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# Effects of saline infusion on the lesion volume during radiofrequency ablation

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# Outline

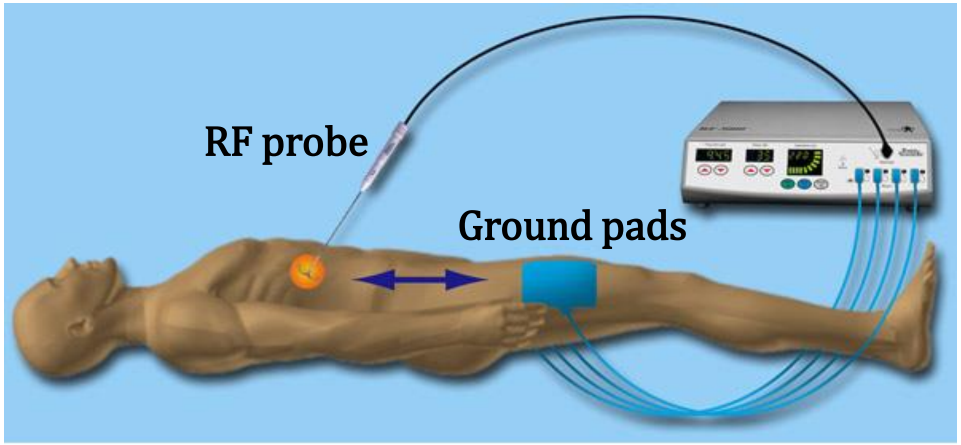
- What is radiofrequency ablation?
- Saline-infused radiofrequency ablation
- Computational model
- Results
- Conclusions

# What is radiofrequency ablation?

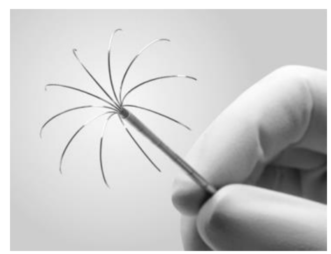


- A minimally invasive treatment of cancer
- Use predominantly for liver cancer

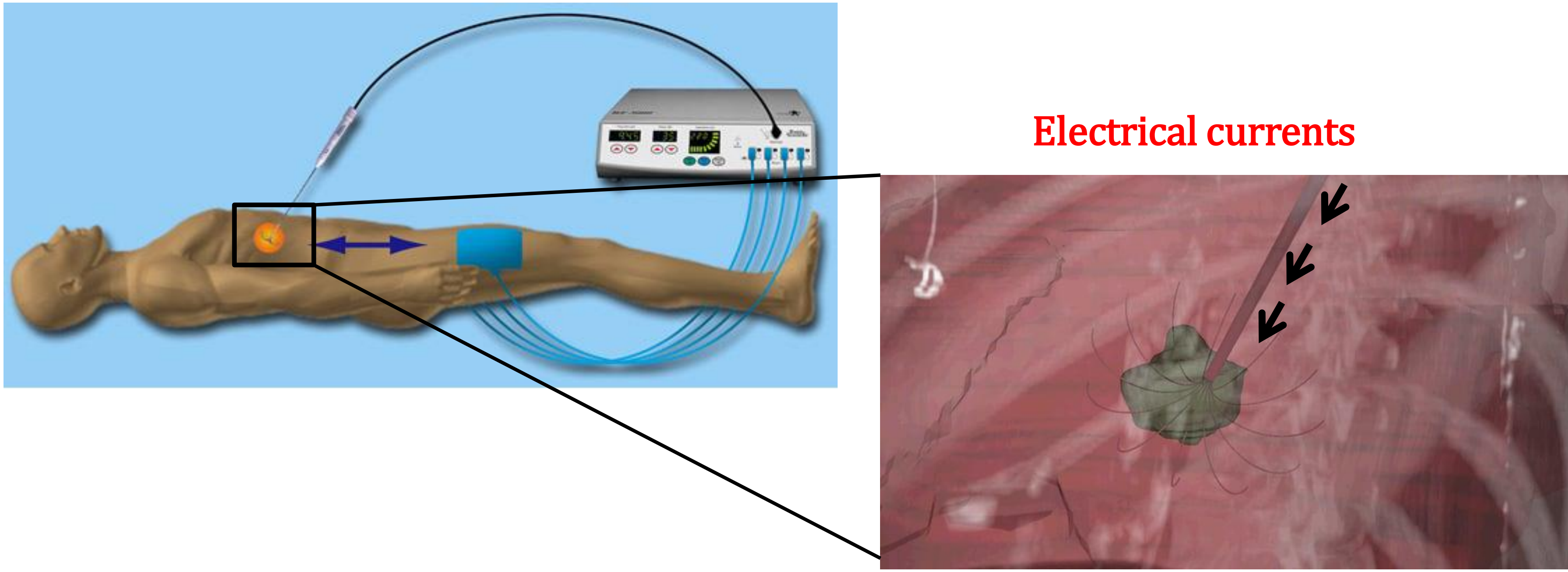
# What is radiofrequency ablation?



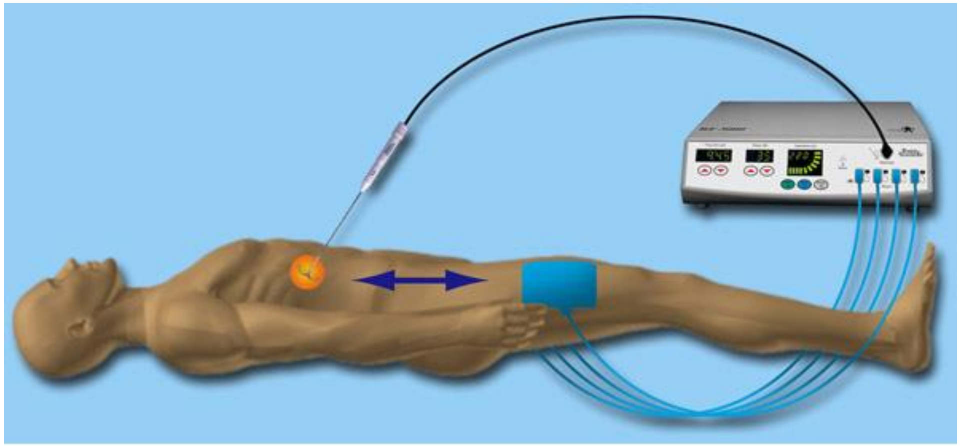

- RF probe inserted percutaneously into the liver.
- Usually under image guidance (CT, MRI or Ultrasound)



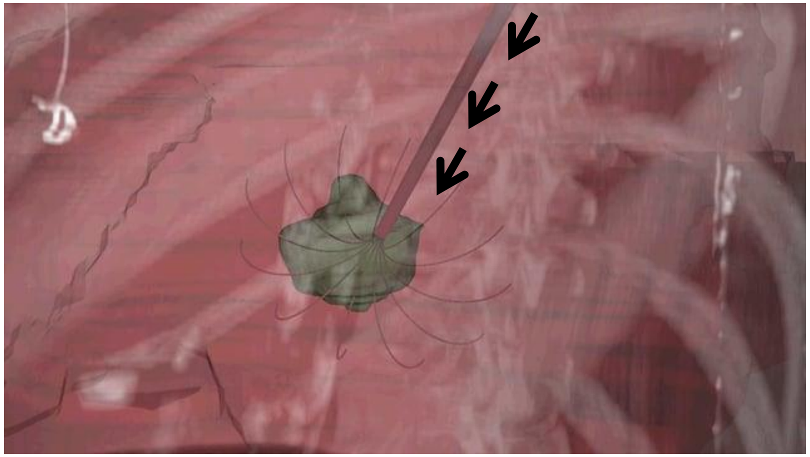
# What is radiofrequency ablation?



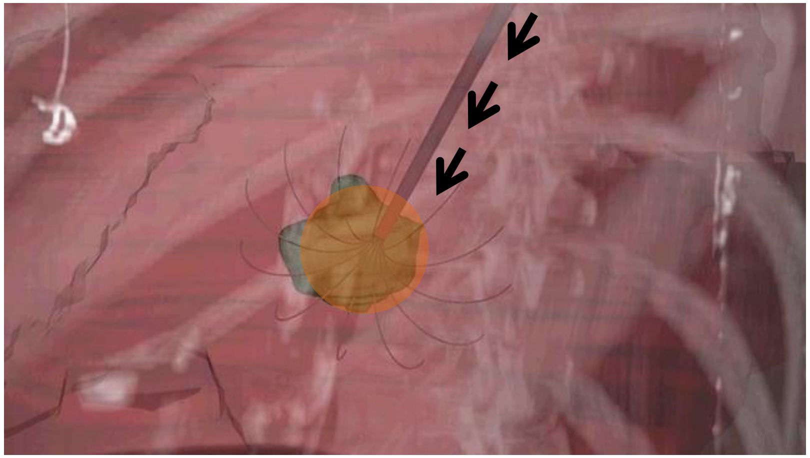
# What is radiofrequency ablation?



