PATIENT-SPECIFIC SIMULATION OF LIVER TUMOR ABLATION

Audigier C.[1,2], Mansi T.[2], Delingette H.[1], Kamen A.[2], Comaniciu D.[2], Ayache N.[1]

[1] INRIA Sophia-Antipolis, Asclepios Team, Sophia-Antipolis, France

[2] Siemens Corporate Technology, Imaging and Computer Vision, Princeton, NJ, USA

chloe.audigier@inria.fr

Clinical Background

Radio-Frequency Ablation (RFA) is:

- A minimally invasive ablative therapy of liver tumor ablation
- A solution when resection or transplantation are not possible
- Problems/Issues:
  - Rick of recurrence
  - Incomplete treatments

Technical Background

FEM Models :

- To compute heat diffusion [1]
- To predict the optimal placement of the probe
- To predict the state of the cells with Cellular Necrosis Models [2]
- Problems/Issues:
  - Too slow for planning or guidance

Goal

A predictive framework for patient-specific liver tumor ablation which :

1. Models the time-varying diffusivity
2. Models the thermal effect of the parenchyma and vasculature
3. Is real time to allow planning and guidance

Probe location

CT images

Create Anatomical Model

- Segmentation of pre-op CT images
- Registration of post-op to pre-op CT images

Model of Heat Transfer in Liver Tissue

A two-compartment model [3]

- **Pennes model in large vessels**

The blood temperature is assumed constant in CT-visible vessels

$$(1-\epsilon)\rho_t c_t \frac{\partial T}{\partial t} = (1-\epsilon)Q + (1-\epsilon)\nabla.(d_t \nabla T) + H(T_{b0} - T)$$

- **Wulff-Klinger model in the small arteries**

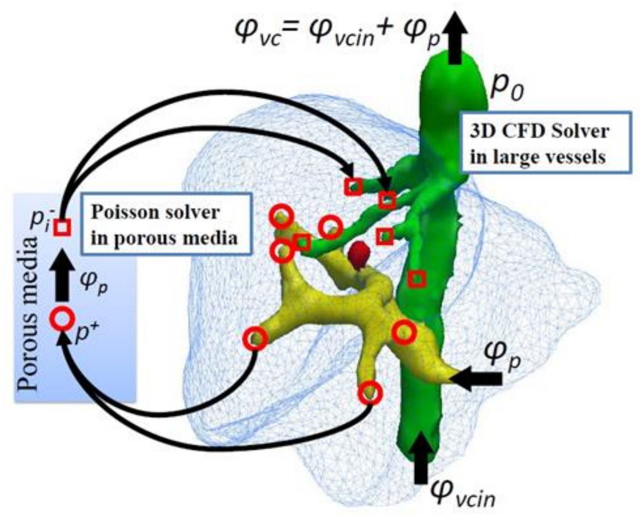
The blood and tissue temperatures are assumed to be at equilibrium in porous media

$$(1-\epsilon)\rho_t c_t \frac{\partial T}{\partial t} = (1-\epsilon)Q + (1-\epsilon)\nabla.(d_t \nabla T) - \epsilon \rho_b c_b \mathbf{v}.\nabla T$$

