PRE-CLINICAL MODELLING AND SIMULATION OF HEPATIC RADIOFREQUENCY ABLATION

Presenter : **Sundeep Singh**

Co-author : **Dr. Ramjee Repaka**

School of Mechanical, Materials & Energy Engineering,
Indian Institute of Technology Ropar, Punjab, India.

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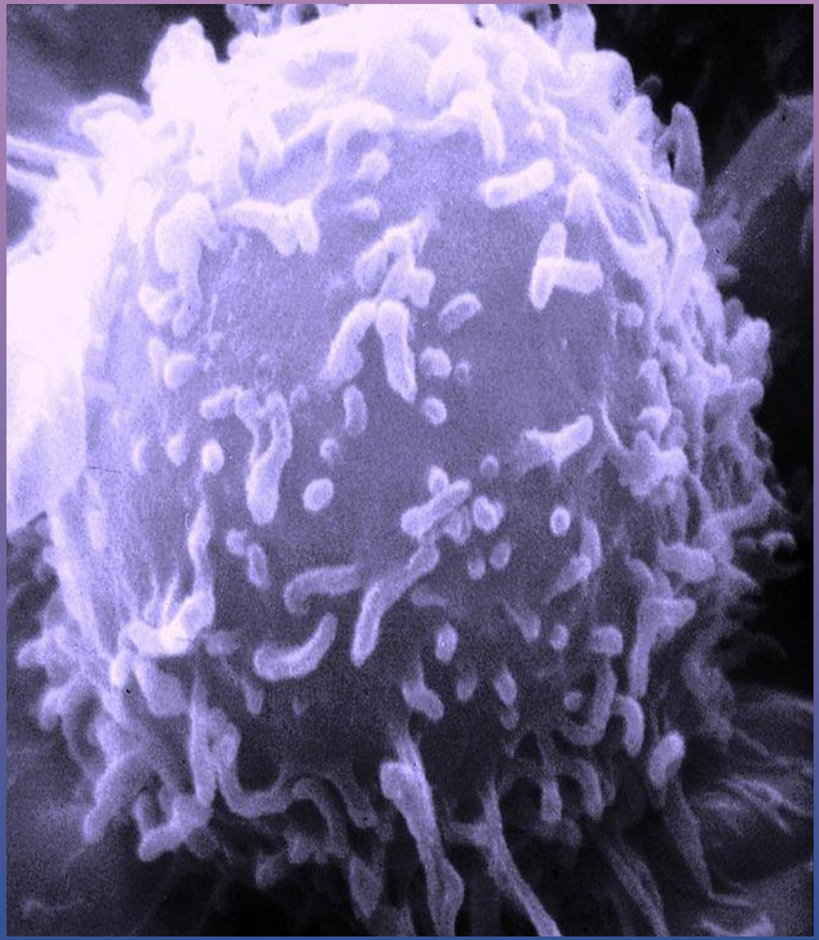
Overview of Presentation

