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Assessment of the Efficacy of the Radiofrequency Electrode Active Tip Length on the Volume Reduction Ratio of Benign Thyroid Nodules

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Motivation and purpose

➢ Benign thyroid nodules are a clinical problem affecting a significant portion of the population.

➢ Radiofrequency ablation (RFA) is a promising treatment alternative to surgery for patients with benign thyroid nodules.

  ▪ During RFA, a thin needle electrode is inserted into the nodule under ultrasound guidance. RF energy is then delivered through the electrode, generating heat and causing coagulative necrosis within the nodule.

| RFA Advantages	RFA Challenges
✓ Reduced invasiveness	▪ Minimize damage to healthy surrounding tissues
✓ Shorter recovery time	
✓ VRR ranges from 50% to 90%	▪ Decrease the time of the treatment

➢ **AIM:** This study uses numerical simulations based on Finite Element (FE) method to predict the influence of the RF electrode active tip length on the ablation zone.

  ▪ The computational model may contribute to treatment planning and improving outcomes.

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3D Finite Element Model

➢ Geometric model of the neck region, comprising:
  ▪ Skin
  ▪ Fat
  ▪ Muscle
  ▪ Thyroid
  ▪ Bening Nodule with a volume V = 20 ml [1]

➢ **RF electrode:**
  ▪ 18-gauge RF electrode
  ▪ Shaft length: 100 mm
  ▪ **Active tip:** 5 mm → 40 mm at step of 5 mm
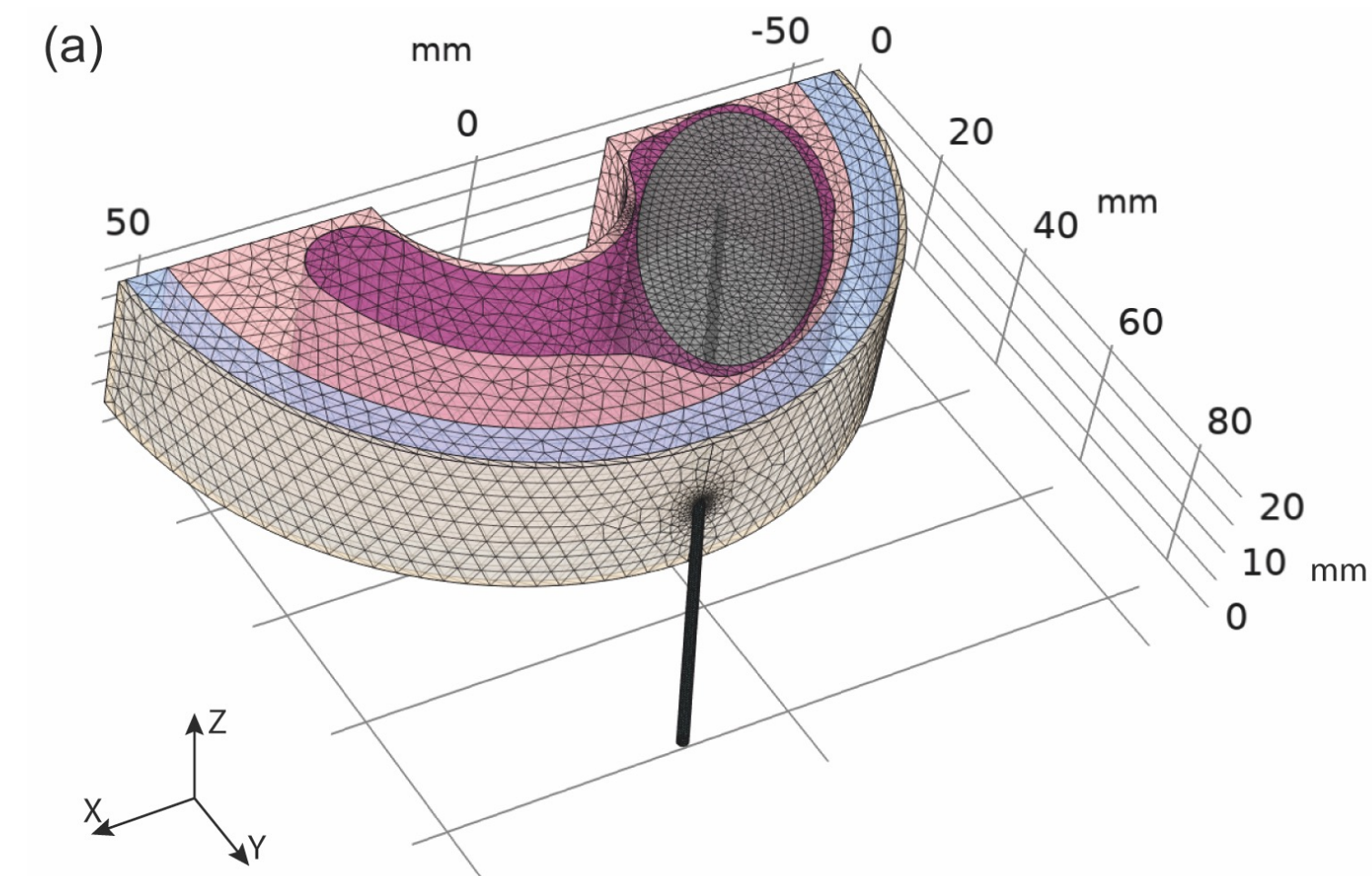
➢ **Mesh:** ~200k tetrahedral element mesh that leads to 900k degrees of freedom

