Phantom for Microwave Ablation Device Testing

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1. Abstract

Microwave ablation is a cutting-edge process by which microwaves are emitted through thin antennas at 2.45 GHz to kill cancer cells through rapid heating. Our client, Dr. Chris Brace, tests new devices in bovine liver tissue; due to the opaque nature of the liver, it is very difficult to study the size of the ablation zone. In addition, the liver is only viable for a short period of time and is associated with a high cost. **Therefore, a consistent, homogeneous, transparent liver phantom with a clear ablation zone indicator is needed.** Different combinations of base gels – egg white, sodium polyacrylamide, silicone, sodium alginate, and poly(vinyl alcohol) – and indicators – thermochromic dye, egg white albumin, and bovine serum albumin – at different concentrations were tested. The dielectric properties, temperature of ablation, size of the ablation zone after five minutes of ablation at approximately 50 Watts were tested and compared to values obtain for similar tests on bovine livers. **A liver phantom was created out of egg white and egg white albumin**. For every egg white, 2.7 grams of egg white albumin were added, and the combination was stirred gently until the protein dissolves. The phantom has a permittivity of 52.51 Farads per meter (F/m) conductivity 2.25 Siemens per meter (S/m), an ablation temperature of 53.8 ºC, an ablation zone that measures 4.3 by 3.0 cm after five minutes of ablation. Further testing is still needed to verify the absolute consistency of these values; other materials may also be considered to better match the properties of the liver.

2. Background Information

- Microwave ablation
  - medical treatment for abdominal cancers
  - thin antennas positioned in tumors
  - microwaves rapidly heat, causing cell death
  - testing: animal livers (expensive, short shelf-life, can't see ablation zone)
    - phantoms (created for different types of ablation, usually very heterogeneous)
  - improved testing methods desired

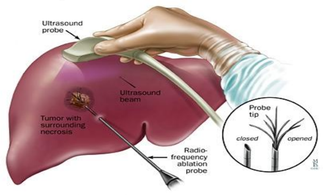

Figure 1: Probe is place in tumor and microwaves are supplied to rapidly kill cells during an ablation procedure.

- Liver Properties

	Units	Liver
Relative permittivity	F/m	43.3
Effective conductivity	S/m	1.68
Wavelength	Cm	1.8
Thermal conductivity	W/m K	0.564
Density	kg/m^3	1050
Specific heat capacity	J/kg K	3600
Perfusion rate	ml/min kg	1000

Table 1: Tissue Properties of the Liver at 37ºC, 2.45 GHz[6]

3. Design Specifications

Important qualities of a liver phantom:

- mimic qualities of liver
  - dielectric properties: permittivity (45 ± 5 F/m), conductivity (1.7±0.2 S/m)
- homogenous
- reproducible
- transparent
- clearly indicate ablation zone
- able to withstand high temperatures from 160 to 180 ºC without melting or deforming.
- reusable or easy to assemble
- cost effective (approximately $20 to $30)

4. Results

Final design: ***The final design is a mixture of egg white with added egg albumin; the ablation zone is clearly indicated by a clump of coagulated protein that can easily be measured. The dielectric properties are also similar to the liver. The phantom costs less than $2.00.***

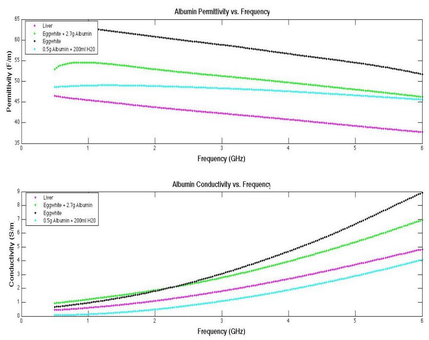

Figure 2 – Comparisons of dielectric properties of liver, egg white, albumin and the phantom.

	Egg White	Bovine Liver	Egg White Plus Egg Albumin
Quantity	4 eggs	225ml	4 eggs plus 0.8g albumin
Ablation Time	5 min	5 min	5 min
Initial Temp	15.3ºC	22.6ºC	16.6ºC
Ablation Temp	56.8C	Not observed	53.8ºC
Final Temp	111.7ºC	Not observed	108.8ºC
Width (cm)	2.8	3.2	3.0
Height (cm)	4	5.5	4.3

Table 2 – Summary table of ablation experiments of egg white, liver specimen and the phantom.