INTRODUCTION

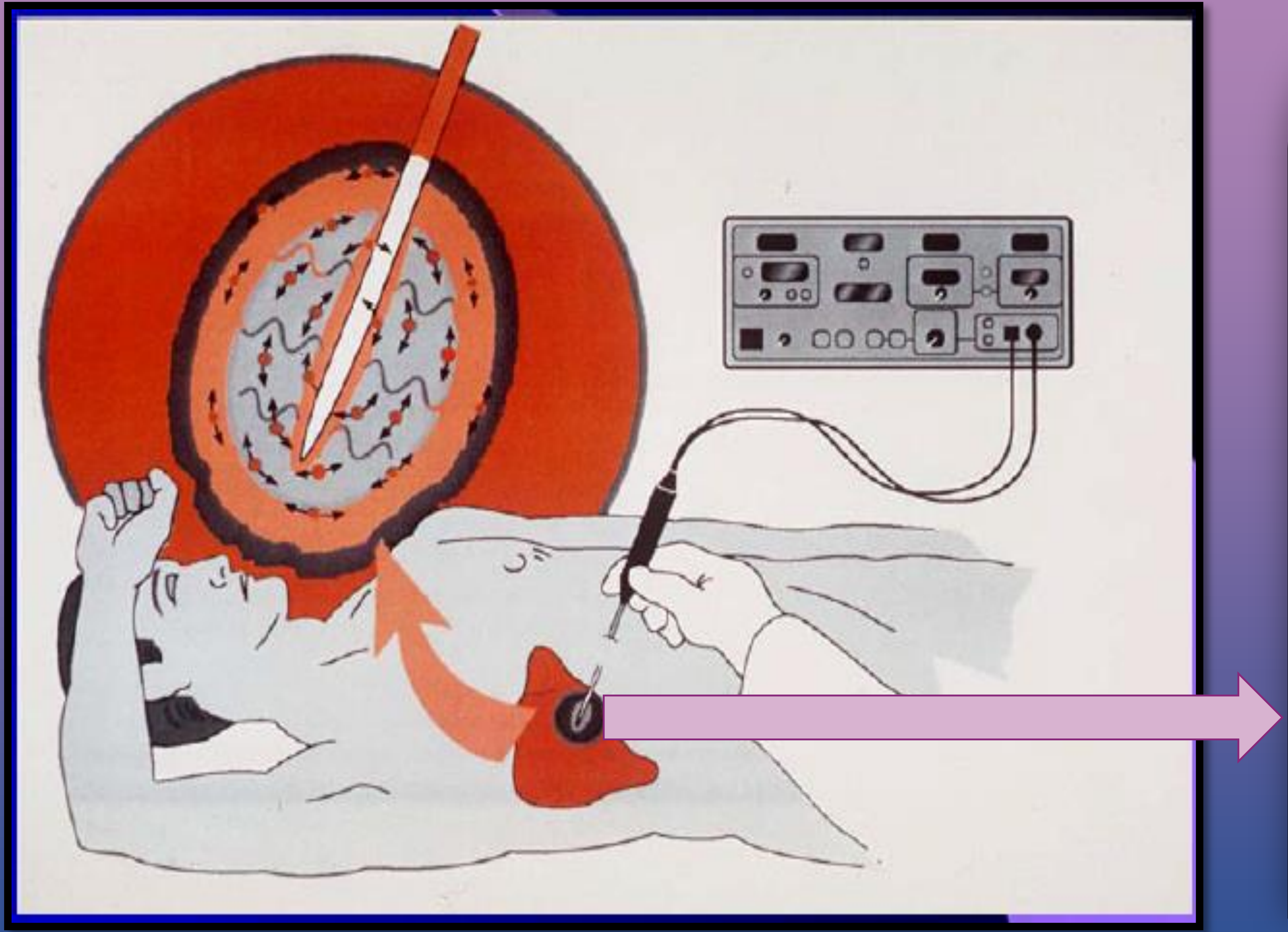
- Despite significant progress in understanding, diagnosing, treating, and preventing the disease in the past decades, cancer still remains the major threat to human beings.
- Cancer is a leading cause of mortality worldwide, with 8.2 million deaths in 2012.
- Primary liver cancer is the second leading cause of cancer mortality after lung cancer.
- Minimally invasive thermal ablation techniques have become common with the advancement in modern imaging.
- Out of all the thermal ablative techniques, radio-frequency ablation (RFA) is the widely studied treatment method for variety of primary and metastatic hepatic tumors.