(a)
(b) Augmented view of the RF electrode extremity
Insulated Shaft / Active tip

Reference:
[1] Deandrea et al. (2021). *European Radiology*, 31:5189–5197

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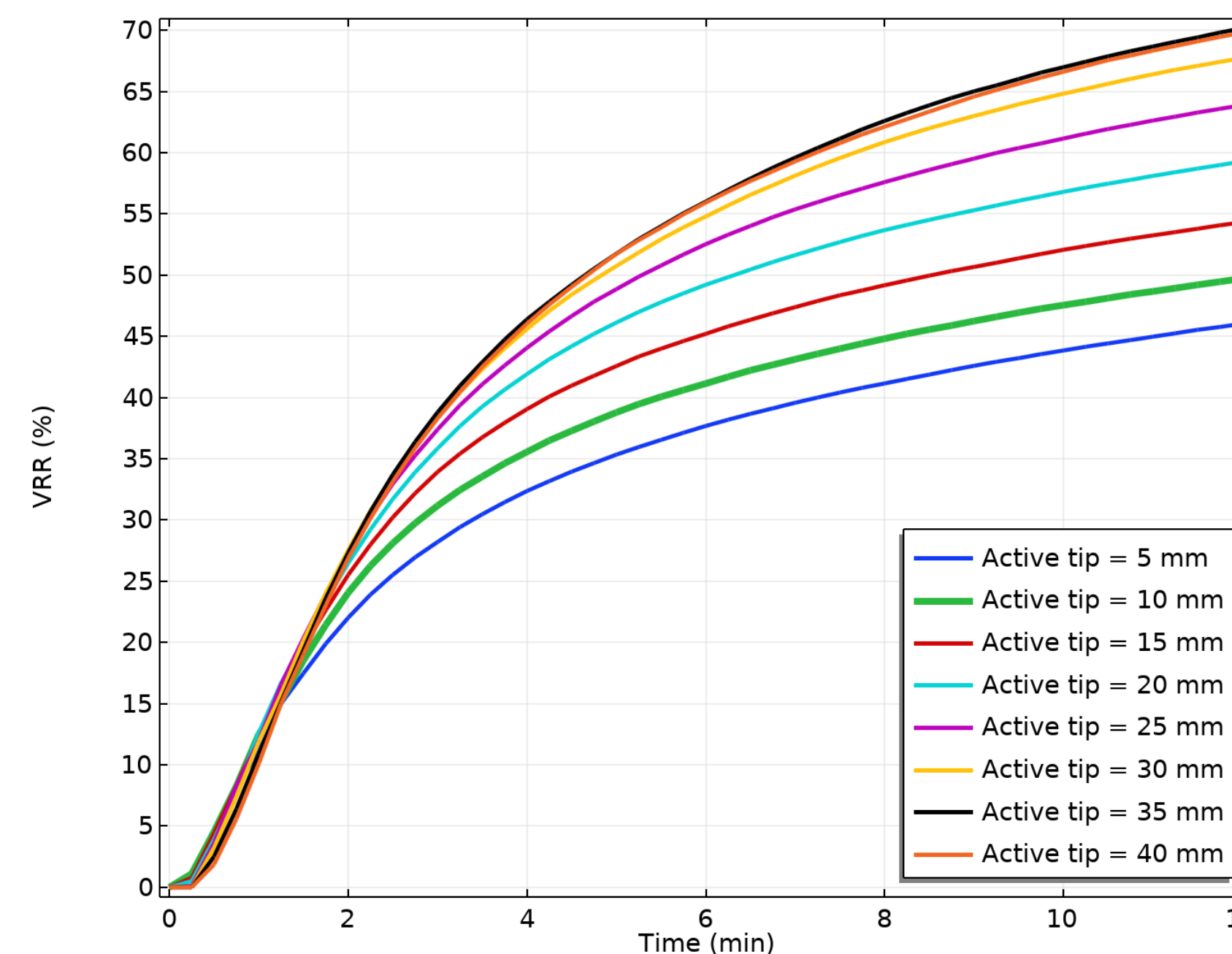| Introduction ○○○ | Methods ○● | Results & Discussion ○○○ | Conclusions ○ |