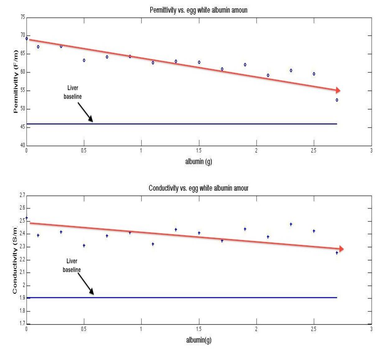

Figure 3 – Addition of egg white albumin adjust dielectric properties of egg white.

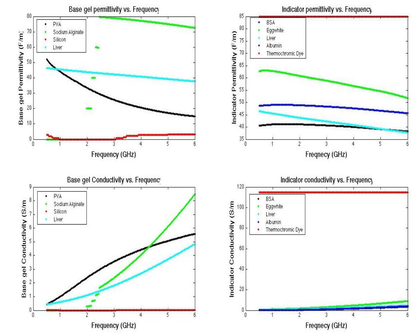

Figure 4 – Summary of dielectric properties of base gels and indicators

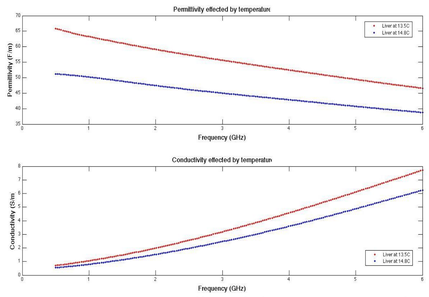

Figure 5 – Temperature affects dielectric properties of a liver specimen; warmer livers have lower permittivity and conductivity.

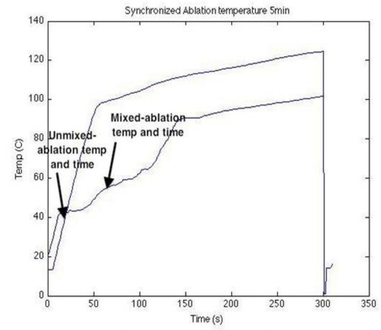

Figure 6 – Mixed vs. unmixed egg white in a synchronized ablation temperature measurement.

5. Procedures

Experimental

The samples were firstly inspected and tested for thermal property testing. Critical temperature, thermal instability, and indicating technique was initially assessed by testing on a hot plate. Later, the dielectric property testing was measured by the Agilent Technologies® E50701C ENA Series Network Analyzer and collected in the NI LabVIEW. The microwave ablation was performed with a the Cober Muegge microwave source with 50watts adjusted power. The ablation testing was performed in a 5 minute period for each sample specimen. A temperature probe was applied to measure synchronized ablation temperature.

Material

Four base gels were tested: Sodium alginate; polyacrylamide (Water Lock), Dow Corning dielectric silicon gel; Poly(vinyl) alcohol (PVA).
Four indicators were tested: Bovine Serine Albumin (BSA); egg white albumin; egg white; Hallcrest@ thermochromic dye.

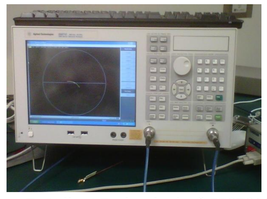

Figure 7: Agilent Technologies® E50701C ENA Series Network Analyzer was used to measure dielectric properties.

Figure 8: The final design is egg white plus albumin. The ablation zone is clearly seen.

6. Conclusion

- Phantom: egg white + egg albumin protein
  - Homogenous
  - Relatively transparent
  - Cost effective
  - Clear ablation zone
  - Similar dielectric properties, ablation zone size, ablation temperature, and heat propagation as liver
  - Easy preparation
- The egg white albumin did not reduce the dielectric properties equally: the permittivity decreased more significantly than the conductivity.
- Dielectric properties contribute to the size of the ablation zone
  - Egg white + albumin has greater ablation zone than just egg white
    - More protein to denature
    - More air in egg white which affects properties
- Temperature affects dielectric properties:
  Higher temperature = lower permittivity & conductivity

7. Future works

- More repetitions of current methods
- Other methods for preparing sodium alginate, poly(vinyl alcohol) gels
- Try other proteins or concentrations to better match properties of liver
- Determine percentage of protein in phantom to validate consistent procedure

8. Acknowledgement

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- John Puccinelli, PhD (Advisor)
- Ji Zhen, PhD
- Lisa Sampson

9.References

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