Extended Abstract

The Effect of Tumor Position and Abdominal Fat on the Hyperthermia Process of Magnetic Nanoparticles in the Treatment of Peritoneal Metastasis

Mohadese Ranjbaran[1], Mohammad Hossein Tavakoli[1], Zahra Keshtpour Amlashi[2], Safoora Nikzad[3]

[1]Department of Physics, Faculty of Science, Bu-Ali Sina University, Hamadan 65174, I.R. Iran

[2]Cancer Research Center, University of Medical Sciences, Hamadan 65178, I.R. Iran

[3]Department of Medical Physics, Faculty of Medicine, University of Medical Sciences, Hamadan 65178, I.R. Iran

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Abstract

This study evaluates the potential of magnetic hyperthermia using Fe_3O_4 nanoparticles for the treatment of peritoneal metastases, with a focus on the effects of abdominal fat and tumor location. In this method, tumor tissues were heated to 42–46 °C under an alternating magnetic field to selectively destroy cancer cells while sparing healthy tissues. To investigate the heat transfer mechanisms, a finite element numerical simulation was performed. The magnetic field distribution was calculated using Maxwell's equations, while nanoparticle heat generation was modeled according to Rosensweig's theory. This heat source was then incorporated into the Pennes bioheat transfer equation to determine the temperature distribution in both tumors and surrounding tissues. The results revealed that abdominal fat does not significantly hinder heat penetration, and effective tumor ablation can be achieved even in areas with thick fat layers. However, tumor position strongly influenced heat distribution, necessitating more precise treatment adjustments. Overall, magnetic hyperthermia demonstrates strong potential as a localized and minimally invasive therapy, either alone or combined with conventional treatments.

Keywords: Magnetic nanoparticles, Hyperthermia, Peritoneal metastasis, Magnetic field, Cancerous tumor.

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1. INTRODUCTION

Cancer remains one of the major health challenges worldwide, and its treatment becomes increasingly complex when accompanied by metastasis. Specifically, peritoneal metastases often originate from gastric or other gastrointestinal and abdominal cancers, spreading to the peritoneal cavity. Treating these metastases is particularly challenging, as conventional methods like chemotherapy, radiotherapy, and surgery often have limited success. A key limitation of these traditional treatments is their inability to selectively target cancer cells without damaging healthy tissues, and the presence of abdominal fat can further reduce their efficacy.

Magnetic hyperthermia therapy (MHT) has emerged as a promising, non-invasive approach. In this method, magnetic nanoparticles, particularly superparamagnetic iron oxide nanoparticles (SPIONs), are exposed to an alternating magnetic field (AMF). This exposure generates localized heating of 42–46°C within the tumor, a temperature range that selectively destroys cancer cells while largely preserving surrounding healthy tissue. SPIONs offer high thermal and magnetic stability, biocompatibility, and controlled heat generation, making them particularly suitable for targeting metastatic tumors.

The success of MHT depends on multiple factors, including the physical and chemical properties of the nanoparticles, the intensity and spatial distribution of the magnetic field, tumor location, and treatment duration. In particular, tumor position and abdominal fat play critical roles in heat distribution and treatment efficacy; however, these factors have received limited attention in previous research. The aim of this study is to develop a comprehensive numerical model of magnetic nanoparticle hyperthermia for the treatment of peritoneal metastases. The model will examine the effects of tumor location and abdominal fat on magnetic field distribution, heat generation, and the uniformity of temperature within both tumors and surrounding healthy tissues, providing insights for optimizing treatment protocols and improving clinical outcomes [1].

2. Mathematical Model

Heat generation by MNPs is obtained as follows [2]:

$$P = \mu_0 \pi \chi_0 f H^2 \frac{2\pi f \tau_{eff}}{1 + (2\pi f \tau_{eff})^2} \qquad (1)$$

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where P, μ_0, χ_0, f, and H are the power dissipation of MNPs per unit volume, the permeability of free space, equilibrium susceptibility, the frequency of the applied magnetic field, and the magnetic field intensity, respectively. To get the temperature distribution during hyperthermia, using Pennes bio-heat transfer equations for healthy tissue and tumor tissue, the following relationships are used, respectively [3]:

$$\rho_1 c_1 \frac{\partial T}{\partial t} = \nabla.(k \nabla T) + \rho_b c_b \omega_b (T_a - T) + Q_{met} \quad (2)$$

$$\rho_2 c_2 \frac{\partial T}{\partial t} = \nabla.(k \nabla T) + \rho_b c_b \omega_b (T_a - T) + Q_{met} + P \quad (3)$$

3. RESULTS AND DISCUSSION

Figure 1 shows the temperature distribution within the tumor at different locations. The temperature profile was analyzed using the Pennes bioheat equation, with nanoparticle-generated heat as the input. Computational results indicate that all tumor regions reached the therapeutic temperature range of 41–47 °C, which is sufficient for inducing cancer cell destruction. The highest temperature was observed along the tumor's central axis, with a symmetric temperature gradient around the center. Moving away from the center, the temperature decreased due to heat transfer to surrounding healthy tissues, with the lowest temperatures occurring at the tumor surface and at the boundary between the tumor and healthy tissue. With tumor metastasis, the maximum temperature increases due to a larger surface area and greater heat loss to surrounding tissues. The temperature distribution becomes less uniform, with the difference between the tumor center and surface increasing from 4.7°C (pre-metastasis) to 7.1°C (complete metastasis). Computational results show that treatment is more efficient and easier to control before metastasis, while metastatic tumors require more time for uniform cancer cell destruction. Key challenges remain in controlling localized temperature and improving nanoparticle heating efficiency.