Model Parameters

Nominal Parameters from literature [4] used for all patients

Model of Venous Circulation System



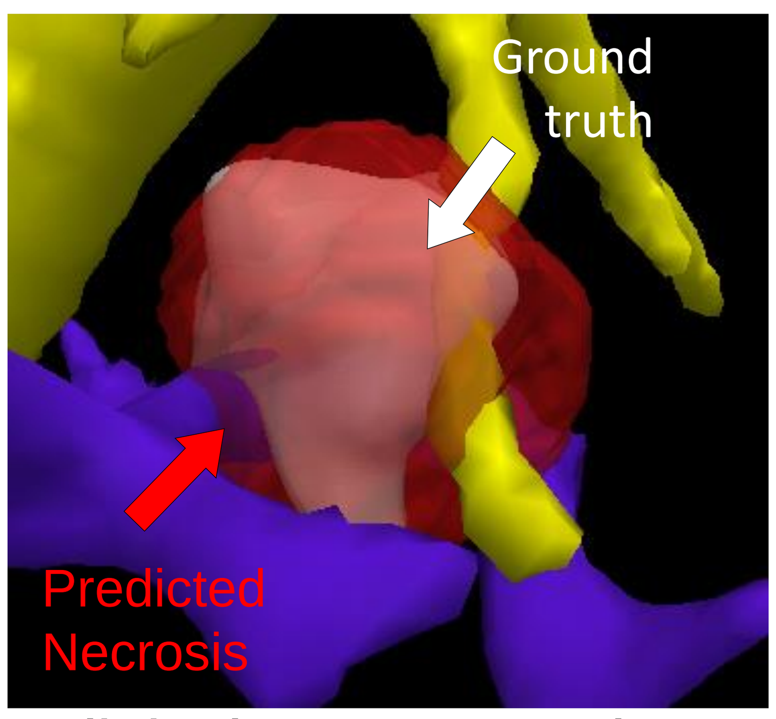
- Flow computation in the vena cava and the portal vein using CFD
- Inside the liver parenchyma using Darcy's law (Porous Media)

Model of Cellular Necrosis

$$A \underset{k_b}{\overset{k_f(T)}{\rightleftarrows}} V \xrightarrow{k_f(T)} D$$

A three-state cell death model to account for tissue necrosis [4]

Results



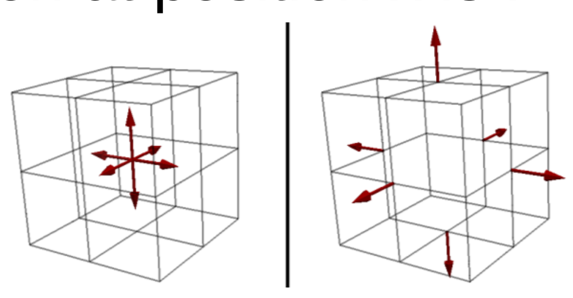
- Clinical RFA protocol simulated
- **1 minute of ablation is computed in 1.14 minutes**

Lattice Boltzmann Method (LBM)

- Implementation on GPU
- The model is solved on an isotropic Cartesian grid, with LBM [5]. A statistical description of the system is used, f is the distribution function and the governing equation at position x is :

$$\mathbf{f}(\mathbf{x}+\mathbf{e_i}\Delta x, t+\Delta t) = \mathbf{f}(\mathbf{x},t) + \mathbf{A}[\mathbf{f}^{eq}(\mathbf{x},t) - \mathbf{f}(\mathbf{x},t)] + \boldsymbol{\omega}\Delta t H(T_{b0} - T(\mathbf{x},t))$$

$$f_i^{eq}(\mathbf{x},t) = \omega_i T(\mathbf{x},t)[1 + \frac{\mathbf{e_i}.\mathbf{v}}{cc_s^2}],\ \boldsymbol{\omega} = \{\omega_i\}_{i=1..7},\ T(\mathbf{x},t) = \sum_{i=1}^{7} f_i(\mathbf{x},t)$$



Perspectives

Personalization of the important tissue parameters

Pre-clinical Validation with extensive

New opportunities in RFA planning and guidance

References

[1] Jiang, Y. et al. Formulation of 3D finite elements for hepatic radiofrequency ablation, 2010

[2] O'Neill, D. et al. A Three-State Mathematical Model of Hyperthermic Cell Death, 2011

[3] Audigier, C. Lattice Boltzmann Method For Fast Patient-Specific Simulation of Liver Tumor Ablation from CT images

[4] Payne, S. Image-based multi-scale modelling and validation of RFA in liver tumours, 2011

[5] Rapaka, S. LBM-EP: LBM for Fast Cardiac Electrophysiology Simulation from 3D Images, 2012