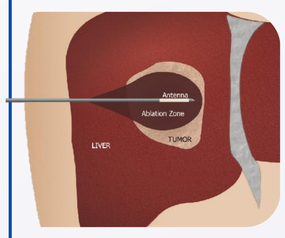
FROM MICROWAVE HEATING TO BIOIMPEDANCE

Coupled 2.45GHz-20kHz Modeling of Liver Ablation in COMSOL

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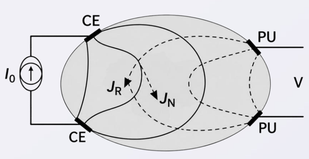
STUDY 1 Microwave field (2.45 GHz, 60 W) → $E \rightarrow Q_{mw}$ → **STUDY 1** Bioheat transfer (T(r,t), 0-600 s) → $T(r,t)$ → **STATE TRANSFER** Material update → $\sigma(r,T)$, $\varepsilon_r(r,T)$ → **STUDY 2** Electric Currents ($Z_{tr}(t,T)$)

01 Introduction



Microwave ablation (MWA) creates nonuniform heating. Bioimpedance can provide a complementary electrical response, but it depends on tissue properties and electrode sensitivity. We connect microwave heating to tetrapolar bioimpedance in one COMSOL framework to examine this relationship.

Sensitivity



Sensitivity (S) describes the extent to which each tissue region contributes to the measured impedance signal. Regions with high sensitivity have a stronger influence on the Z_{tr} value.

Discussion & Conclusion

The temperature- impedance relationship reflects the implemented conductivity law and is consistent with impedance trends reported during porcine-liver MWA by Zhang *et al.* (2024). Stable sensitivity topology indicates that spatial weighting is mainly geometry-driven.

The framework consistently transfers thermal states to the 20kHz electrical model. The temperature-impedance relationship supports further monitoring studies with frequency-specific properties and experimental validation.

02 Multiphysics Model and Methods

2.1 Model Geometry and Mesh

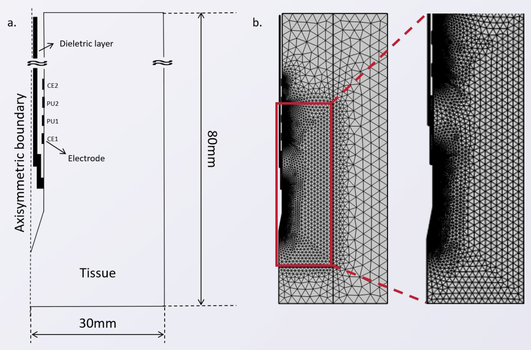


Fig. 1. 2D axisymmetric model geometry (a.) and finite element mesh (b.) for the liver model. The zoomed view show the region of interest (ROI) near the antenna/ electrode region.

- 2D axisymmetric
- Liver + MWA antenna + 4 electrodes
- ROI: the region near antenna & electrodes
- Mesh: free triangular with 69,818 elements
- Mesh quality: min 0.445, avg 0.914

2.2 Physics Interfaces

- **Electromagnetic Waves, Frequency Domain** — Microwave electromagnetic field: 2.45GHz
- **Bioheat Transfer** — Temperature field, from microwave heating
- **Electric Currents, Frequency Domain** — Low-frequency bioimpedance response, 20kHz
- **Multiphysics Coupling: EM→Heat→Electrical** — Sequential coupling of physics interfaces

2.3 Simulation Parameters

- **Microwave: 2.45GHz, 60W**
- **Bioimpedance: 20kHz, 0.5mA**
- **Simulation time: 0-600s**
- **Sampling every 10s: 61 states**

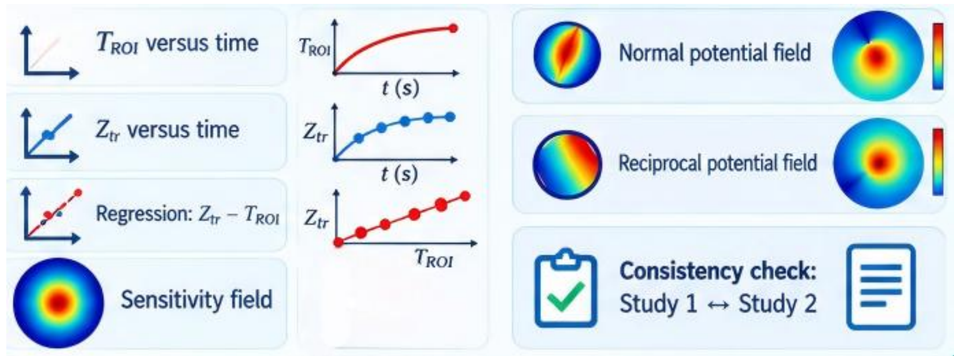
2.4 Sequential Coupling Logic

1. **Step 1: Solve the eletromagnetic field E**
2. **Step 2: Compute the heat source $Q_{mw} = \frac{1}{2}\sigma|E|^2$**
3. **Step 3: Solve bioheat model to obain T(r,t)**
4. **Step 4: Update σ(T), ε_r(T)**
5. **Step 5: Transfer thermal snapshots to Electric Currents**
6. **Step 6: Compute $Z_{tr} = \frac{\Delta V}{I_0}$**