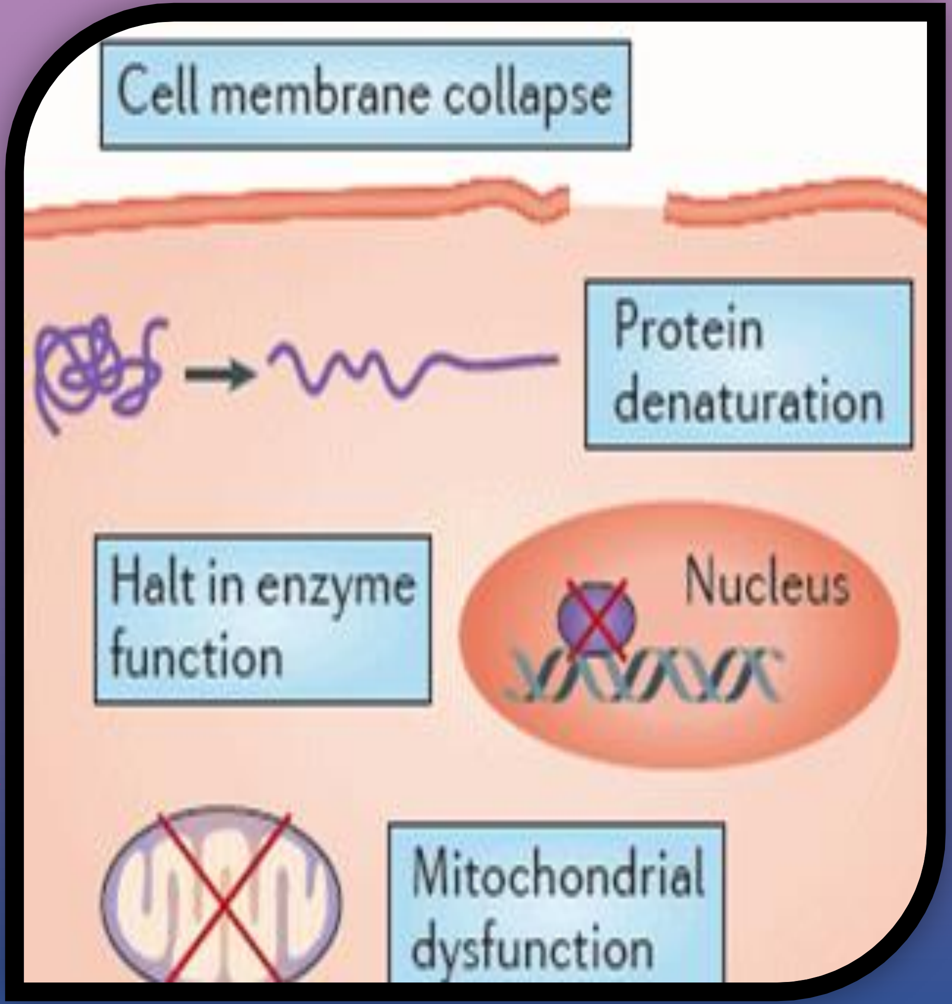
RFA THEORY

- During RFA, one or more electrodes are inserted percutaneously into the tumorous tissue with the help of image guidance techniques.
- Once positioned, high-frequency alternating current (450–550 kHz) is delivered through these electrodes into the tissue that induces frictional heating.
- The higher temperature above 50 ^{0}C causes destruction of tumor cell by instantaneous induction of protein coagulation.
- Interestingly, the higher temperatures should be strictly below 100 ^{0}C to avoid tissue carbonization and water vaporization.
- Additionally, RFA planning is hampered if the ablated tumor is near the large blood vessels that causes a heat sink effect, and thus decreases the ablation volume

RADIOFREQUENCY ABLATION



Source: M. Ahmed and S. N. Goldberg, Radiofrequency tissue ablation: principles and techniques.