Electrical currents



Temperature increases due to resistive heating



Heat causes the proteins of the tissue to denature and subsequently, die.

# Limitations of RFA

- Is effective only for treating cancer tissues that are **< 3cm** in diameter.
- Temperature near the RF probe can reach 100°C. At this temperature, **water from tissue vaporizes**.

# Saline-infused RFA

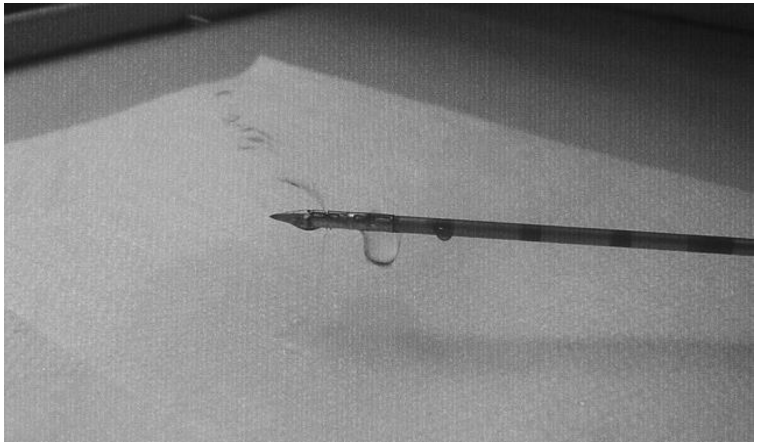
- One way to overcome the limitation of RFA is to infuse saline into the tissue prior to ablation.

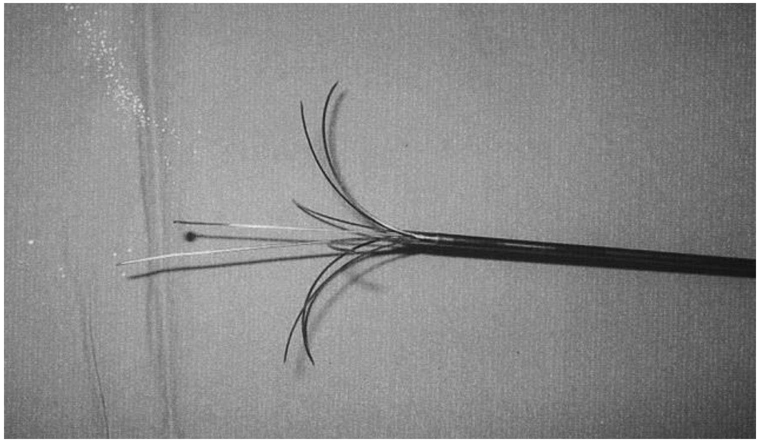
- Two types: simultaneous perfusion-ablation and perfusion, then ablation.

How does it work?

- Saline has electrical conductivity that is approximately 12 times that of normal tissue.

- By saturating the tissue with saline, more regions will experience increased heating during ablation.





# Saline-infused RFA

- Existing lab studies have shown that saline infusion prior to RFA does increase the lesion volume [1, 2].

- Clinical implementation still far from reality.

Why?

- Difficulty in predicting the movement of saline inside the tissue during infusion.

- Risk of extravasation that may lead to over-ablation [3].

[1] F. Burdío et al., Vascular and Interventional Radiology 796 (2011) W837-W843.
[2] S. N. Goldberg et al., Radiology 219 (2001) 157-165.
[3] A. R. Gilliams, W. R. Lees, Cardio Vascular and Interventional Radiology 28 (2005) 476-480.

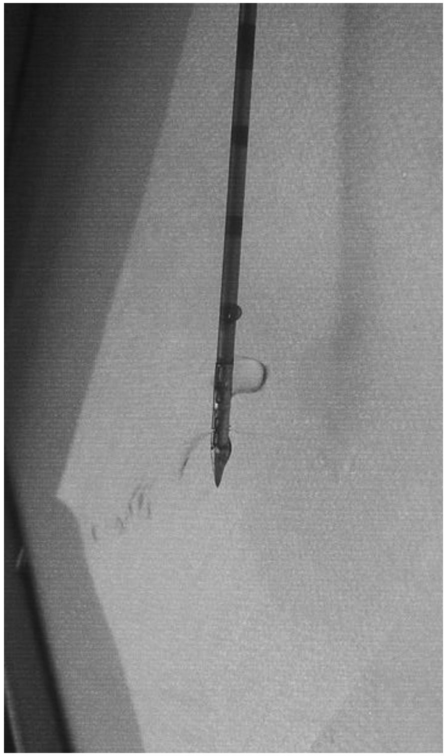
# Computational modelling

- A computational model is developed to further understand how saline infusion a priori affects the lesion formation during RFA.

- Effects of **saline volume** are investigated.

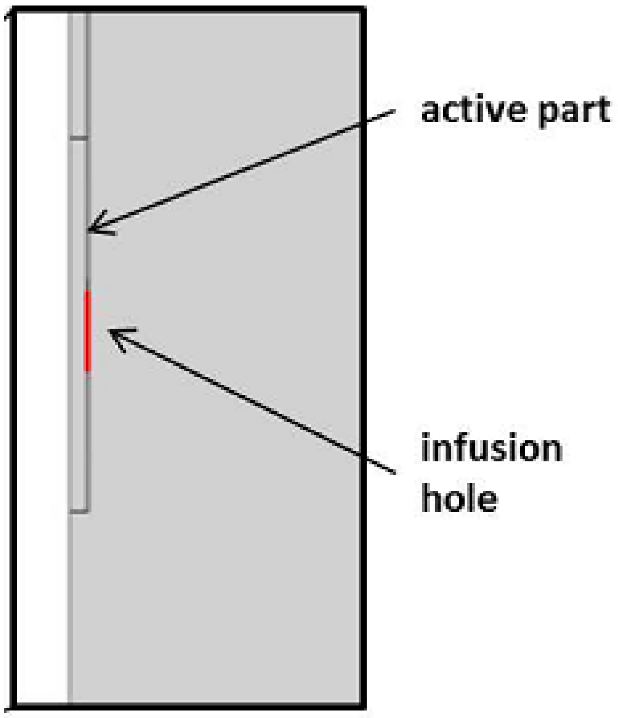
# Computational model

- A single RF probe is used to construct the computational model.



# Computational model

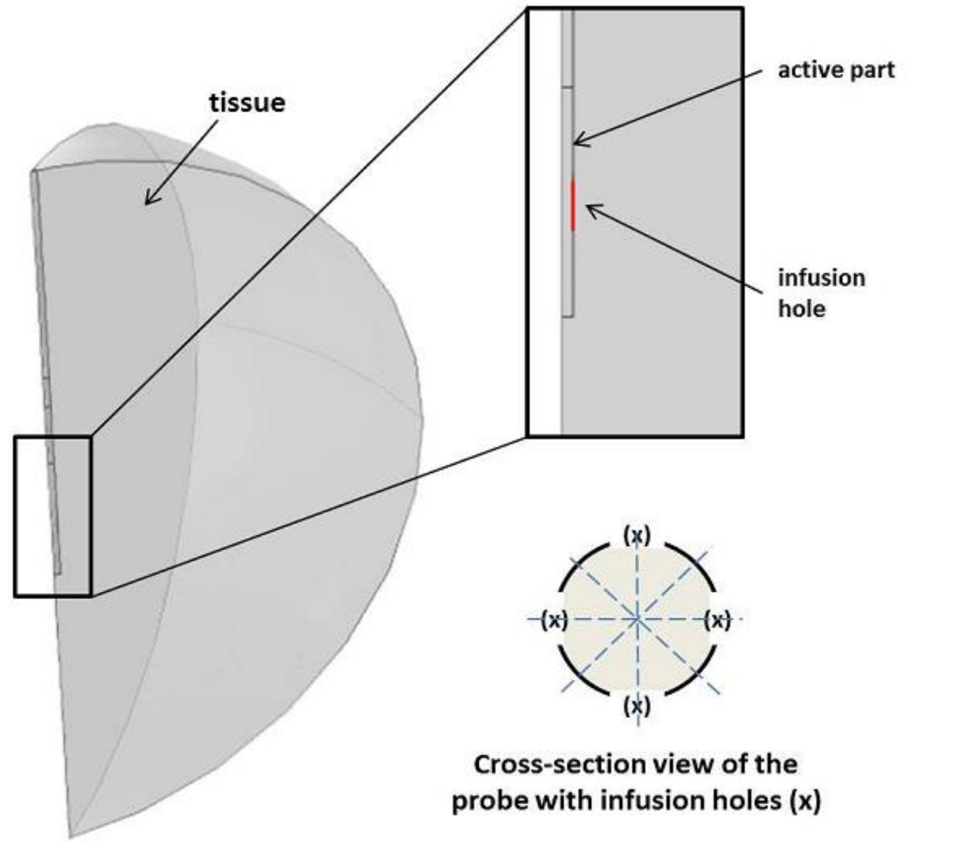
- A single RF probe is used to construct the computational model.
- The probe consists of two parts: conductive and non-conductive.
- Infusion hole is assumed to be located at the centre of the active part.



