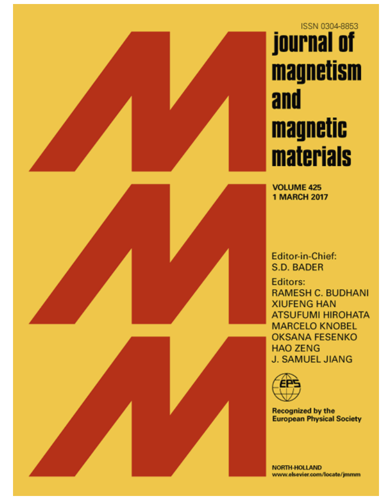

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A method for increasing the homogeneity of the temperature distribution during magnetic fluid hyperthermia with a Fe-Cr-Nb-B alloy in the presence of blood vessels

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ABSTRACT

Magnetic hyperthermia ablates tumor cells by absorbing the thermal energy from magnetic nanoparticles (MNPs) under an external alternating magnetic field. The blood vessels (BVs) within tumor region can generally reduce treatment effectiveness due to the cooling effect of blood flow. This paper aims to investigate the cooling effect of BVs on the temperature field of malignant tumor regions using a complex geometric model and numerical simulation. For deriving the model, the Navier-Stokes equation for blood flow is combined with Pennes bio-heat transfer equation for human tissue. The effects on treatment temperature caused by two different BV distributions inside a mammary tumor are analyzed through numerical simulation under different conditions of flow rate considering a Fe-Cr-Nb-B alloy, which has low Curie temperature ranging from 42 °C to 45 °C. Numerical results show that the multi-vessel system has more obvious cooling effects than the single vessel one on the temperature field distribution for hyperthermia. Besides, simulation results show that the temperature field within tumor area can also be influenced by the velocity and diameter of BVs. To minimize the cooling effect, this article proposes a treatment method based on the increase of the thermal energy provided to MNPs associated with the adoption of low Curie temperature particles recently reported in literature. Results demonstrate that this approach noticeably improves the uniformity of the temperature field, and shortens the treatment time in a Fe-Cr-Nb-B system, thus reducing the side effects to the patient.

Keywords: Temperature prediction, blood vessel, magnetic fluid hyperthermia, bio-heat transfer equation.

1. Introduction

Magnetic fluid hyperthermia (MFH) has been demonstrated to be an effective method for the treatment of cancer, mainly due its low side effects and high efficiency [1-2]. Magnetic nanoparticles (MNPs) in magnetic fluid are injected into tumor region, and then they ablate tumor cells by using the heat absorbed from an alternating magnetic field (AMF) [3-4]. New MNPs with low Curie temperature (LCT) have been reported in literature in recent years and their main advantage over traditional MNPs is the ability to prevent damaging the treatment region due to excessive heating [5-8]. The underlying principle is that this type of MNP stops absorbing the energy from AMF when its Curie temperature is exceeded, thus imposing an automatic temperature regulation. The ideal effective temperature for tumor hyperthermia depends upon clinical analysis, but it is generally in the interval that ranges from 42 °C to 45 °C.

Even though there are many reports in literature related to the effects in temperature distribution caused by nanoparticle concentration, size and distribution, and also by frequency and intensity of the electromagnetic field, just some more recent reports consider the existence of blood vessels (BVs) inside the tumor [9-12]. However, oncologic studies reveal that tumors usually appear around BVs, and that they can even develop their own complex networks of BVs [13-14]. The BVs inside a tumor have an obvious impact on the ablation of tumor cells for their cooling effect during hyperthermia therapy, especially if large BVs are considered [15-16]. The uniformity of temperature field is the most important issue in MFH, which determines the effects of treatment for its

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