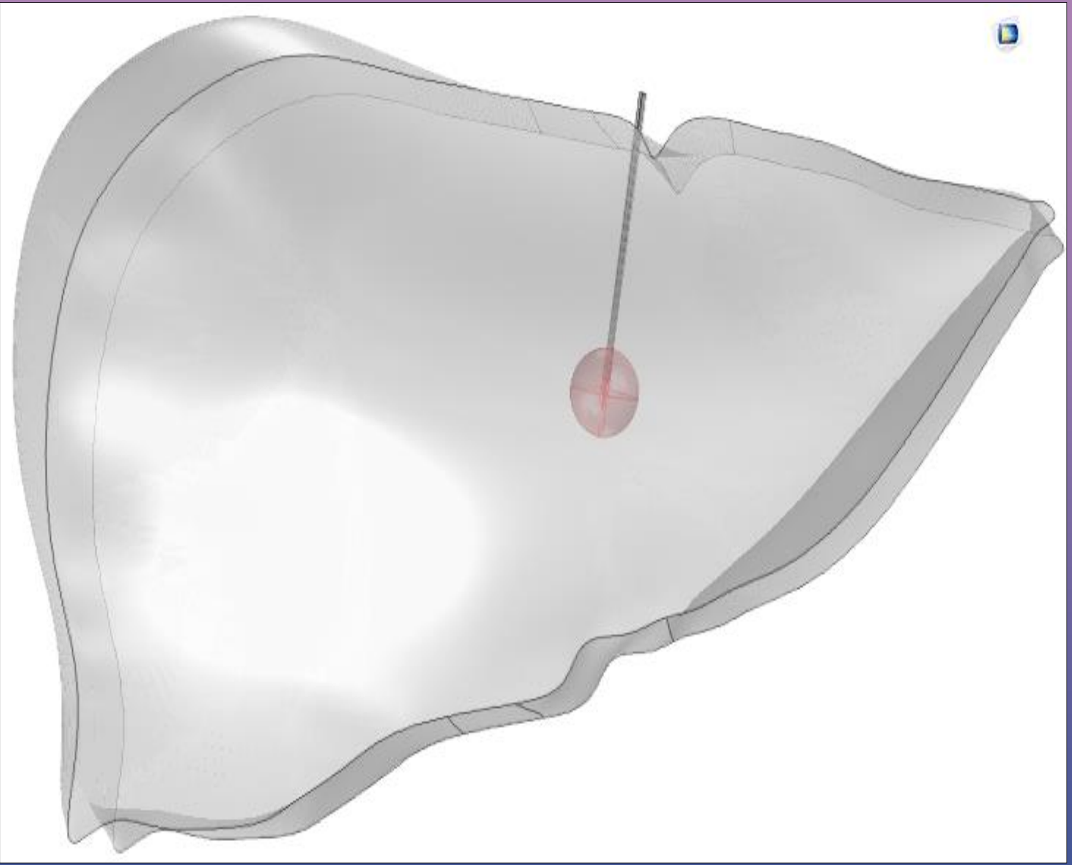
Source: K.F. Chu & D.E. Dupuy, Thermal ablation of tumours: biological mechanisms and advances in therapy.

NUMERICAL MODELING

- The model of realistic human liver anatomy has been constructed based on the anatomical details available in the literature.

- A spherical tumor of varying diameter (D< 5 cm) of stage T1 of TNM (Tumor, Node, Metastasis) based on staging guidelines given by American Joint Committee for Cancer Staging (AJCCS) has been embedded into the liver.

- Furthermore, the tumor diameter has been varied to consider two stages, viz., stage 0 (D < 2 cm) and stage A (2 cm ≤ D < 3 cm) based on the staging guidelines given by Barcelona Clinic Liver Cancer (BCLC) staging system.



GOVERNING EQUATIONS

- The electric field distribution within the tissue due to applied voltage on RF electrode is computed by laplace equation

$$\nabla \cdot (\sigma \nabla V) = 0$$

$$E = -\nabla V$$

$$J = \sigma E$$

- The temperature within the liver tissue subjected to electric heating during RFA is calculated by pennes bioheat equation

$$\rho c \frac{\partial T}{\partial t} = \nabla (k \nabla T) - \rho_b c_b \omega_b (T - T_b) + Q_m + J.E$$

- The damage integral is computed using first order arrhenius equation

$$\Omega(t) = ln \frac{C_0}{C_{UD}(t)} = \int A \, exp \left[-\frac{E_a}{RT(t)} \right] dt$$

MODELING OF BLOOD PERFUSION AND VARIABLE CONDUCTIVITY

- Earlier studies have shown that, blood perfusion (ω_b) within the tumor is more than the surrounding healthy tissue and is assumed to be increasing initially due to vasodilation of capillaries caused by heating of perfused tissue, and later decreases with time/induced damage.

$$\omega_b(t) = \begin{cases} \omega_{b,0} & \text{for } \Omega(t) \le 0 \\ \omega_{b,0}\left[1 + 25\Omega(t) - 260\Omega(t)^2\right] & \text{for } 0 < \Omega(t) \le 0.1 \\ \omega_{b,0}\exp\left[-\Omega(t)\right] & \text{for } \Omega(t) > 0.1 \end{cases}$$

