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EFFECT OF CATHETER CONTACT FORCE ON LESION VOLUME IN PULSED FIELD ABLATION: A COMPUTATIONAL STUDY

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INTRODUCTION & AIM

Cardiac arrhythmia is one of the most common disorders affecting millions of people globally. It is characterized by irregular heart rhythms (i.e., heart beating either too fast or too slow), and if left untreated, could result in serious complications such as stroke, heart failure, and sudden cardiac arrest. Minimally-invasive thermal ablation therapies are widely used in clinical practices for treating arrhythmias by locally heating and destroying the diseased tissue to electrically isolate the regions that generate or propagate arrhythmia and make it inactive. However, the precise localization of the heat confined only to the culprit tissue always remains challenging, and the excessive temperatures generated during these therapies could lead to significant complications. To address the issue of rising temperatures during thermal therapies, more recently Pulsed Field Ablation (PFA) has emerged as an exciting non-thermal therapy. During PFA, microsecond-scale, high-voltage electrical pulses are applied to damage the diseased tissue by irreversible electroporation [1]. This study aims to quantify the effect of tissue deformation induced by the application of catheter contact force on the treatment outcomes of PFA.

METHOD

The temperature distribution and irreversible electroporation-based ablation volume (i.e., electric field intensity of greater than 1000 V/cm) are attained by solving the coupled electrical-thermal-mechanical-fluid model within the computational domain (see Fig. 1) utilizing finite element-based COMSOL Multiphysics software. The simplified version of Maxwell's equations (known as a quasi-static approximation) is used to solve the electrical problem, Penne's bioheat transfer model is used to predict the temperature distribution, Mooney–Rivlin model is used to predict the tissue deformation, and Navier-Stokes equation is used to simulate the blood flow [2-3].