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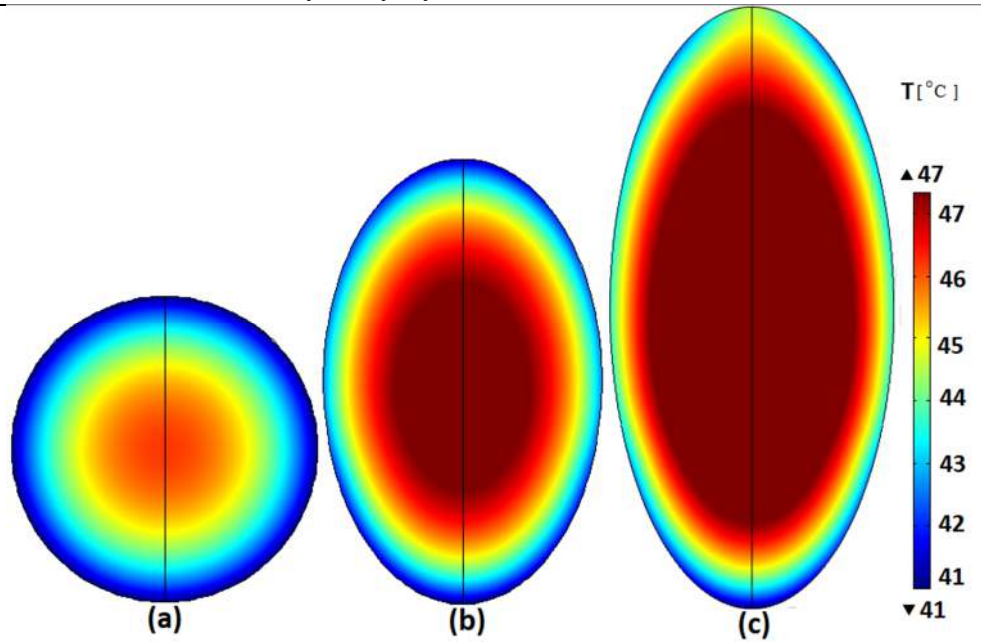


Figure 2- Temperature distribution in the tumor at different locations (Figs. 4a and 4b):
(a) Tumor in the stomach (before metastasis), (b) Tumor with 50% metastasis to the peritoneum, (c) Complete peritoneal metastasis.

This study investigated the effects of tumor location and abdominal fat content on the magnetic field distribution, heat generation, and temperature during magnetic nanoparticle hyperthermia. The governing equations were solved using the finite element method with cylindrical coordinates. Numerical results showed that:

1. The magnetic field generated by the induction coil is more uniformly distributed in pre-metastasis tumors. In contrast, the highest magnetic field intensity occurs in full peritoneal metastasis, while the lowest is observed in gastric tumors before metastasis. Abdominal fat amount and thickness do not affect the magnetic field within the tumor.

2. Heat generated by nanoparticles is more uniformly distributed in gastric tumors before metastasis. Maximum heat generation occurs in full peritoneal metastasis and minimum in gastric tumors. Abdominal fat does not influence heat generation.

3. The highest temperature is always at the tumor center. Pre-metastasis tumors exhibit a more uniform temperature distribution with smaller temperature differences, making treatment easier and less challenging.

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4. In all cases, tumor cells reached the therapeutic range of 41–47°C, indicating that this method can treat cancer under all conditions, though pre-metastasis treatment is simpler.

5. Abdominal fat has no effect on treatment efficacy, making this approach feasible for obese patients.

6. The maximum temperature in healthy tissue was 44.4°C, showing no damage to adjacent normal tissue.

Reference

[1] Z. Hedayatnasab, F. Abnisa, W.M.A.W. Daud, Review on magnetic nanoparticles for magnetic nanofluid hyperthermia application, Materials & Design, 123 (2017) 174-196.

https://doi.org/10.1016/j.matdes.2017.03.036

[2] R.E. Rosensweig, Heating magnetic fluid with alternating magnetic field, Journal of magnetism and magnetic materials, 252 (2002) 370-374.

https://doi.org/10.1016/S0304-8853(02)00706-0

[3] H.H. Pennes, Analysis of tissue and arterial blood temperatures in the resting human forearm, Journal of applied physiology, 1 (1948) 93-122.

https://doi.org/10.1152/jappl.1948.1.2.93

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