- The electrical conductivity dependence on temperature has been calculated from

$$\sigma(T) = \sigma_0\left[1 + \alpha_\sigma (T - T_c)\right]$$

MATERIAL PROPERTIES

Tissue	**Electrical conductivity S/m**	**Specific heat J/kg.K**	**Thermal conductivity W/m.K**	**Density kg/m^3**	**Blood perfusion s^{-1}**
Liver	0.333	3600	0.512	1060	0.0017
Tumor	0.1168	4200	0.552	999	0.0156
Electrode	9.8×10^5	500	36.7	8100	–
Trocar	10^{-16}	1010	0.23	2190	–

BOUNDARY CONDITIONS

Computational Domain

- Electric Potential = 0 V
- Temperature = 37 ^{0}C

Inactive Part of Electrode

- Electrical Insulation
- Thermal Insulation

Active Part of Electrode

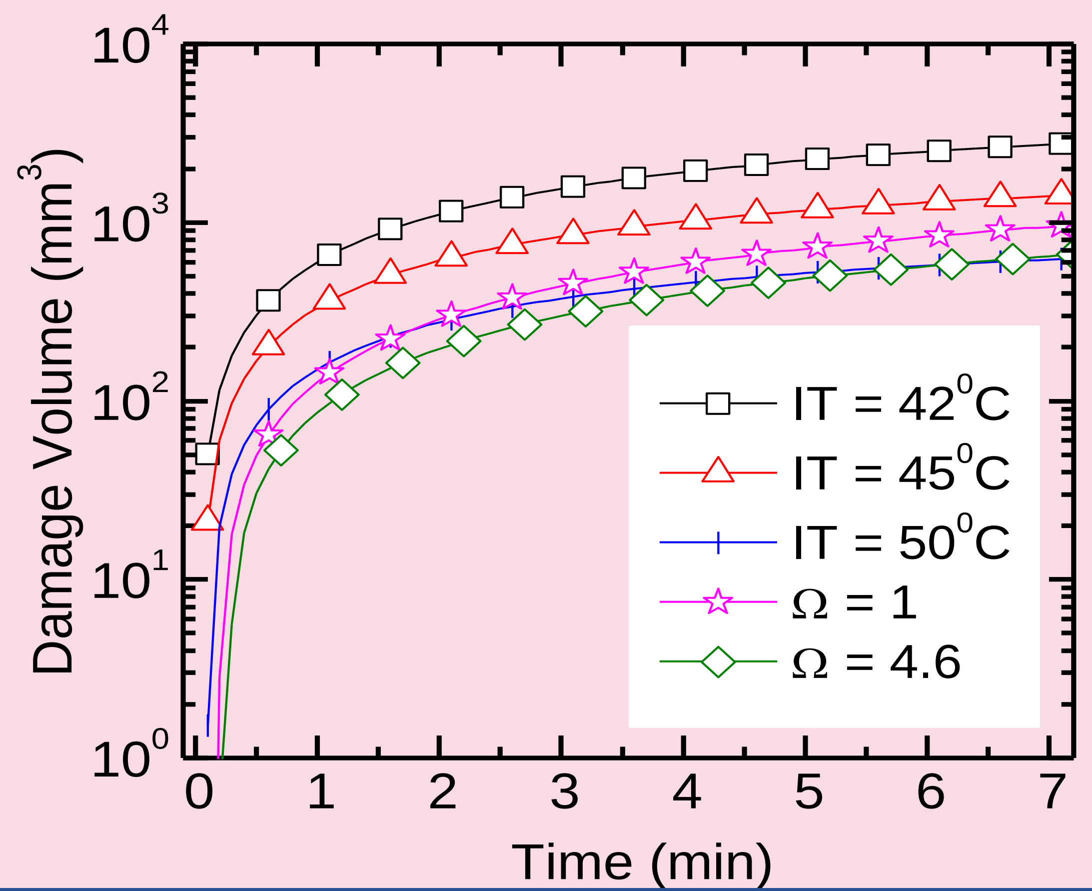
- Electric Potential 10-30 V
- Initial Temperature = 25 ^{0}C

RESULTS

Optimal voltage and treatment time for different tumor diameters during RFA.