# Computational model

- Surrounding tissue is spherical and assumed to be homogeneous and isotropic.

- Only one-eighth of the model is built by taking into account symmetry in the geometry.




Cross-section view of the probe with infusion holes (x)

# Computational model

The entire process of saline-infused RFA involve:

- Transport of saline
- Heating of tissue
- Lesion formation

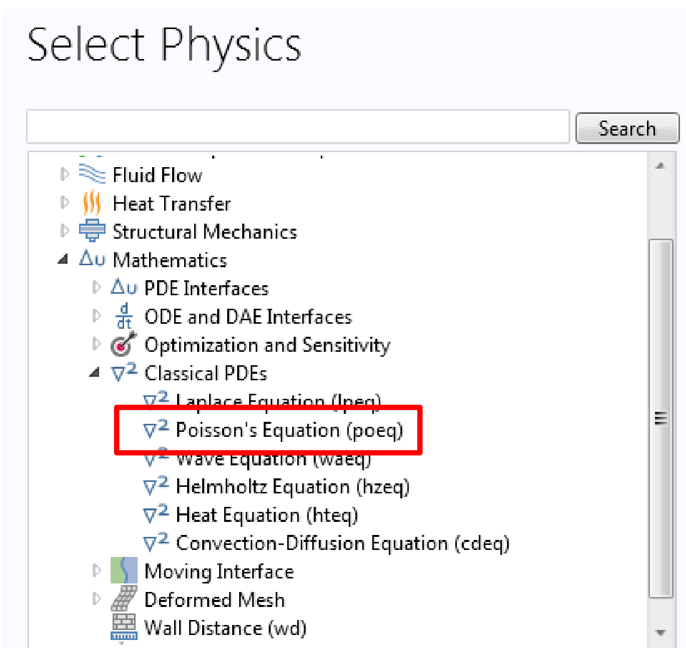
# Computational model

Transport of saline (flow) [4]:

$$\nabla \cdot (K \nabla p) = \phi_v - \phi_L, \qquad \mathbf{u} = -K \nabla p,$$ Darcy equation

$$\phi_v = \frac{J_v}{V} = \frac{L_{pv} S_v}{V} \left[ p_v - p - \sigma_t \left( \pi_v - \pi_i \right) \right],$$ Reaction terms due to vasculature

$$\phi_L = \frac{J_L}{V} = \frac{L_{pL} S_L}{V} \left( p - p_L \right)$$ Reaction terms due to lymphatics



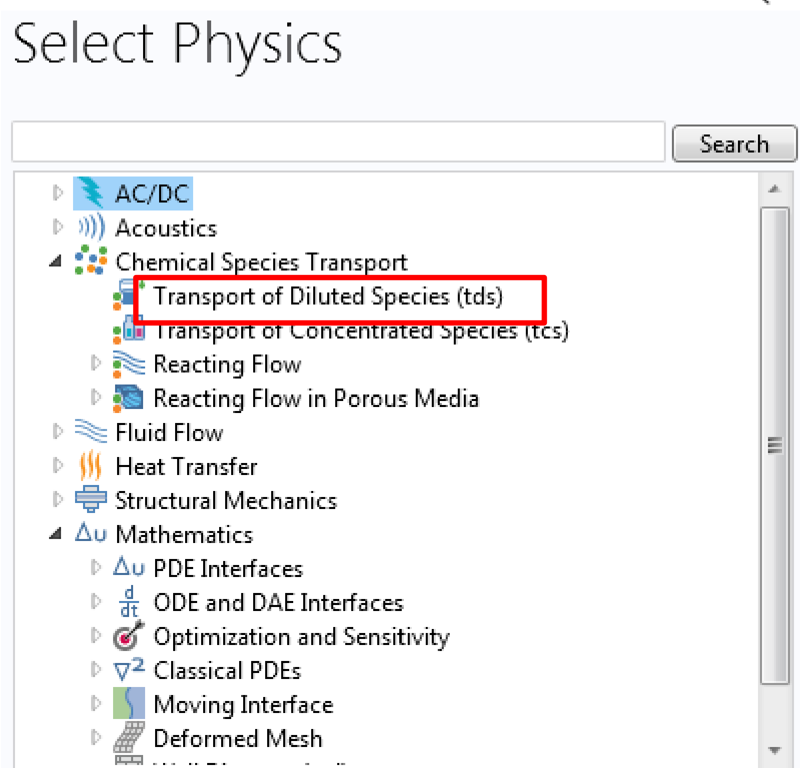

[4] L. T. Baxter, R. K. Jain, Microvascular Research 37 (1989) 77-104.

# Computational model

Transport of saline (solute transport) [4]:

$$\frac{\partial c}{\partial t} = \nabla \cdot (D \nabla c) - \mathbf{u} \cdot \nabla c + \phi_s,$$ Convection-diffusion equation

$$\phi_s = \frac{J_v(1-\sigma)}{V} c_{pl} + \frac{P_v S_v}{V} (c_{pl} - c) \left( \frac{Pe}{e^{Pe} - 1} \right) - \frac{J_L}{V} c$$ Combined reaction term




[4] L. T. Baxter, R. K. Jain, Microvascular Research 37 (1989) 77-104.

# Computational model

Heating of tissue (Joule heating):

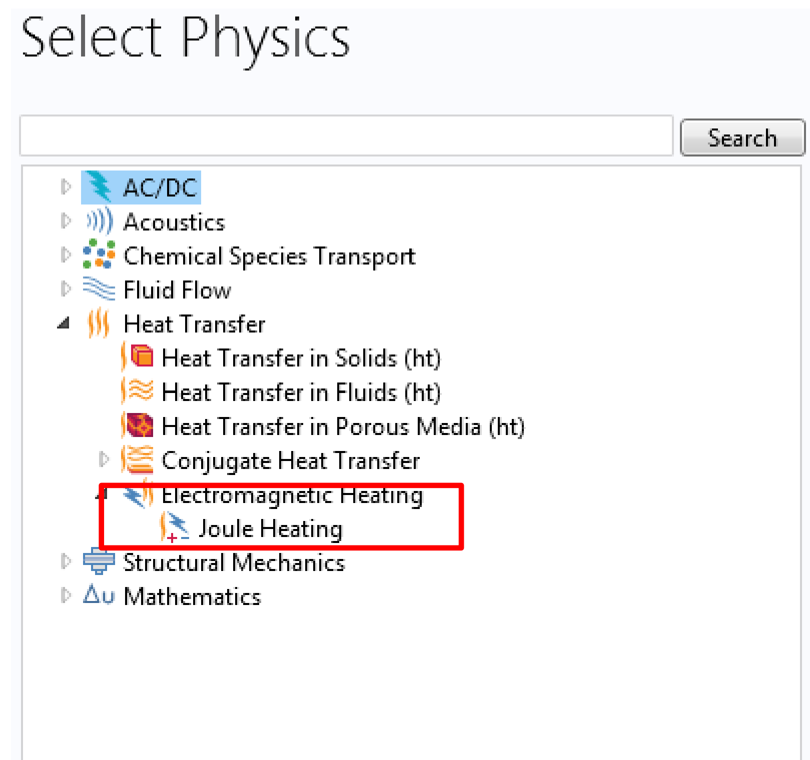
$$\nabla \cdot (\sigma(c)\nabla\phi) = 0,$$ Electrical equation

$$\rho C \frac{\partial T}{\partial t} = \nabla \cdot (\kappa \nabla T) + q + \rho_b C_b \omega(G)\left(T_b - T\right) + Q_m,$$ Bioheat equation

$$q = \sigma(c)\left|\nabla\phi\right|^2$$

Resistive heating

- Tissue electrical conductivity is a function of saline concentration.
- Blood perfusion depends on tissue viability.