Theoretical framework

➢ RFA is modelled as a coupled electro-thermal problem where the electric field is applied to induce tissue heating:
  ▪ The **electric field** is solved by Laplace equation.
  ▪ **Temperature distribution** is estimated with Pennes bioheat equation.
  ▪ **Thermal damage** is evaluated using Arrhenius equation.

➢ **RF ablation operating conditions:**
  ▪ Power = 50 W
  ▪ Frequency = 480 kHz
  ▪ Treatment duration: 12 min

➢ **Workflow:**
  ▪ Parametric study for the active tip length of the RF electrode in the interval 5 mm to 40 mm at step of 5 mm.

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Nodule Volume Reduction Ratio (VRR)

Active tip = 5 mm
Active tip = 10 mm
Active tip = 15 mm
Active tip = 20 mm
Active tip = 25 mm
Active tip = 30 mm
Active tip = 35 mm
Active tip = 40 mm

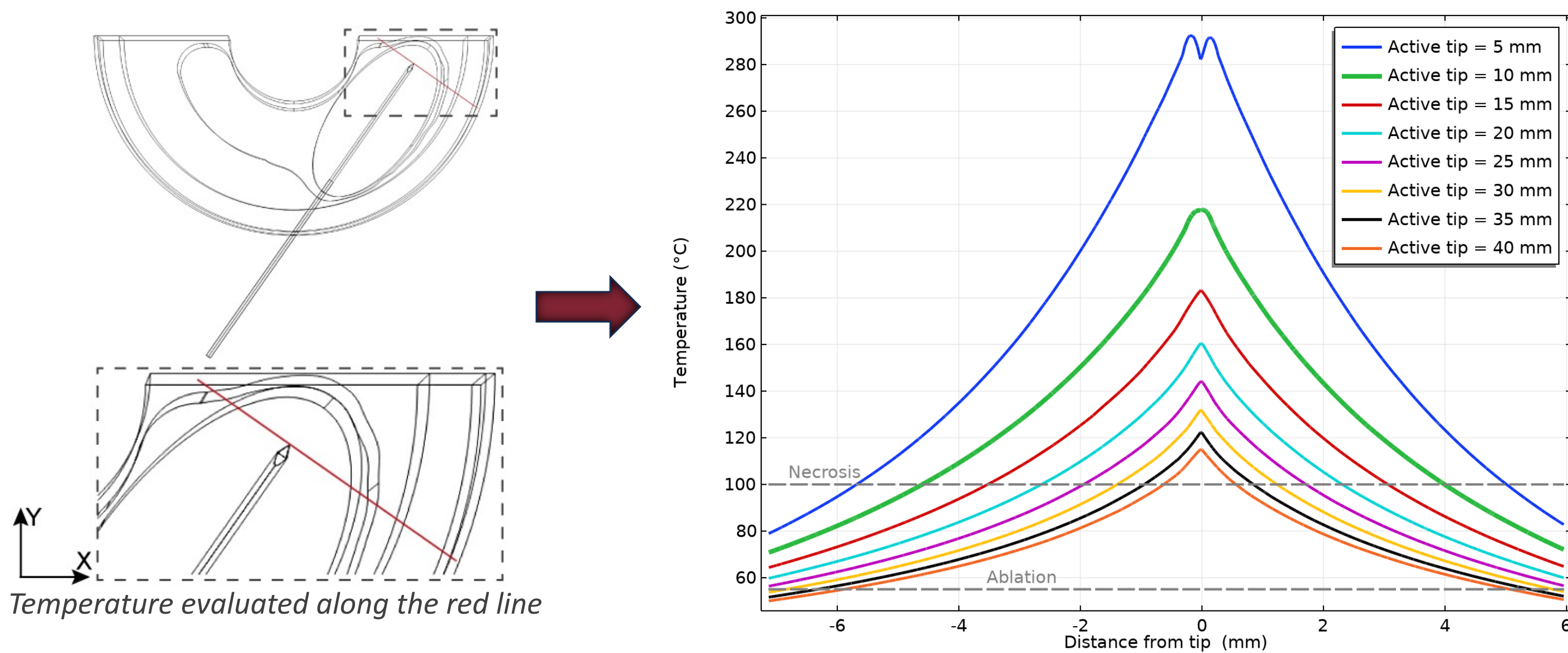$$VRR = \frac{initial\ nodule\ volume - final\ nodule\ volume}{initial\ nodule\ volume} \cdot 100$$

➢ For an active tip length = 10 mm, the VRR is in agreement with clinical outcomes [1], validating the FE model.