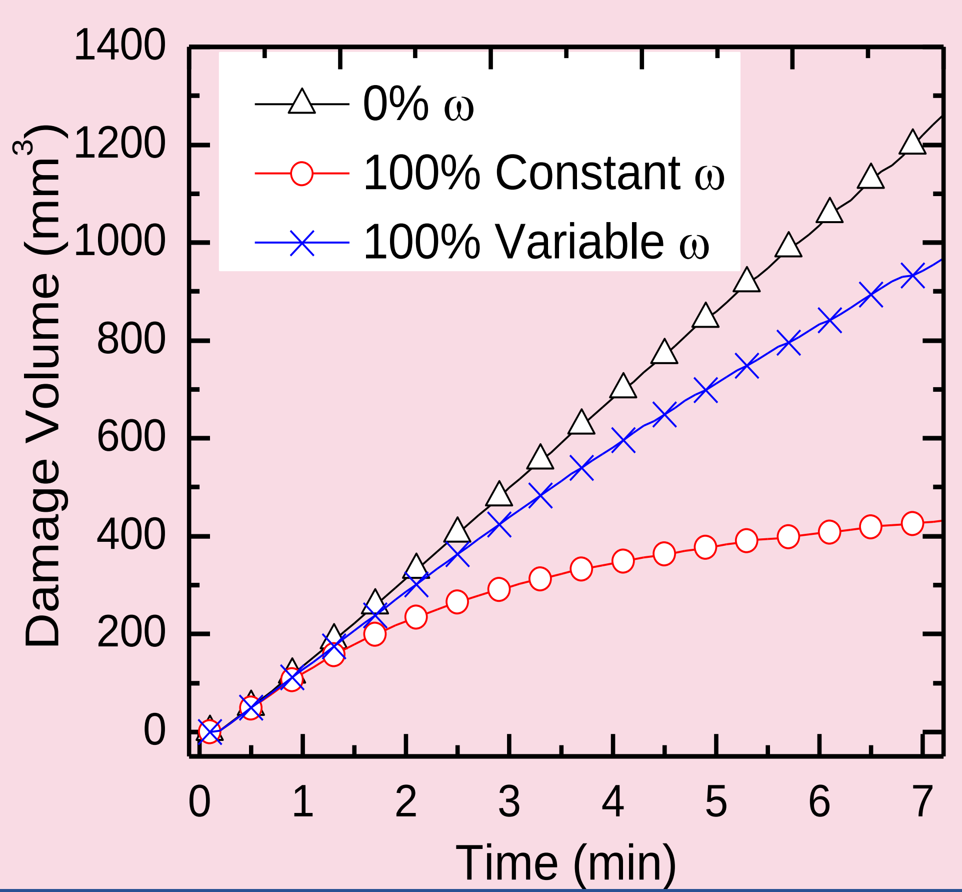
Tumor Diameter	Optimal Voltage	Time to reach Ω =1	Time to reach Ω =4.6
D = 1 cm	20 V	4.7 min	7.2 min
D = 1.5 cm	25 V	8.4 min	12.9 min
D = 2 cm	30 V	12.7 min	18.7 min

Total volume of tissue necrosis using thermal damage integral and isothermal temperatures.

