

Pre-clinical Modelling and Simulation of Hepatic Radiofrequency Ablation

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Abstract

Radio-Frequency ablation (RFA) technique has received considerable interest as a minimally invasive treatment technique used for the destruction of a variety of primary and metastatic hepatic tumors. A parametric study of hepatic radio-frequency ablation has been done in order to determine the optimal value of the applied energy (i.e., the power and treatment time) adequate to ablate the target tumor for different stages of liver cancer. A three-dimensional thermoelectric analysis on FEM model consisting of human liver, electrode and tumor has been conducted by varying the applied voltages (10-30 V) and tumor diameters. The induced lesion volume has been quantified by employing first-order Arrhenius rate equation and the effects of variable conductivity and blood perfusion have been addressed in this study. The finite element analysis revealed that, the effective damage of tumor volume depends on the input power, treatment time and tumor size. It has been confirmed that temperature isotherms and tissue damage patterns are not synonymous and temperature isotherms grossly overestimate the size of thermal lesion produced as compared to the damage front. These results can be used to provide a practical and fast guideline to clinical practitioners.

INTRODUCTION: Minimally invasive thermal ablation of tumors has become common since the advent of modern imaging [1]. RFA (Figure 1) is a widely studied minimal invasive treatment method for inoperable cancer of liver having number of benefits, including decreased risk of complications from anesthesia, improved cosmesis and shortened recovery time, which may decrease the morbidity and mortality of patients [2]. Temperatures between 60 °C and 100 °C are generated by a high-frequency alternating current, which induces frictional heating that causes cell injury and subsequent coagulative necrosis (Figure 2)[3].

USE OF COMSOL MULTIPHYSICS®:After importing the 3-D CAD model of liver, the tumor [4] and trocar [2] have been constructed using geometry interface of COMSOL (Figure 3). In the present study, electric currents (ec) physics of AC/DC module and bioheat transfer (ht) physics of Heat Transfer module of COMSOL Multiphysics have been used to solve the FEM problem.

RESULTS:

1. The optimal values of treatment time and power have been provided for different stages of liver cancer based on damage integral.
2. The effect of perfusion on lesion size has been studied, and it is concluded that tumor perfusion is more significant than surrounding tissue perfusion.

3. It has been revealed that, below 100 °C inclusion of variable electrical conductivity of both tissue and tumor has very little impact on the maximal ablation temperature reached during RFA.
4. It has been confirmed that the size of thermal lesions is grossly overestimated when calculated using isotherms compared to the damage front.

CONCLUSION: For different stages of tumor the voltage and treatment time have been optimised to achieve a good control during clinical RFA by employing mild voltages and reasonably longer time for minimizing an undesirable thermal injury to the healthy tissue. These results along with patient-specific models for RFA planning and simulation can be used to provide a practical and fast guideline to clinical practitioners.

Reference

- [1] S.N. Goldberg, Radiofrequency tumor ablation: Principles and techniques, *European Journal of Ultrasound*, 13(2), pp. 129–147 (2001).
- [2] Supan Tungjitkusolmun et al., Three-dimensional finite-element analysis for radio-frequency hepatic tumor ablation between, *IEEE Trans. Biomed. Eng.*, 49(1) (2002).
- [3] K.F. Chu & D.E. Dupuy, Thermal ablation of tumours: biological mechanisms and advances in therapy, *Nature Reviews Cancer*, 14(3), pp. 199-208 (2014).
- [4] F.L. Greene et al., *AJCC Cancer Staging Atlas, Part VI*, Springer, New York, 217-234.

Figures used in the abstract

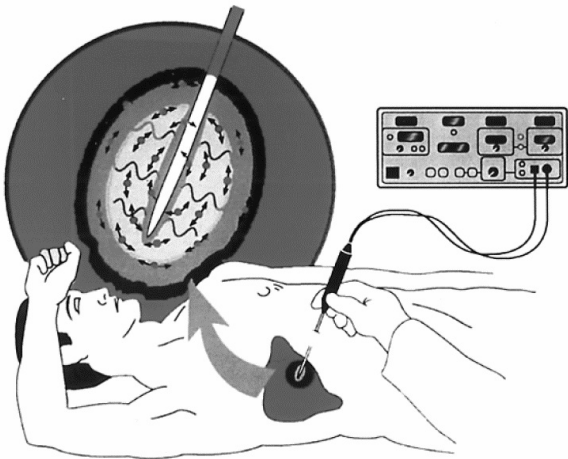


Figure 1: Figure 1. Schematic illustration of percutaneous radio-frequency ablation in the liver [1]. This figure demonstrates the insertion of an RF electrode into a tumor within the liver. The electrode is connected to the RF generator. Resistive heating occurs as a result of ionic agitation surrounding the electrode as the RF energy oscillates during attempts to reach its ground (in this case, the grounding pad is not visualized on the patient's back).

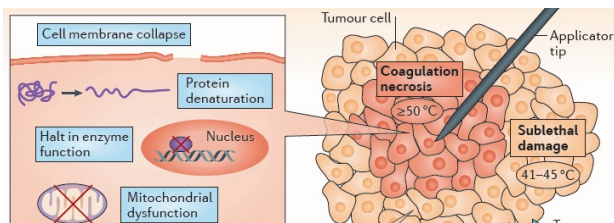


Figure 2: Figure 2. The zone of radio-frequency ablation [3]. Coagulative necrosis occurs at a temperatures $\geq 50^{\circ}\text{C}$ which leads to collapse of cell membrane, protein denaturation, a halt in enzyme activity and DNA polymerase function, and mitochondrial dysfunction.

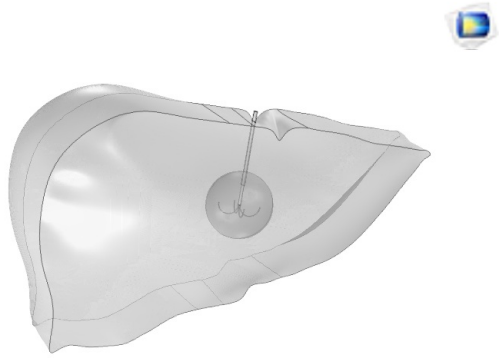


Figure 3: Figure 3. Schematic of 3-D model for hepatic radiofrequency ablation in COMSOL MULTIPHYSICS.