PhD ABSTRACTS

STUDY OF DOSIMETRIC AND THERMAL PROPERTIES OF A NEWLY DEVELOPED THERMO-BRACHYTHERAPY SEED FOR TREATMENT OF SOLID TUMORS

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Studies on the curative effects of hyperthermia and radiation therapy on treatment of cancer show strong evidence of synergistic enhancement when both radiation and hyperthermia treatment modalities are applied simultaneously. A variety of tissue heating approaches developed to date still fail to overcome essential limitations such as inadequate temperature control, temperature non-uniformity, and prolonged time delay between hyperthermia and radiation treatments. We propose a new self-regulating Thermo-brachytherapy (TB) seed, which serves as a source of both radiation and heat for concurrent administration of brachytherapy and hyperthermia.

The proposed seed is based on the Best® Iodine-125 seed model 2301, where the tungsten marker core and the air gap are replaced with ferromagnetic material. The ferromagnetic core produces heat when subjected to an alternating electromagnetic (EM) field and effectively shuts off after reaching the Curie temperature (T_C) of the ferromagnetic material, thus establishing temperature self-regulation. The seed has a ferromagnetic Ni-Cu alloy core having a Curie transition at a temperature of 52 °C. This study summarizes the design and development of the self regulating ferromagnetic core TB seed for the concurrent hyperthermia and brachytherapy treatments. An experimental study of the magnetic properties of the $Ni_{1-x}Cu_x$ ($0.28 \leq x \leq 0.3$) alloys, and the simulation studies of radiation and thermal distribution properties of the seed have been performed. A preliminary experiment for the ferromagnetic induction heating of Ni-Cu needles has been carried out to ensure the practical feasibility of the induction heating.

Radiation dose characterizing parameters (dose rate constant and other TG-43 factors) were calculated using the Monte Carlo method. For the thermal characteristics, we studied a model consisting of single or multiple seeds placed in the central region of a cylindrical phantom using a finite-element analysis method, with and without considering the effect of the blood perfusion.

The experimental study of the Ni-Cu alloys shows that heat treatment has a strong influence on the magnetic properties of the Ni-Cu alloy. The Curie transition temperature, (T_C), of the $Ni_{1-x}Cu_x$ alloy decreases drastically with an increase in copper composition in the alloy. The study of the thermal expansion properties of the seed materials in the range of 37°C to 60°C shows negligible change in dimension due to the change of the temperature during the treatment. Imaging studies using CT and plane X-ray radiographs on the other hand, demonstrated that the new seed preserves the radiographic properties of the standard BEST seed model 2301 and is realistic for clinical use.

The modification of the internal structure of the seed slightly changes dose rate and other TG-43 factors characterizing radiation distribution. The thermal modeling results show that the temperature of the seed surface rises rapidly and stays constant around T_C of the ferromagnetic material. The amount of heat produced by the ferromagnetic core is sufficient to raise the temperature of the surrounding phantom to the therapeutic range. The volume of the

phantom reaching the therapeutic temperature range increases with the increase in frequency or magnetic field strength. An isothermal distribution closely matching the radiation isodose distribution can be achieved within a target volume by tuning the frequency and intensity of the alternating magnetic field. The effect of heat loss due to the blood perfusion in a living tissue can be compensated by adjusting the magnetic field parameter. The results of the preliminary induction heating experiment conducted in a ham slice (implanted with ferromagnetic needles) demonstrated practical feasibility of induction heating and thermal self regulating property of the ferromagnetic Ni-Cu alloy.

Modeling studies of the radiation and thermal properties of the TB seed show that the therapeutic implementation of the concurrent hyperthermia and brachytherapy treatment of the tumor is feasible. The seed has the capability of addressing some of the limitations of conventional hyperthermia treatment techniques, and has several advantages. The proposed seed model has high potential in the implementation of concurrent brachytherapy and hyperthermia treatments.

REFERENCES

1. J. van der Zee, D. G. González, G. C. van Rhoon, J. D. P. van Dijk, W. L. J. van Putten, A. A. M Hart, “Hyperthermia combined with radiotherapy: prognostic significance” CME Journal of Gynecologic Oncology 6, 364-370 (2000).
2. I. A. Brezovich, W. J. Atkinson, and M. B. Lilly, “Local Hyperthermia with interstitial Techniques” Cancer Research 44, 4752s-4756s (1984).
3. S. D. Ferguson, J. A. Paulus, R. D. Tucker, S. A. Loening, and J. B. Park “Effect of Thermal Treatment on Heating Characteristics of Ni-Cu Alloy for Hyperthermia: Preliminary Studies” Journal of Applied Biomaterials, Vol. 4, 55-60 (1993).
4. Bhoj Gautam, E.Ishmael Parsai, Diana Shvydka, John Feldmeier, and Manny Subramanian, “Dosimetric and Thermal Properties of a Newly Developed Thermobrachytherapy Seed with Ferromagnetic Core for Treatment of Solid Tumors” Medical Physics Vol 39 (4) April pp 1980-90 (2012)

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