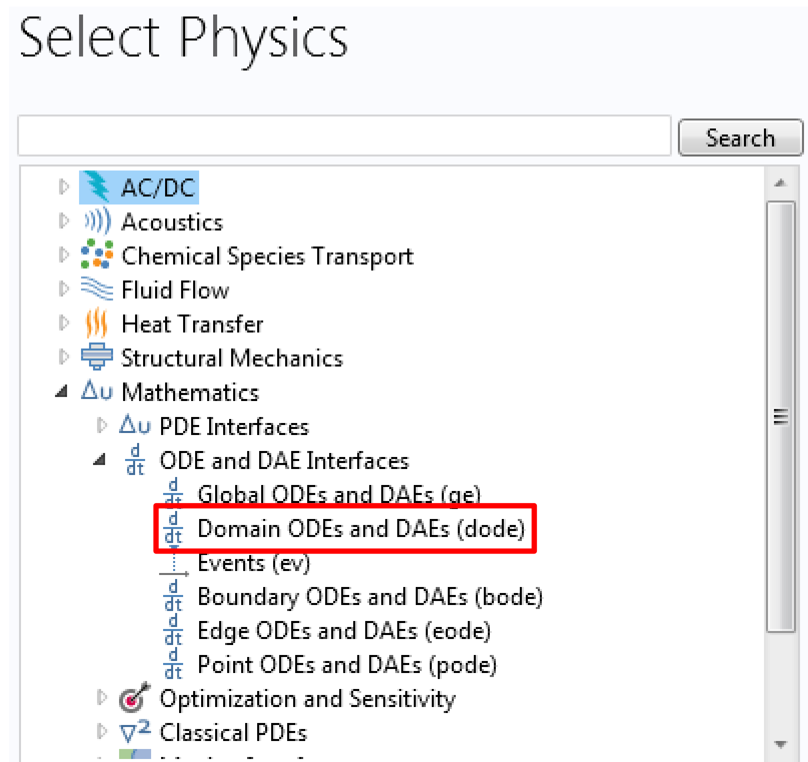
# Computational model

Lesion formation (cell death model):

$$A \underset{k_b}{\overset{k_f}{\leftrightarrows}} V \overset{k_f}{\rightarrow} D,$$

Three state cell death model [5]

$$\frac{dA}{dt} = -k_f A + k_b (1 - A - D),$$
$$\frac{dD}{dt} = k_f (1 - D).$$

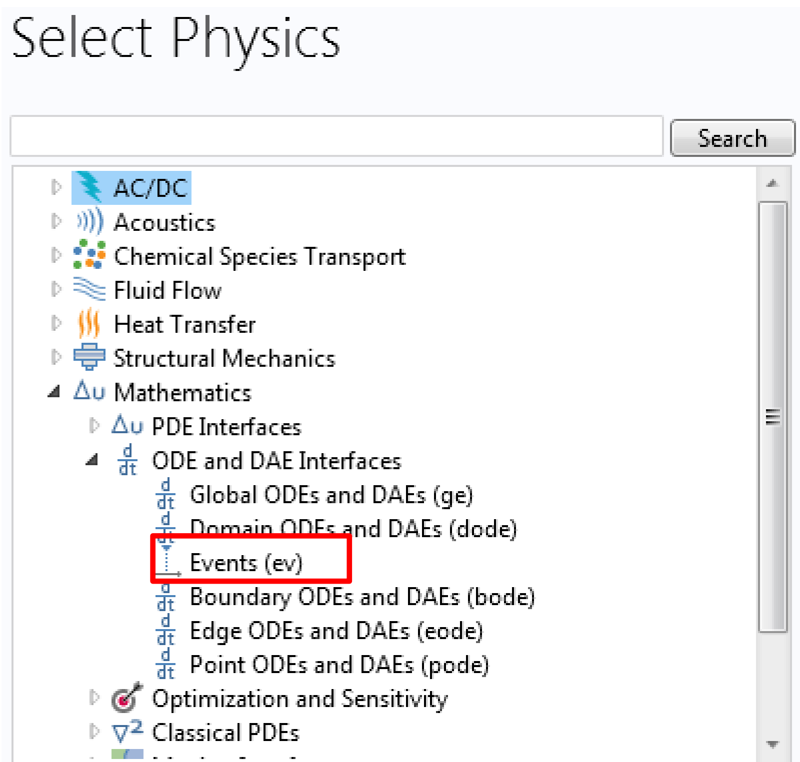



[5] D. P. O'Neill et al., Annals of Biomedical Engineering 39 (2011) 570-579.

# Computational model

- We also assume a **temperature-controlled** ablation protocol.

“Heating stops whenever the maximum tissue temperature reaches 100°C and restarts when the maximum tissue cools to 90°C”



# Computational model

Assumptions:

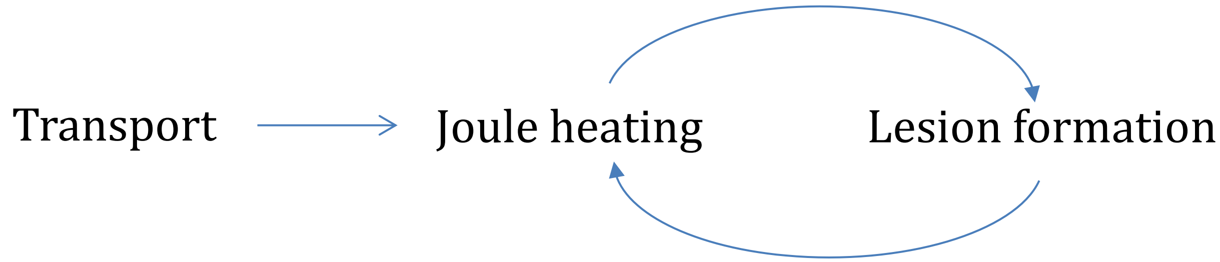
- Tissue electrical conductivity <u>increases linearly</u> with temperature.

$$\nabla \cdot (\sigma(c)\nabla\phi) = 0,$$

- Blood perfusion ceases when tissue viability exceeds a certain threshold.

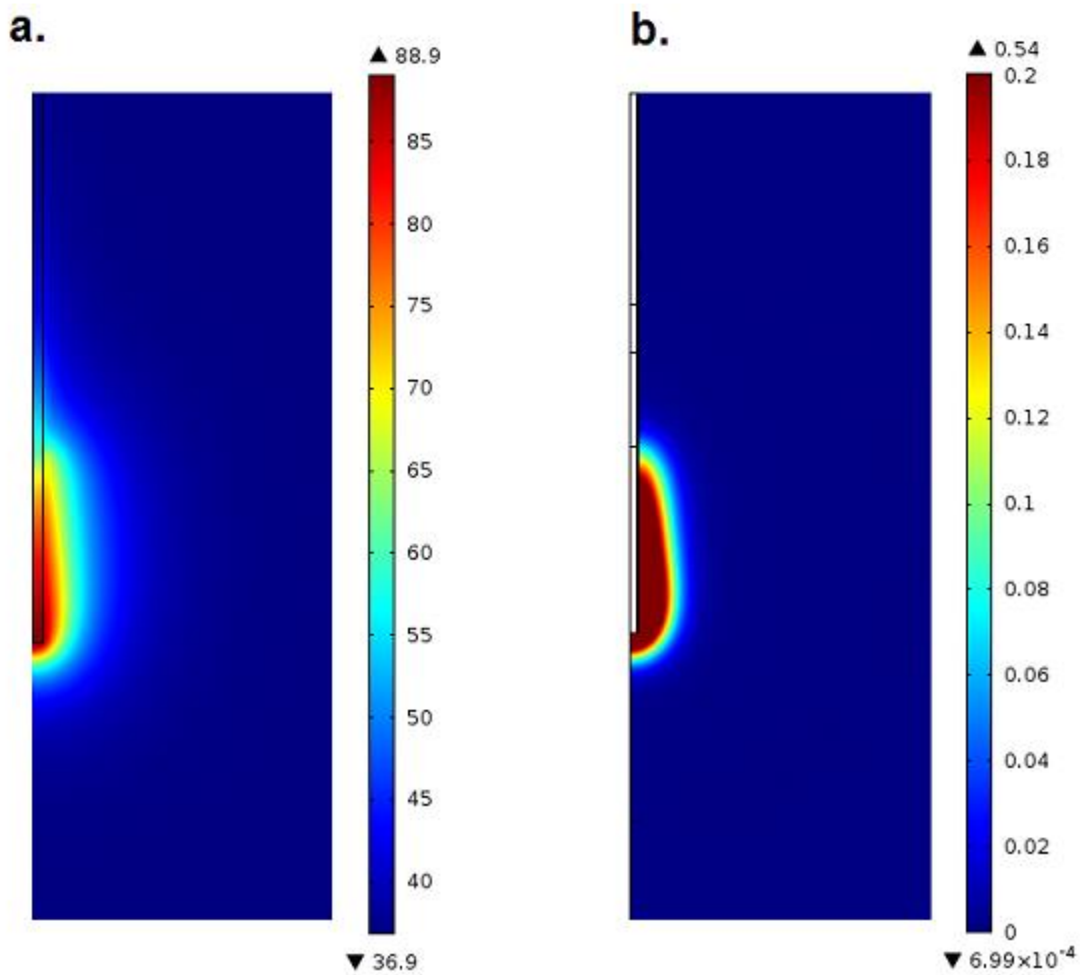
$$\omega(G) = \begin{cases} \omega_b, & \text{if } G \leq G_c, \\ 0, & \text{if } G > G_c. \end{cases} \qquad G = 1 - D$$

