Augmented Reality for Cryoablation Procedures

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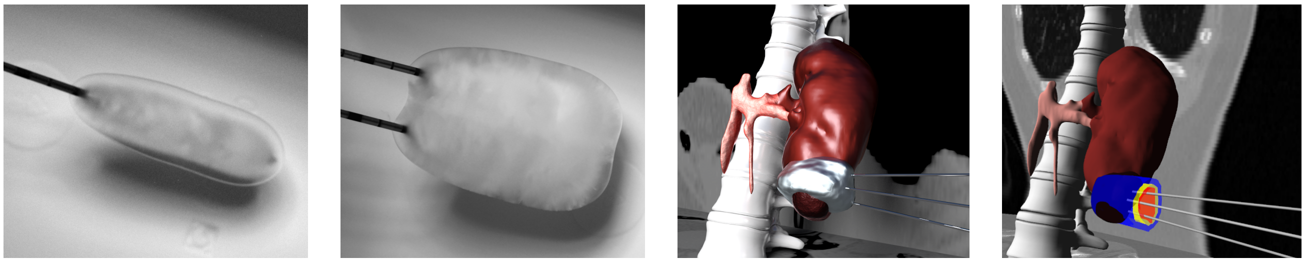

Figure 1: *Our physics-based simulation aims at estimating accurately the iceball and the isotherms during a cryoablation procedure*

1 Introduction

Cryotherapy is a rapidly growing minimally invasive technique for the treatment of different kinds of tumors, such as breast cancer, renal and prostate cancer. Several hollow needles are percutaneously inserted in the target area under image guidance and a gas (usually argon) is then decompressed inside the needles. Based on the Thompson-Joule principle, the temperature drops drown and a ball of ice crystals forms around the tip of each needle. Radiologists rely on the geometry of this iceball (273 K), visible on computer tomographic (CT) or magnetic resonance (MR) images, to assess the status of the ablation. However, cellular death only occurs when the temperature falls below 233 K. The complexity of the procedure therefore resides in planning the optimal number, position and orientation of the needles required to treat the tumor, while avoiding any damage to the surrounding healthy tissues.

This planning is currently done qualitatively, based on experience, and can take several hours, with a result that is often different from the expected one. To solve this important limitation of cryotherapy, a few planning systems have been proposed in the literature. Currently, commercial systems are nearly non existent, and emerging tools are limited to a visualization of the isotherms obtained for each needle in ideal conditions (usually in a gel). They do not account for any influence of the soft tissue properties, the presence of blood vessels, or the combined effect of multiple needles highlighted in [Young et al. 2012]. As a consequence, large safety margins over 5 mm are defined, as detailed in [Georgiades et al. 2012].

To address this challenge, our method extracts information from medical images (CT or MR) and allows to assess different strategies with an augmented visualization of the resulting iceball and the associated isotherms, as illustrated in Fig. 1.

2 Our Approach

To estimate the heat transfer, our work relies on the Pennes' model [Pennes 1948], based on the enthalpy method. This physiological approach accounts for blood perfusion in living tissue, key in the estimation of the iceball. Our heat transfer model is implemented using the Finite Element method. Starting from medical images (CT or MR), we define a region of interest around the tumor and create hexahedral elements from the image voxels. Blood vessels can easily be extracted from the images and incorporated within the simulation.

The diffusion term involves the integral of the derivative of the shape function ∇N_i, which is computationally-demanding. We propose a pre-computation of these derivatives using the regular feature of our hexahedra. The diffusion term can then be expressed as a sparse matrix and saved using a compressed raw storage. Compared to linear tetrahedra, our approach reveals to be more accurate using the same number of elements. Implemented on GPU, the performance of our approach is currently being evaluated, and already shows promising results.

For each configuration of the needles, our method allows to compute the resulting iceball as well as the 233 K isotherm, using a marching cube algorithm. This work therefore provides the radiologists with a substantial visual guidance before the operation. Using our work, the clinician can thus test interactively various ablation strategies and evaluate the resulting 233 K isotherm. Moreover, our numerical simulation may allow to extend the use of the cryoablation technique to non-expert radiologists. The Fig. 1 shows the estimation of the iceball (273 K isotherm) in white, but also the 233 K isotherm, ensuring cellular death, in red.

As future work, we intend to use this efficient GPU simulation in order to build an automated planning system. Using the predictive power of our simulation, this system would estimate the optimal positions and orientations of each needle.

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