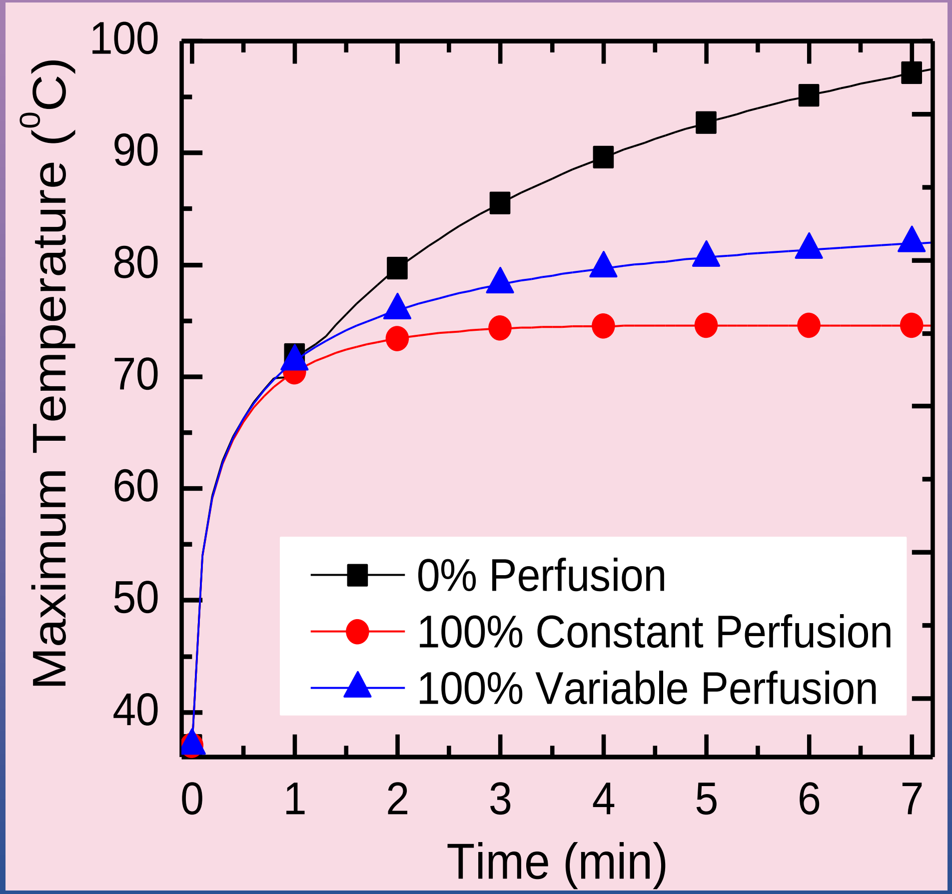


RESULTS

Effect of perfusion on lesion volume corresponding to thermal damage integral Ω ≥ 1 with time.

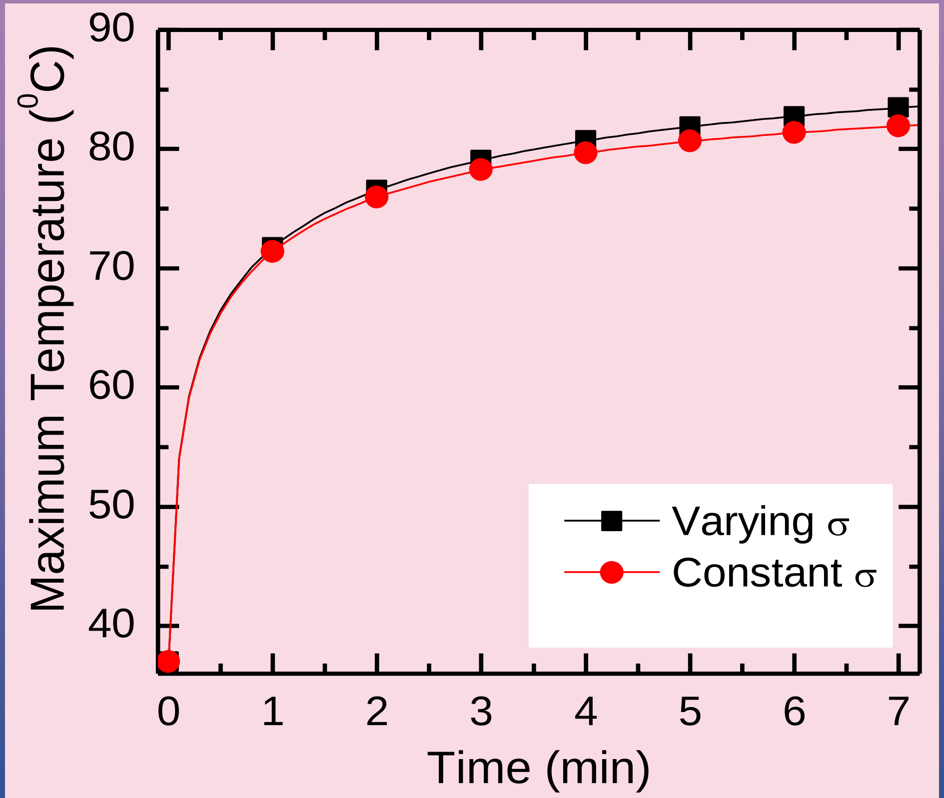


Effect of perfusion on maximum temperature achieved during RFA with time.