These assumptions lead to a <u>coupled problem</u> between the electro-thermal model and the cell death model.



# Results

Temperature distribution (a) and lesion size (b) after 10minutes of ablation **without prior saline infusion**.



# Results

- Effects of 5, 10, 15, 20 and 25ml of saline are investigated.

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| Parameter | Infusion volume (ml) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 |
| Lesion size ($cm^3$) | 0.14 | 1.49 | 1.99 | 1.82 | 1.71 | 1.69 |
| Percentage increase (%) | 0.00 | 31.85 | 75.76 | 60.99 | 50.63 | 49.39 |

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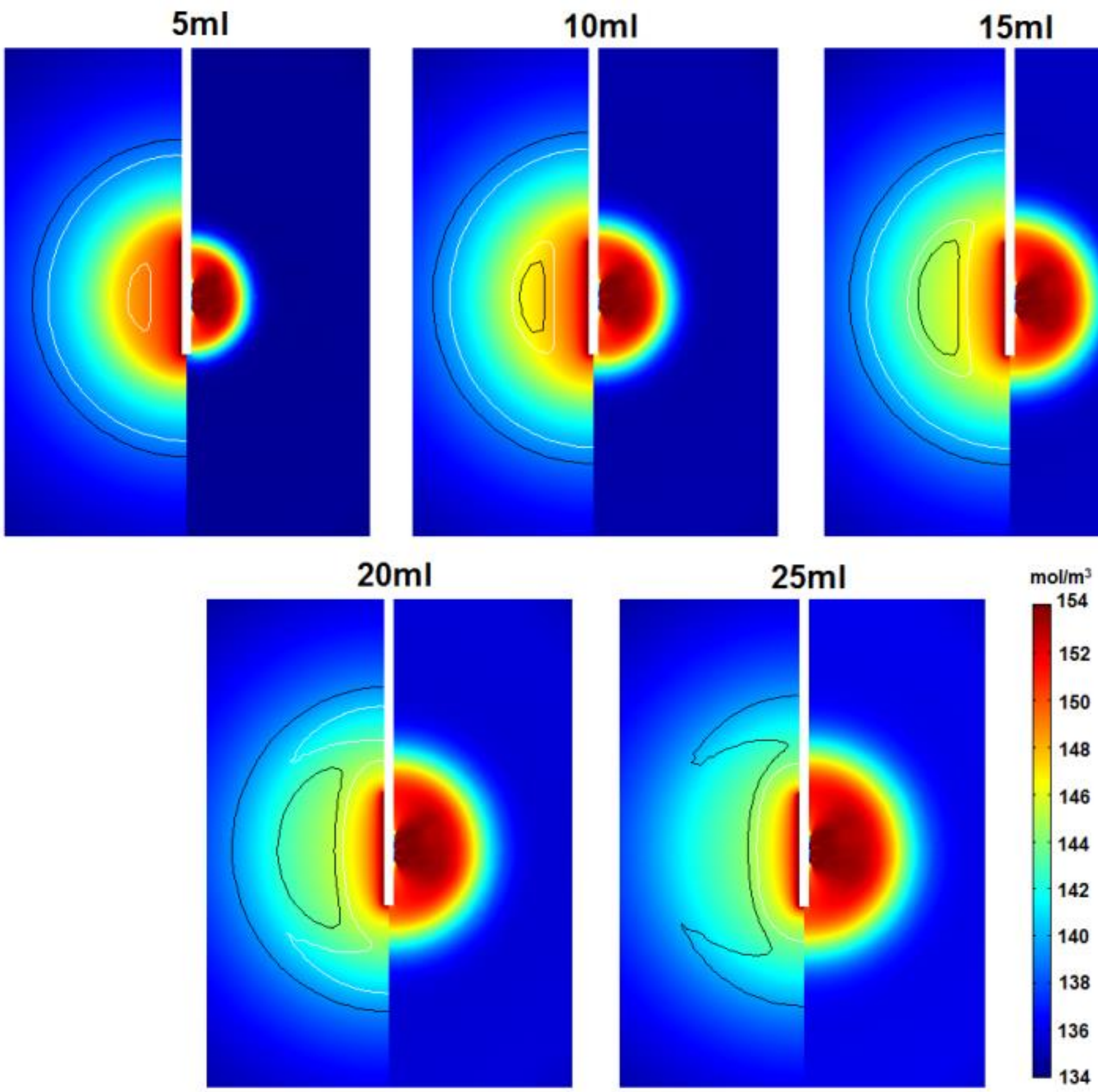
- Lesion volume is larger in cases with saline infusion than that without saline infusion.
- Largest lesion found with 10ml of infusion.

# Results




Left panel: Potential gradient

Right panel: Saline concentration distribution

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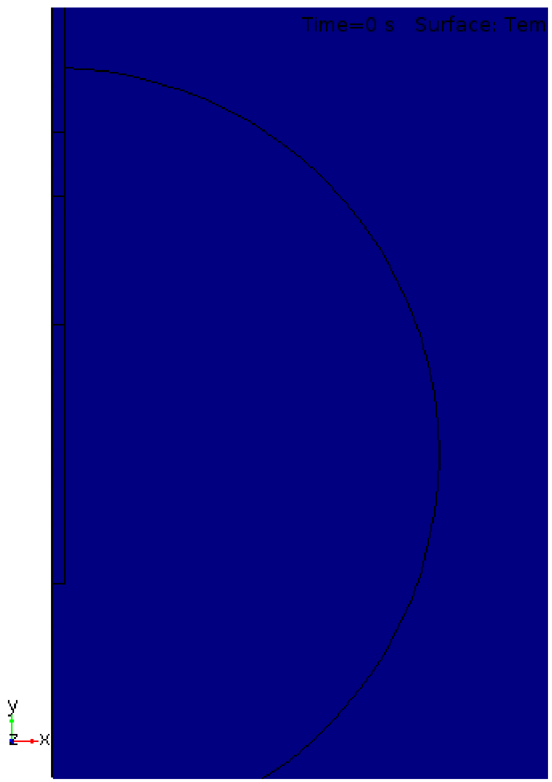
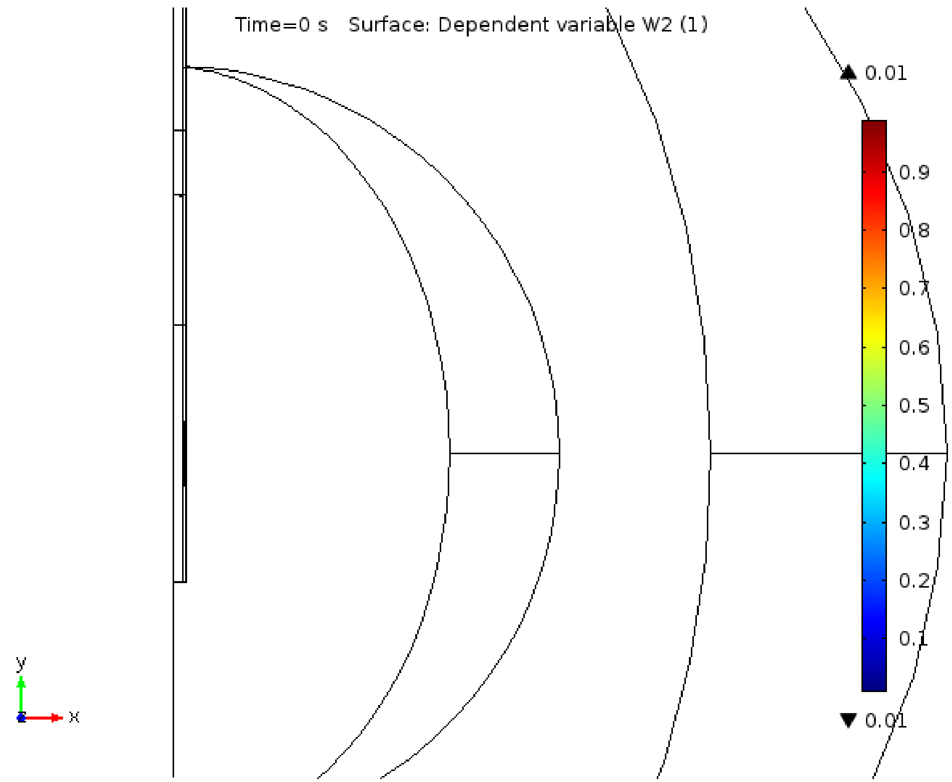
# Results