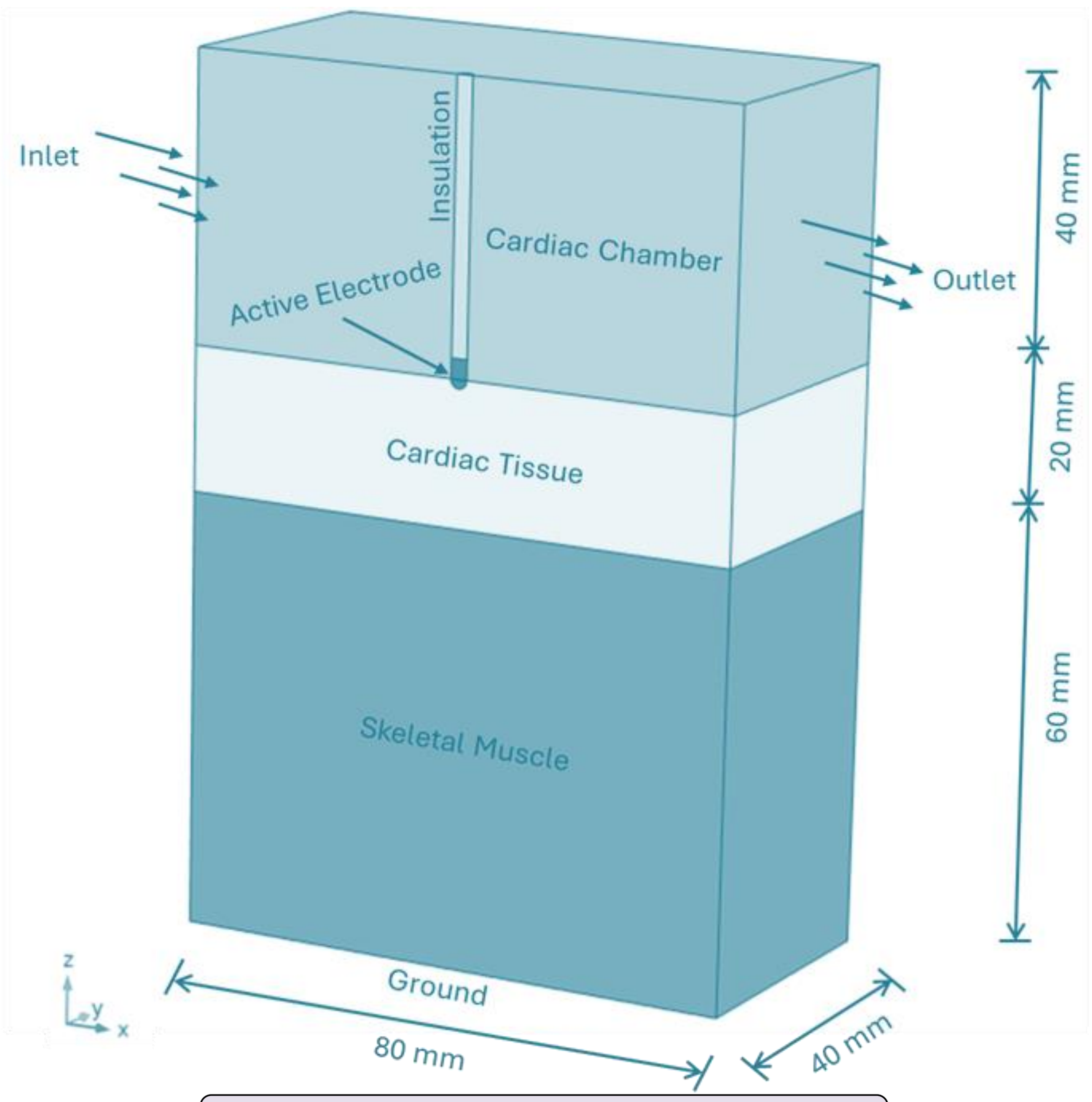

Fig. 1: Computational domain.

RESULTS

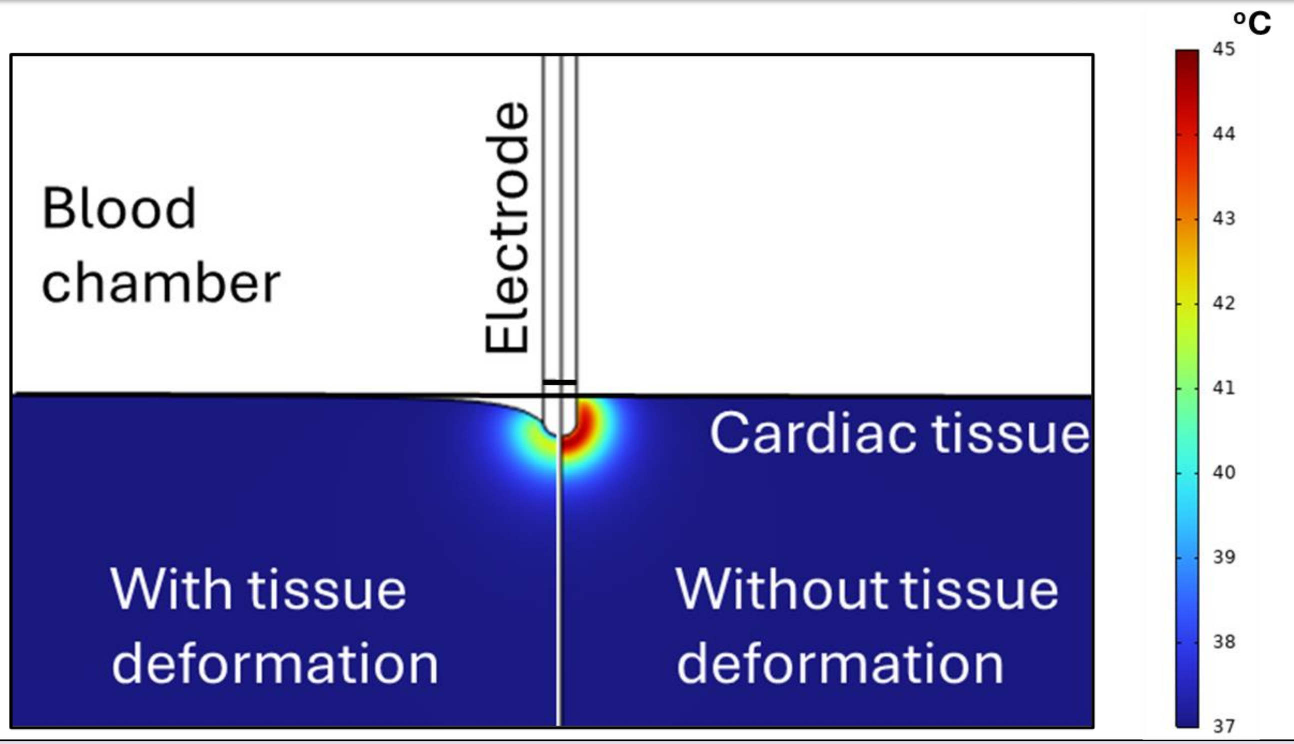

Fig. 2: Comparison of temperature distribution post 20 s of PFA procedure.