2.5 Main Equations

EM	$\nabla \times (\mu_r^{-1}\nabla \times E) - \kappa_0^2\left(\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}\right)E = 0$
Bioheat	$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + Q_{mw}$
Electric Currents	$\nabla \cdot J = 0$
	$J = (\sigma + j\omega\varepsilon_0\varepsilon_r)E$
	$E = -\nabla V$
	$T_{ROI} = \frac{1}{V_{ROI}}\int T dV$
	$Z_{tr} = \frac{V_{PU1} - V_{PU2}}{I_0} = \frac{\Delta V}{I_0}$
Sensitivity	$S = \frac{J_N \cdot J_R}{I_0^2}$

2.6 Post-processing & Outputs



03 Results

3.1 T_{ROI} vs Time

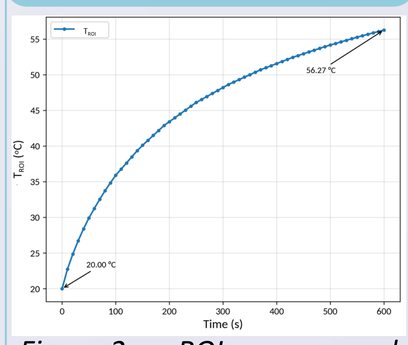


Fig. 2. ROI- averaged temperature (T_{ROI}) versus time. T_{ROI} increased from 20.00°C at 0s to 56.27°C at 600s.

3.2 Z_{tr} vs Time

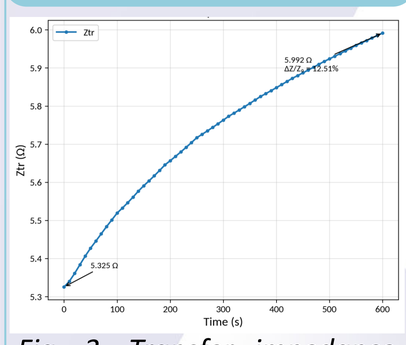


Fig. 3. Transfer impedance (Z_{tr}) versus time. Z_{tr} increased from 5.325Ω at 0 s to 5.992Ω at 600s, relative increase of 12.51%.

3.3 Z_{tr} vs T_{ROI}

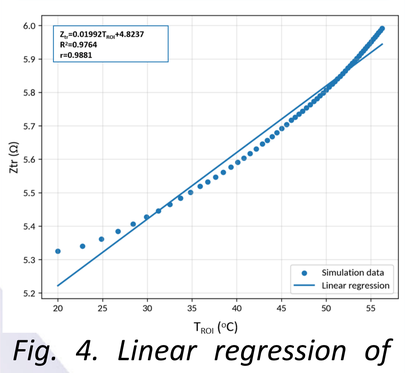


Fig. 4. Linear regression of transfer impedance versus ROI-averaged temperature.

3.4 Field Distribution During Heating (0, 300, 600s)

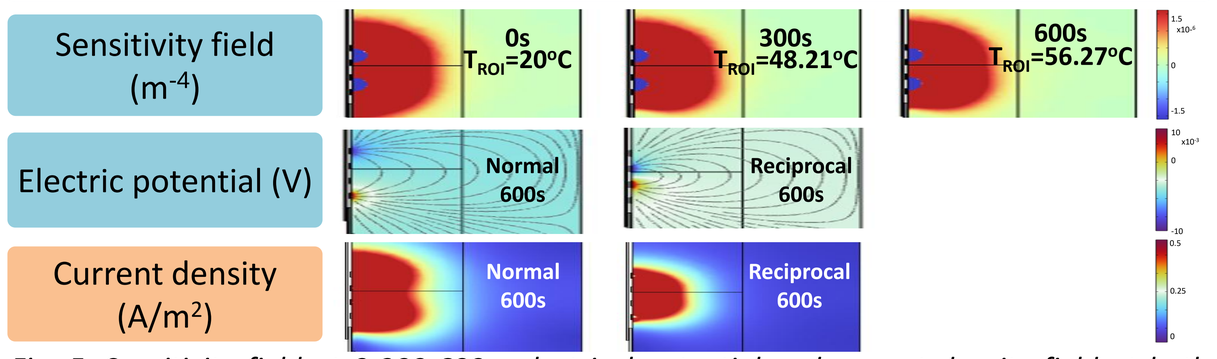


Fig. 5. Sensitivity field at 0-300-600s, electrical potential and current density field at both normal & reciprocal measurement at 600s. The sensitivity topology remains similar during heating, while the elctrical response magnitude changes; current density fields vary between normal and reciprocal measurement.

References

[1] S. Singh and R. Melnik, "Coupled thermo-electro-mechanical models for thermal ablation of biological tissues and heat relaxation time effects," Physics in Medicine & Biology, vol. 64, 245008, 2019.
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[3] S. A. Dipa, M. M. Pramanik, M. Rabbani, and M. A. Kadir, "Effects of temperature on electrical impedance of biological tissues: ex-vivo measurements," Journal of Electrical Bioimpedance, vol. 15, pp. 116-124, 2024.

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