➢ Longer active tips increase the VRR by up to 20 percentage points.

Reference:
[1] Deandrea et al. (2021). *European Radiology*, 31:5189–5197

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Temperature behaviour

Temperature evaluated along the red line

Active tip = 5 mm
Active tip = 10 mm
Active tip = 15 mm
Active tip = 20 mm
Active tip = 25 mm
Active tip = 30 mm
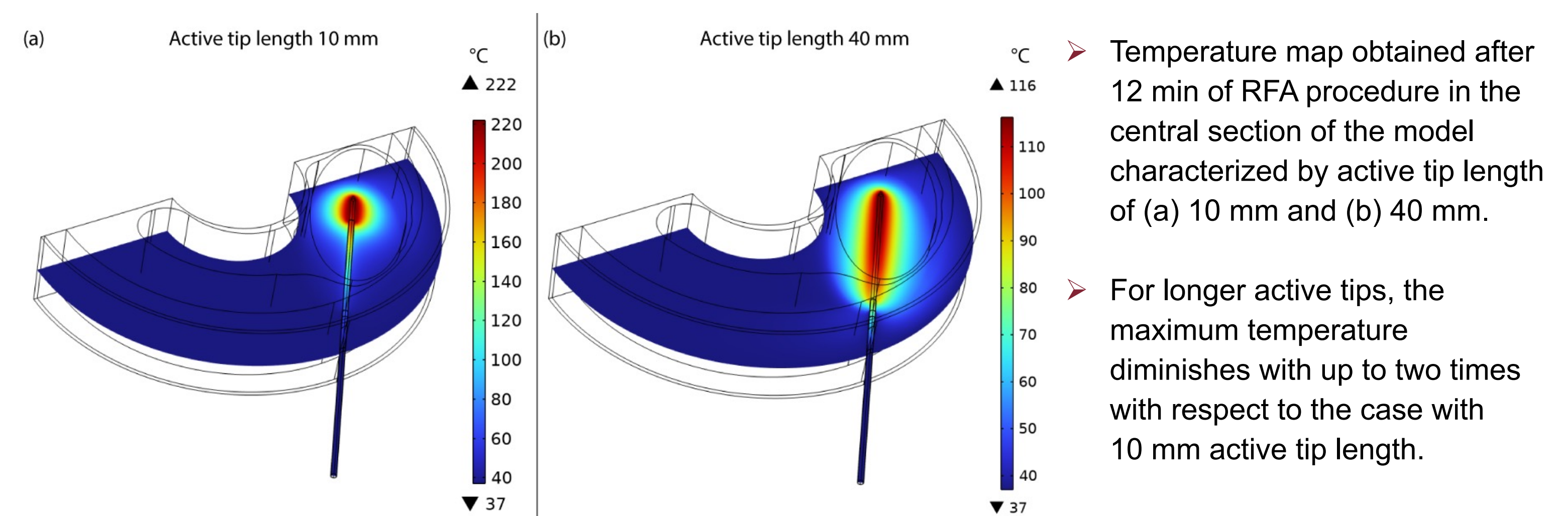Active tip = 35 mm
Active tip = 40 mm

Necrosis
Ablation

➢ For increasing active tips, the transversal width of the ablation zone is reduced with up to 35 percent than the 10 mm active tip case.

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Temperature map

(a) Active tip length 10 mm
(b) Active tip length 40 mm

➢ Temperature map obtained after 12 min of RFA procedure in the central section of the model characterized by active tip length of (a) 10 mm and (b) 40 mm.

➢ For longer active tips, the maximum temperature diminishes with up to two times with respect to the case with 10 mm active tip length.

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Conclusions

➢ The ideal outcome of RFA is the full destruction of tumour without any damage to the healthy tissue.

➢ The FE model shows the influence of the active tip length on the treatment outcome.

➢ FE model highlights that longer active tips are more efficient leading to higher VRR and reduced transversal ablation zone.

➢ Future studies will investigate the shaft length influence on RFA outcomes.

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