<u>Infusion volume: 5ml</u>

## Temperature



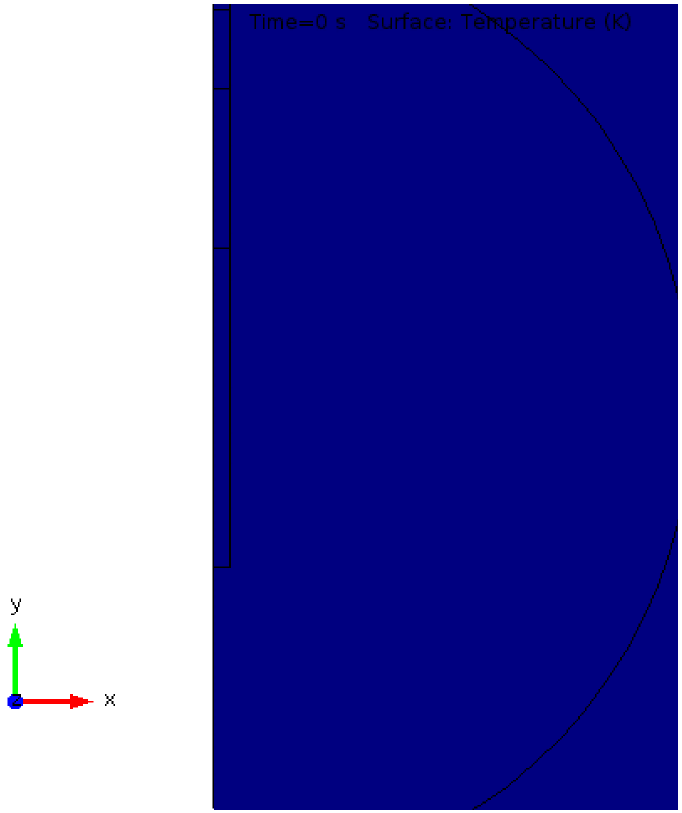

## Lesion formation



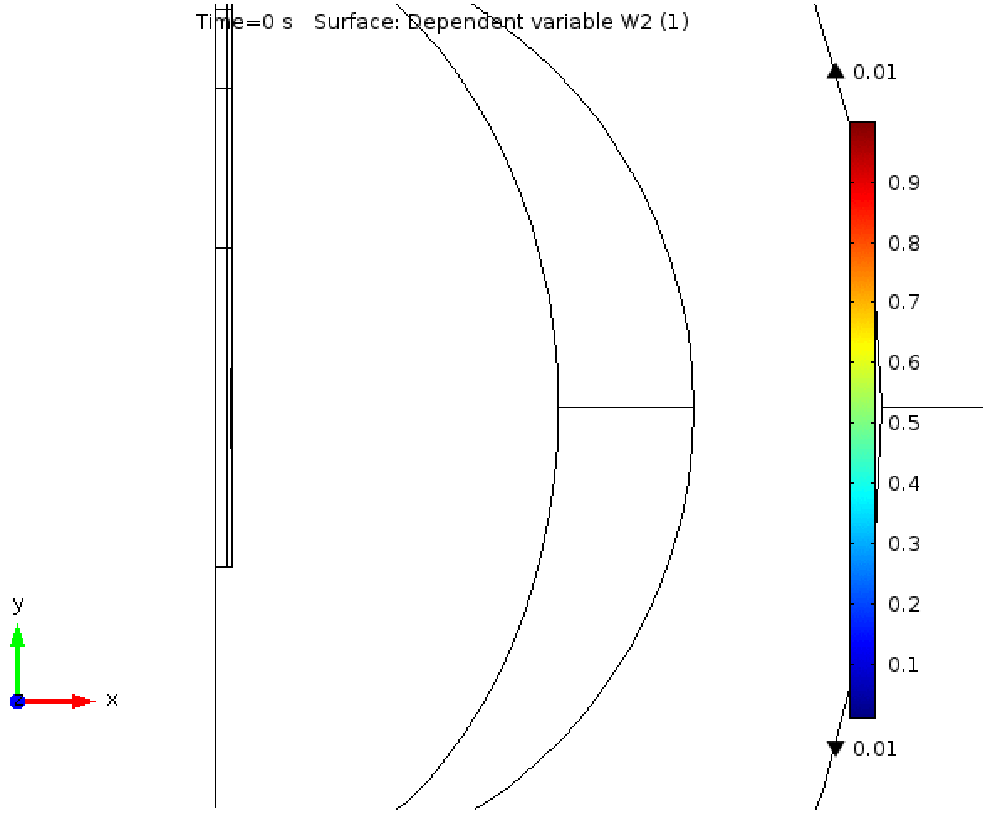
# Results

Infusion volume: 10ml

Temperature



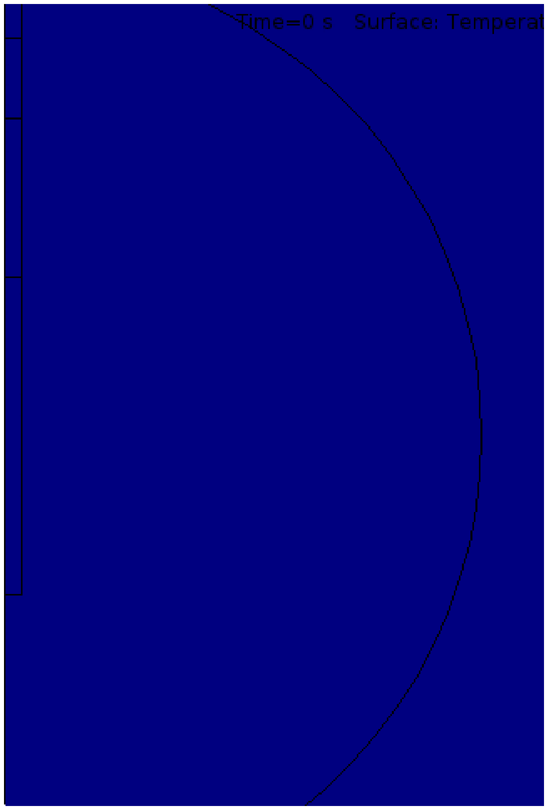

Lesion formation



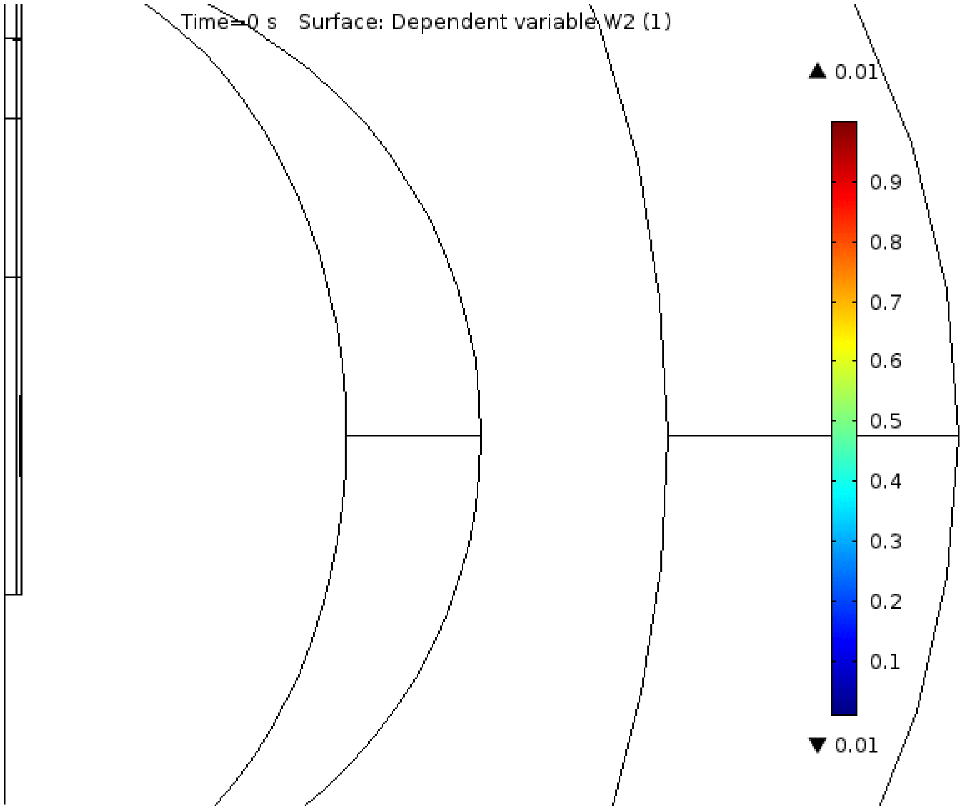
# Results

Infusion volume: 15ml

