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Numerical Simulation and Comparison of Prostate Cancer Hyperthermia Using Microwave and Radiofrequency Waves

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Extended Abstract

Introduction

Cancer is a leading global cause of mortality, characterized by uncontrolled cell growth forming tumors that can be benign or malignant. Malignant tumors pose a significant threat through their ability to metastasize, spreading to other body parts and complicating treatment. Early-stage diagnosis, when the tumor is localized, offers the most effective treatment outcomes, typically involving surgery combined with adjuvant therapies like chemotherapy and radiotherapy to eliminate the primary tumor and prevent recurrence. Among various treatment modalities, hyperthermia—destroying cancer cells by elevating tumor temperature to 41-46°C—has proven effective, particularly for internal tumors in organs like the liver and prostate. This method induces cell death via both necrosis (immediate, localized damage) and apoptosis (programmed, clean cell removal), with techniques including radiofrequency ablation (RFA) and microwave ablation (MWA) being commonly used. This study addresses a critical research gap by conducting a comprehensive numerical investigation to compare the efficacy of two hyperthermia techniques—RFA and MWA—specifically for prostate tumor treatment. While both methods are clinically used, a direct comparative analysis of their effectiveness and the resulting necrotic patterns in prostate tissue has been lacking. RFA utilizes electrical currents (450-500 kHz) to generate heat through resistive heating, whereas MWA employs electromagnetic waves (300 MHz-30 GHz) that cause water molecules to oscillate, producing heat. The primary objective of this research is to numerically model and compare the thermal ablation zones and necrosis profiles induced by each method within the prostate, thereby providing crucial predictive data to determine which technique offers superior performance for treating prostate tumors.

Geometry of the Study

The geometry of the study was adapted to the physics of the probes: a 3D model was used for simulating radiofrequency waves, while a 2D axisymmetric geometry was employed for microwave simulations. For the radiofrequency ablation, a voltage of 8 volts was applied for a duration of 10 minutes. For the microwave ablation, a frequency of 2.45 GHz and a power of 10 watts were set.The most critical parameter in evaluating the efficacy of a hyperthermia treatment method is the accurate modeling of heat transfer and the determination of temperature distribution within the target tissue. Biological tissue can be modeled as a saturated porous medium. The most common and widely accepted model for this bioheat transfer analysis is the Pennes bioheat equation.

Results and Discussion

Based on the obtained results, both radiofrequency (RF) and microwave (MW) hyperthermia methods generate the highest temperature and tissue necrosis in the area adjacent to the heat source (applicator/trocar), and a decreasing gradient in temperature and necrosis intensity is observed with increasing distance. However, a comparison of the two methods reveals different necrosis patterns. In the RF method, necrosis eventually reaches the maximum value (1) at different distances from the source, whereas in the microwave method, the necrosis rate decreases significantly with increasing distance (e.g., up to 20 mm, reaching 0.6, for instance). This indicates that the microwave method, despite deeper penetration, provides better control over the necrosis zone and concentrates the thermal damage more within the target area. Therefore, from the perspective of controlling the treatment zone

and minimizing damage to surrounding healthy tissues, the microwave hyperthermia method is considered more favorable.

Conclusion

This research investigated and compared prostate tumor hyperthermia using two methods: radiofrequency waves and microwave waves. The findings of this study indicate that while both methods are effective in inducing tissue necrosis, there are significant differences in their effect on the necrosis rate and heat distribution. In the radiofrequency hyperthermia method, the temperature contour showed that areas close to the heat source had higher temperatures, and tissue necrosis occurred more intensely in these regions. In contrast, in the microwave method, the temperature and tissue necrosis distribution were wider, and a gradual decrease in the necrosis rate was observed with increasing distance from the heat source. An interesting point is that in microwave hyperthermia, tissues near the applicator reached the temperature required for necrosis in a shorter time compared to radiofrequency waves. Furthermore, the rate of tissue necrosis in microwaves gradually decreased with increasing distance from the heat source, whereas in radiofrequency waves, the necrosis reached the maximum possible extent. These results suggest that the use of microwave waves, due to better control over temperature distribution and tissue necrosis, may be a more efficient method for treating prostate tumors. This method could also reduce the risk of damage to healthy tissues surrounding the tumor. The results of this research can contribute to improving treatment methods and selecting the optimal approach for patients requiring hyperthermia therapy.

Key words: Hyperthermia, Prostate, Radiofrequency, Microwave, Tumor

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