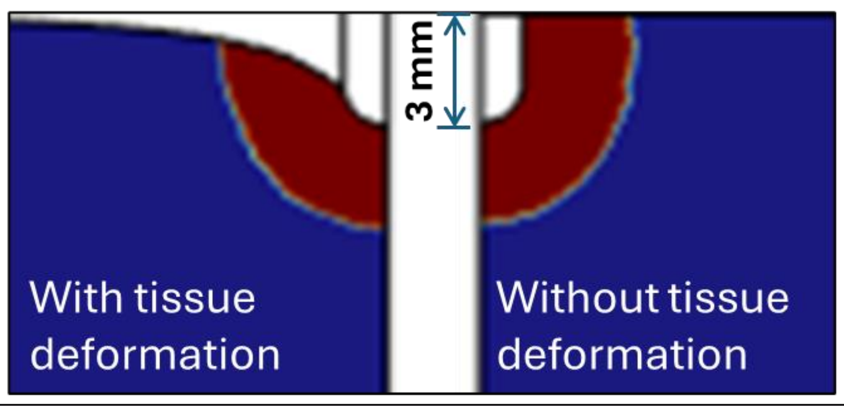

Fig. 3: Comparison of irreversible-electroporation-based damage zone.

Table 1: Material properties.

Material		Density ρ (kg/m³)	Specific heat c (J/kg/K)	Thermal conductivity k (W/m/K)	Electrical conductivity σ (S/m)
Electrode (Active part)		21,500	132	71	4.6×10^6
Catheter (Insulated part)		70	1045	0.026	10^{-5}
Skeletal muscle		1090	3421	0.49	0.373
Cardiac tissue	Liquid phase	1081	3686	0.56	0.228
	Gas phase	370	2155.92		
Blood		1050	3617	0.52	0.706

PFA parameters

Pulse amplitude = 1500 V
Pulse interval = 1 s
Pulse number = 20
Contact depth = 3 mm (~ 35 g contact force)

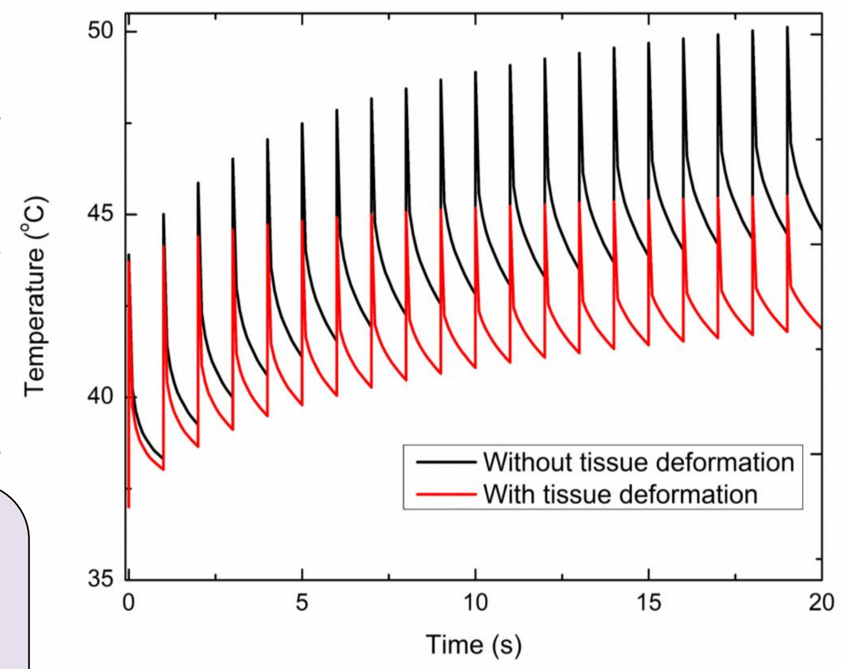

Fig. 4: Temporal variation of maximum tissue temperature.

CONCLUSION

- ➢ Tissue deformation induced due to the application of contact force at the PFA applicator significantly impacts the irreversible-electroporation-based damage volume and the maximum tissue temperature.
- ➢ Neglecting tissue deformation leads to an overestimation of the damage volume and maximum tissue temperature by 27.37% and 9%, respectively.

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