Contribution ID: **446**

Type: **Contributed Oral**

C3Or3B-08: Optimizing cryoprobe tip geometry for enhanced cryoablation efficacy: A numerical simulation approach

Wednesday 21 May 2025 15:45 (15 minutes)

Cryoablation has emerged as a vital minimally invasive technique for treating localized cancers, leveraging cryogenic probes to freeze and destroy tumor tissues. The geometry of cryoprobe tips significantly influences the freezing dynamics, including heat transfer efficiency, ice ball propagation, and the preservation of surrounding healthy tissues.
This study investigates the impact of cryoprobe tip design on cryoablation efficacy through numerical simulations using COMSOL Multiphysics®. A two-dimensional axisymmetric tumor model embedded within tissue layers is constructed, integrating the Pennes bioheat transfer equation and tissue-specific thermophysical properties. Different cryoprobe tip geometries—spherical, cylindrical, and novel designs featuring conical and cylindrical protrusions—are evaluated under constant and pulsating freezing cycles.

Simulations reveal that the novel tip design, with its enhanced surface area, outperforms conventional geometries by achieving a higher frozen tumor fraction with a reduction in injury to healthy tissues compared to conventional tips, as well as improved thermal isotherm control. Additionally, the pulsating freezing cycle demonstrates improved preservation of surrounding healthy tissues while maintaining effective tumor ablation. Comparative analysis of frozen fraction versus time plots underscores the dependence of cryogenic activity on tip geometry, suggesting that optimized tip designs can enhance cryoablation efficacy while minimizing collateral damage. These findings provide valuable insights into cryoprobe tip engineering and contribute to advancing cryosurgical interventions for cancer treatment.

Keywords: Cryoablation, Cryoprobe Tip Geometry, Ice Ball Propagation, Pulsating Freezing Cycles, Numerical Simulation

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Session Classification: C3Or3B - New Devices, Novel Concepts, and Miscellaneous III