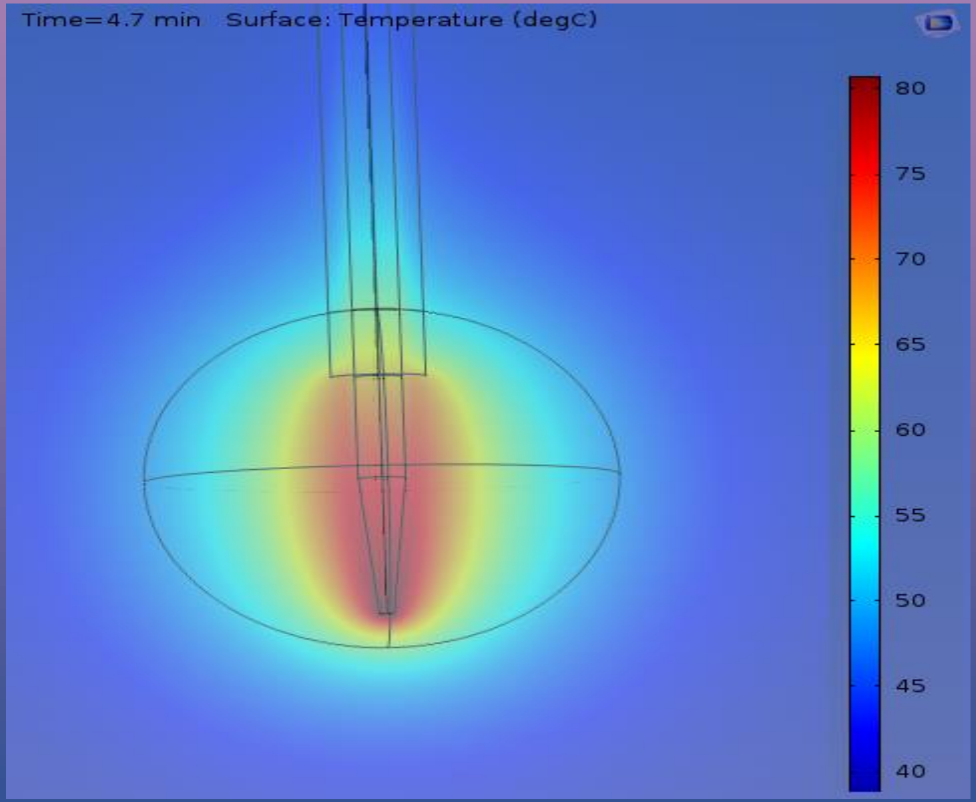


RESULTS

Effect of variable electrical conductivity on maximum temperature achieved with time.



Temperature distribution for 1 cm diameter tumor with 20 V after 4.7 minutes.



CONCLUSIONS

A parametric study has been performed on three-dimensional FEM models of liver having different stages of liver cancer that revealed following results:

1. The increase in thermogenic capacity due to increase in tumor volume causes a significant increase in the treatment time for a particular applied voltage.

2. The blood perfusion has an immense effect on lesion volume produced and the tumor perfusion is more significant than the surrounding tissue perfusion during RFA.

3. The lesion volume produced by damage front and conventional isotherms are not synonymous and the size of thermal lesions is grossly overestimated when calculated using isotherms.

4. The effect of constant electrical conductivity compared to varying electrical conductivity on maximum temperature is negligibly small during RFA.

The present results of pre-clinical modelling and simulation of hepatic cancer, along with patient-specific models can be used to provide a practical and fast guideline to clinical practitioners during RFA.

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THANK YOU FOR YOUR ATTENTION!!

ANY QUESTIONS/QUERY??