Temperature



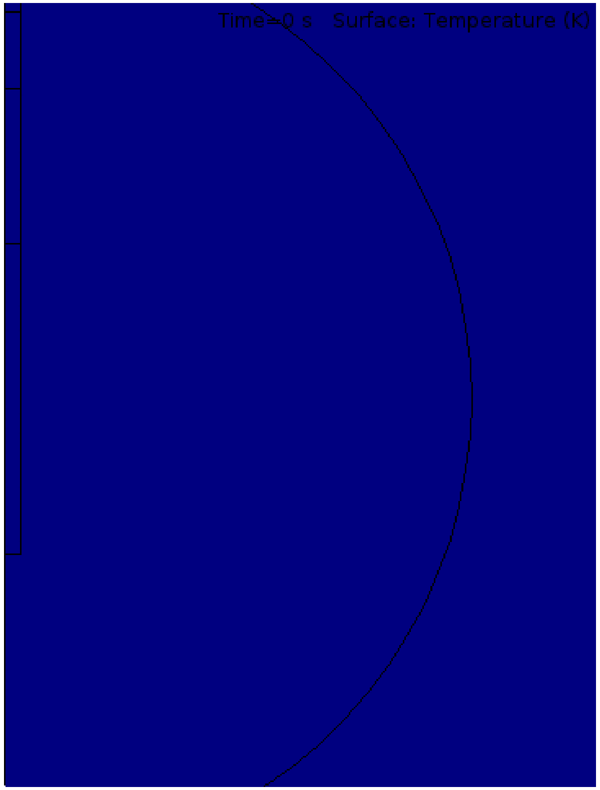

Lesion formation



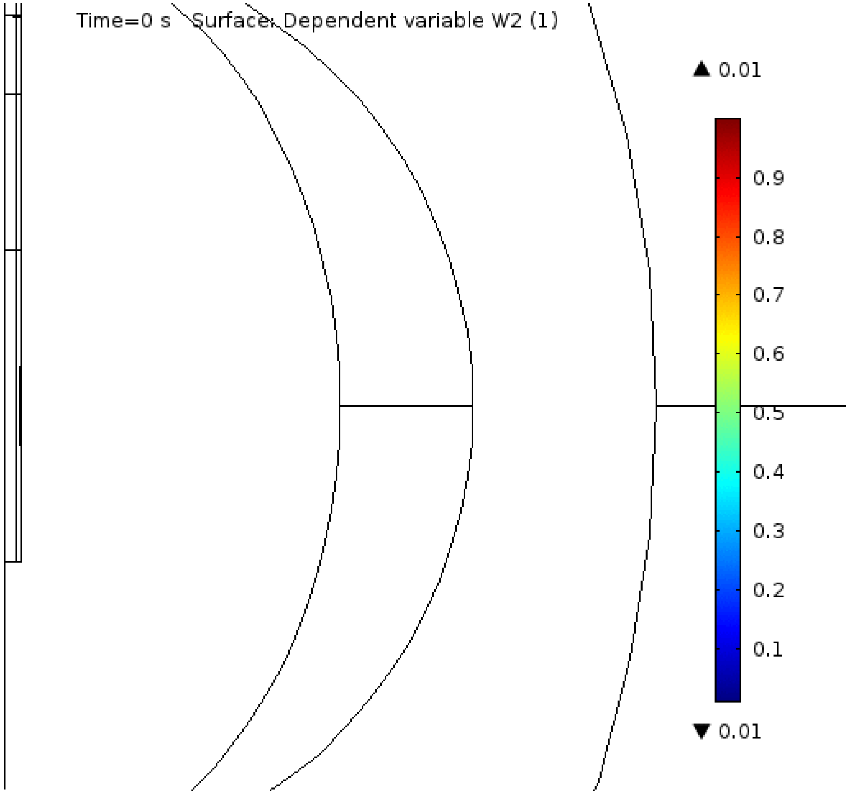
# Results

Infusion volume: 20ml

Temperature




Lesion formation



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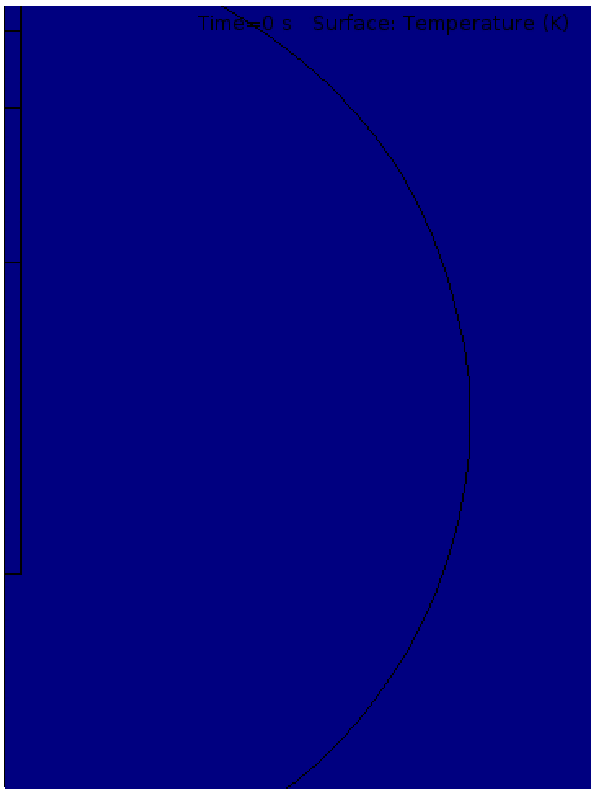
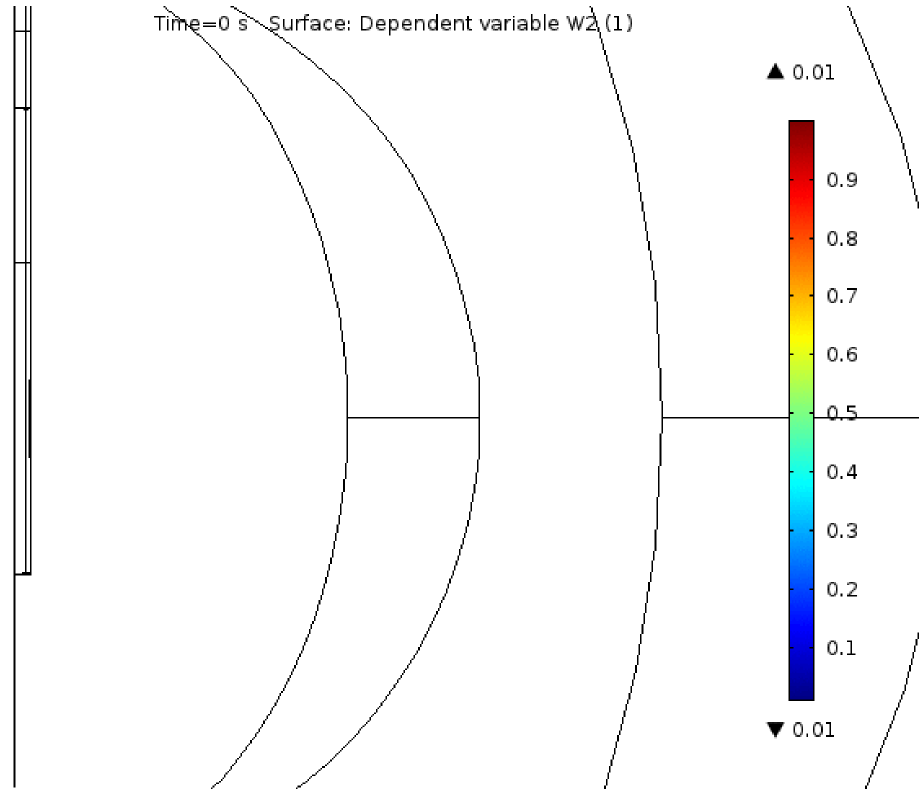
# Results

