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IRE project – Numerical calibration of liver conductivities in IRE treatments based on clinical imaging and electrical current measurements

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Scientific context

Irreversible electroporation therapy provides an interesting alternative to standard ablative techniques, particularly for deep seated tumors near vital organs or important vessels. However these non thermal techniques, which preserve the tissue scaffold and reduce bleeding are still mostly limited to cutaneous and subcutaneous tumors. Such limitation is mainly due to the technical difficulties raised by these therapies for which the a priori determination of the treated zone is trickier than for standard ablative techniques.

The project aims at taking advantage of the specific clinical framework of the APHP interventional radiology team for liver tumors to determine the region of the liver affected by the electric field. The clinical data consist of the pre-treatment MRI, on which the tumor is detected, the position of the electrodes during the treatment and the measurements of the electrical intensities during the pulse delivery.

Description of the project

The clinical protocol provided by the University Hospital J. Verdier is described in Figure 1. It consists of the clinical imaging of the liver before and during the treatment and of the recording of the intensity chronograms during the pulse delivery.

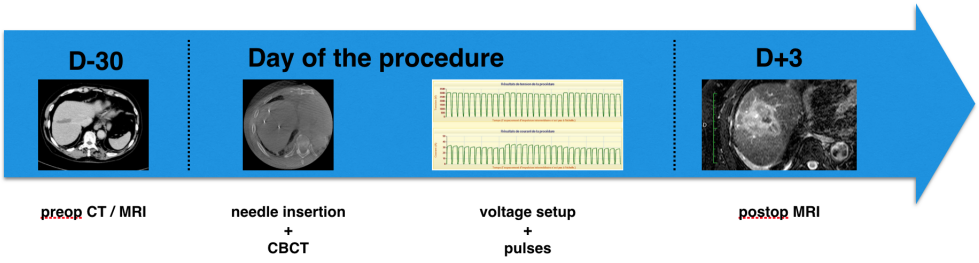
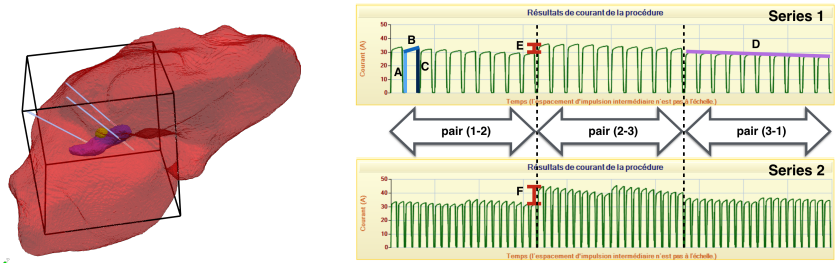


Figure 1: Clinical workflow

Thanks to the semi-automatic segmentation library developed within the team MONC, the exact geometrical configuration of the treatment is obtained (see Fig. 2(a)). However the parameters of the electric model of the liver, and particularly the increase of the conductivity during the pulse delivery are still not known.

Two different models will be consider. First, the standard electrostatic model with non linear and time-dependent conductivity will be investigated. This model reads as

$$-\nabla \cdot (\sigma(t, |\nabla u|)\nabla u) = 0,$$



(a) Geometrical configuration (b) Electrical measurements

Figure 2: Clinical configuration of the pulse delivery and measurements.

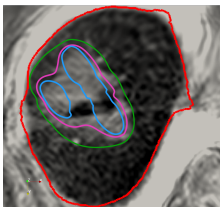


Figure 3: Prediction of the zones affected by the electric field.

where $\sigma(t, |\nabla u|) = \sigma_0 + \sigma_1 X_1(t, |\nabla u|)$, X_1 being given by an ODE presented in [3]. In a second step, we will fit the new dynamical model of tissue electroporation given in [3] which considers two electric currents.

The goal of the project is to take advantage of the chronograms (see Fig. 2(b)) to obtain the electrical conductivities, and then to infer the zone affected by the electric field (the zone for which the field amplitude is above 600V/cm). More precisely, we want to systematize the prediction of the zones reversibly and irreversibly electroporated from the chronograms, as presented in Fig. 3.

In order to determine these zones, a good strategy consists in simultaneously estimating the state of the system – by correcting in time the conductivity tensor – and the electrical parameters using the joint state and parameters sequential strategy of data assimilation presented in [2]. An example of this strategy applied to reaction diffusion systems is given in [1].

References

[1] A. Collin, D. Chapelle, and P. Moireau. A luenberger observer for reaction–diffusion models with front position data. *Journal of Computational Physics*, 300:288 – 307, 2015.

[2] P. Moireau, D. Chapelle, and P. Le Tallec. Joint state and parameter estimation for distributed mechanical systems. *Computer methods in applied mechanics and engineering*, 197(6-8):659–677, 2008.

[3] D. Voyer, A. Silve, L. M. Mir, R. Scorretti, and C. Poignard. Dynamical modeling of tissue electroporation. *Bioelectrochemistry*, 119:98 – 110, 2018.