its optimization are key issues in the MDT and current research is dominated by the efficiency assessment of various arrangements of permanent magnets. Different array configurations, starting from using a simple rectangular magnetic piece, up to more complicated bandage type disposition of magnetic cells were analyzed in order to find the best magnetic force distributions (Dobre et al., 2011; Häfeli et al., 2007; Riegel et al., 2011; Sarwar et al., 2012; Shapiro, 2009). More recently it was suggested that current fed coils could be used instead of permanent magnets as better controlled source of magnetic field, leaving space for system optimization and providing flexibility for various arrangements (Cao et al., 2011; Cherry et al., 2010; Morega et al., 2013; Savastru & Morega, 2012). Technical solutions involving superconductive coils were also launched (Alexiou et al., 2006; Takeda et al., 2007). They are suitable for drug transport through large blood vessels, triggering higher magnetic field gradients and higher forces, but costs on advanced technology appear to limit the applicability.

This paper moves the research further and presents mathematical models and results of numerical simulation for the MDT, when the magnetic field source is a Planar Spiral Coil (PSC). The coil structure and position may be designed to meet specific needs concerning the action of the resulted magnetic forces on drug manipulation. However, it was recognized that the heating effect that accompanies the electrical currents might be a menace; design suggestions for optimizing the PSC concerning higher field gradients, while reducing the unwanted related heating are made here, as a modality to outline the practical value of the research.

The mathematical representation described and analyzed further in the paper is complex by its interdisciplinary nature; three mathematical models, different from the physical perspective describe the coupled phenomena acting together on MDT therapeutic technology. The magnetic field is produced here by one current carrying coil, phenomenon described by *the electromagnetic field problem*. Next, *the hemodynamic* problem describes the pulsatile flow of the complex fluid (chemical drug bound with super-paramagnetic particles incorporated in the blood stream) through an arterial branch, under the influence of the magnetic forces resulting as an interaction of the magnetic field and the