Infusion volume: 25ml

Temperature

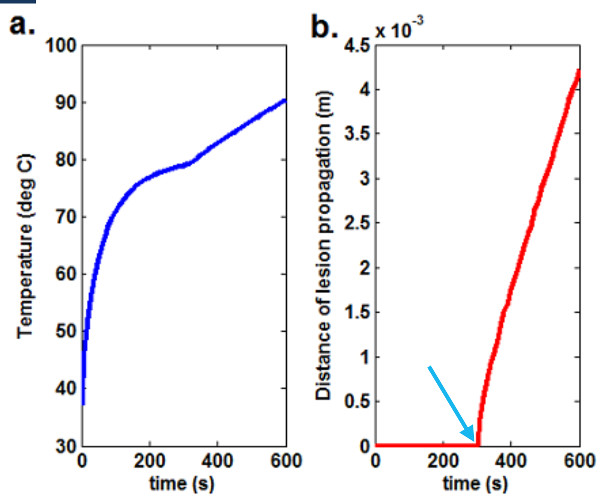



Lesion formation

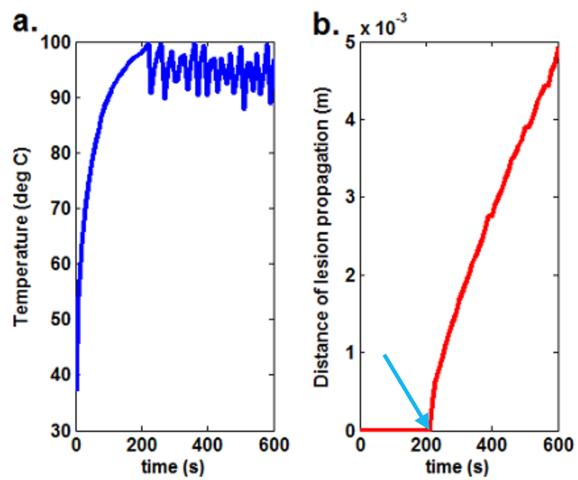


# Results

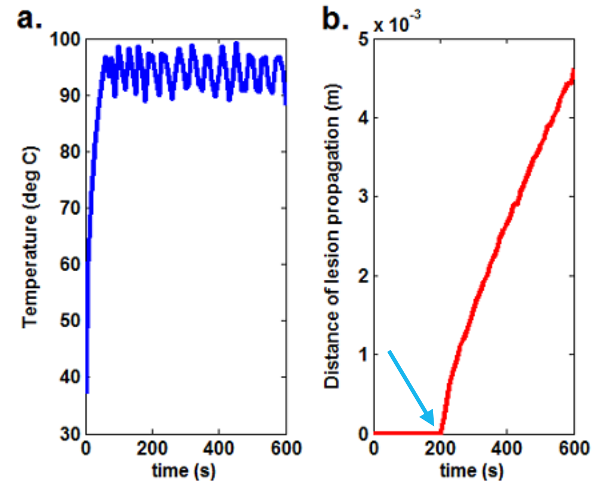
## 5ml



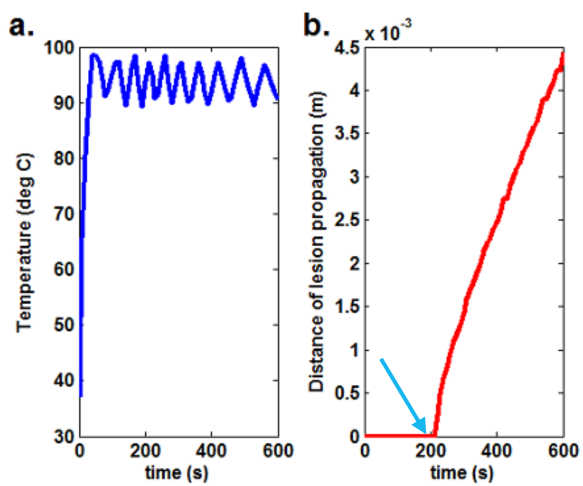

## 10ml



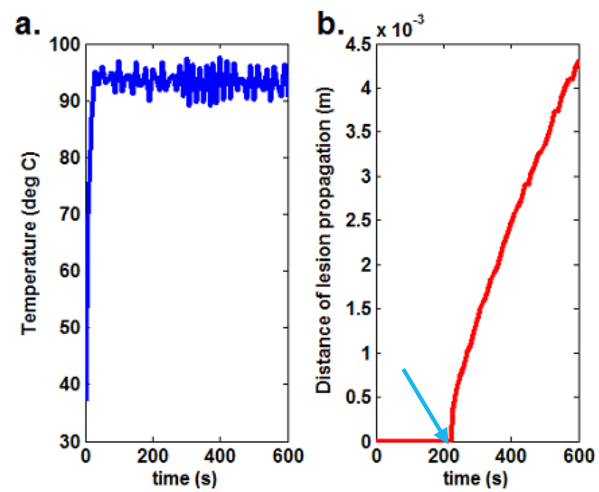

## 15ml




## 20ml




## 25ml



# Conclusions

1. Saline infusion increases the lesion size by **at least 30%**.

2. There is an **optimal infusion rate** that produces the largest increase in lesion size, in this case, 10ml..

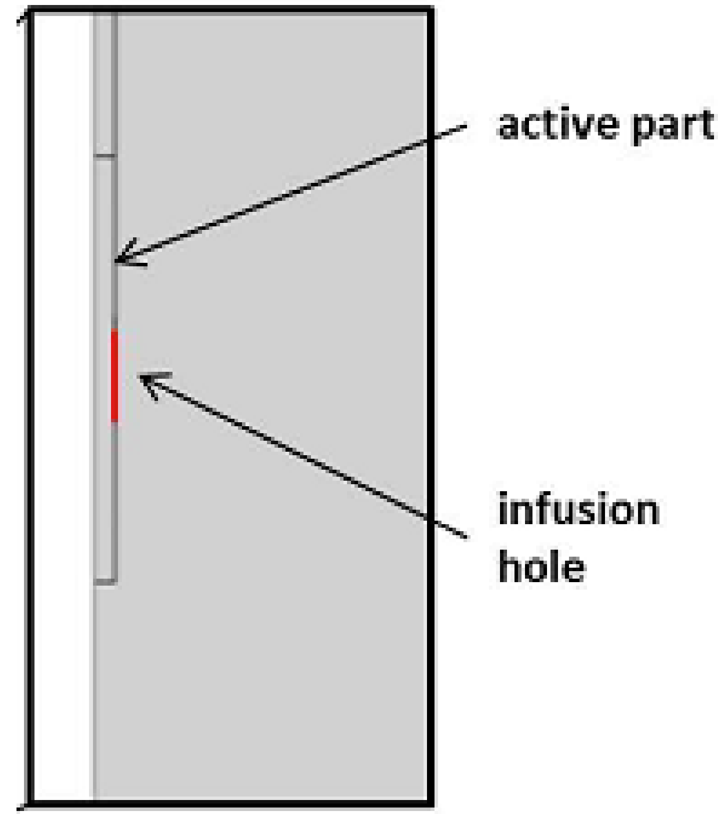
3. A **rapid increase** in temperature followed by **multiple heating and cooling cycles** do not produce larger lesions.

# Future works

1. Material anisotropy.

2. Simultaneous infusion and ablation.
   – Raised electrical conductivity
   – Cooled probe surface

3. Optimize the position of the infusion hole.



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