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Numerical challenges for peroperative liver tumor ablations by electroporation

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Electropermeabilization (also known as electroporation) refers to a significant increase in the electrical conductivity of the cell membrane when cells are exposed to high-voltage pulses (typically a few hundred volts per centimeter).

If the pulse duration is sufficiently short (ranging from a few microseconds to a few milliseconds, depending on the amplitude), the permeabilised membrane can reseal within tens of minutes. This reversible electroporation preserves cell viability and is used in electrochemotherapy to facilitate drug delivery into the cell.

However, if the pulses are too long, too frequent, or of excessively high amplitude, the membrane is irreversibly damaged, leading to cell death. This irreversible electroporation (IRE) serves as a promising, non-thermal, and minimally invasive tumor ablation technique, particularly for patients who are not candidates for traditional treatments such as surgery, radiofrequency (RF) ablation, or cryoablation.

Despite its advantages, this predominantly non-thermal approach— which preserves the tissue scaffold and reduces bleeding— remains largely restricted to easily accessible tumors. This limitation arises mainly from the technical challenges associated with these therapies, particularly the difficulty in precisely determining the treated zone in advance compared to standard ablative techniques.

In this talk, I will first present recent findings on the mathematical modeling of electroporation across different scales, from individual cell membranes to whole tissues. Next, I will introduce a numerical strategy that integrates medical imaging (C-arm Cone Beam CT) and advanced computational methods to accurately assess clinical procedures by mapping the electric field distribution.

Finally, I will discuss a few case reports on percutaneous liver tumor ablation via IRE, demonstrating the feasibility of real-time numerical evaluation of IRE procedures.