JG-04 Low frequency Induction heating of a ferromagnetic catheter: feasibility

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Additive manufacturing of smart materials is a novel field in engineering. The ability to produce adaptable materials in varying geometries opens the door to the creation of a tremendous variety of new sensors, actuators and applications in domains including, transportation, energy production and medicine [1][2]. In this work, our objective is to build a ferromagnetic catheter by using additive manufacturing principles employed for the creation of smart materials. Induction heating phenomena takes place in the ferromagnetic catheter due to the influence of a varying magnetic excitation field. This contactless heat source can be used to heal locally and destroy damaged blood vessels. According to medical specialists, thermal ablation of varicose veins requires a temperature close to 120°C and time constants lower than a few seconds [3]. First investigation results showed great potential for success using the low frequency induction heating (LFIH) method but further surveys and validation steps are still needed before in vivo testing can commence.

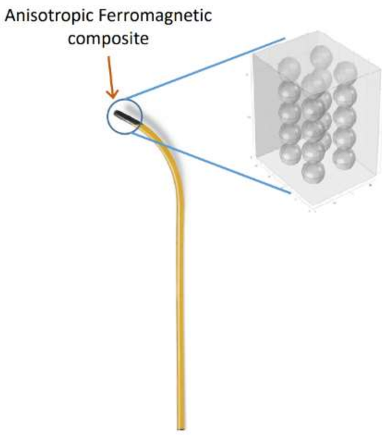

Fig. 1 – Illustration of the ferromagnetic catheter.

In this study, multi-physics simulation results, including ferromagnetic, thermal and fluid mechanics domains were compared to experimental data, then conclusions are proposed to establish the most adapted magnetic waveform (frequency) and its influence on the human tissues.

In our processs, heat is transferred through a contactless method. The flexible 3D printed ferromagnetic catheter is subjected to an alternating magnetic excitation. Under the influence of the magnetic excitation, eddy currents are generated through the catheter creating heat. First published results [4][5] describing this technique have experimentally demonstrated the feasibility of heat generation but the conditions tested and simulated were still far from the in vivo environment. In this study, we go deeper into the investigation process, we propose simulation results (magnetic, thermal …) under much realistic experimental conditions. In [4], the authors limit the magnetic excitation signal to a few kHz. The purpose is to avoid undesired charge displacements in the surrounding tissue, but this restriction is strictly assumption based and further investigations must be under-taken to determine the optimal value for ablation while minimizing charge displacement. No further investigations have been proposed to establish a significant cutoff frequency.

In this new research, a ferromagnetic model for the simulation of the ferromagnetic composite magnetic behavior is developed first. This model is based on previous work on the same topic [6]-[9] and it investigates the frequency dependence of the composite hysteresis area, i.e. the heat generated through the LFIH influence. Next, comparisons between the model and experimental situations are investigated to set the ferromagnetic model parameters and to establish the most efficient LFIH frequency. Finally, multi-physics simulation results combined with experimental tests are reviewed to predict the ferromagnetic composite's behavior on living tissues under the influence of the optimized magnetic excitation.

Before validating the ferromagnetic catheter as a realistic treatment method for varicose veins, special attention must be given to the undesired charges or ionic displacements in the healthy surrounding tissues causing local temperature elevations and degradations. A compromise between treatment and negative effects on surrounding tissue must be made to establish the best working frequency. Numerical simulations are proposed to establish the optimized configuration of the magnetic source (frequency, amplitude) and of the ferromagnetic catheter behavior, these results constitute a huge step toward a first medical test.

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