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Standardized numerical simulations of cardiac electrical stimulation devices

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**Context**

The SimCardioTest project aims to improve the interest and benefits of in silico simulations in the case of cardiovascular diseases.

We work on the electrical part with MicroPort CRM pacemakers manufacturers.

An interface separates the electrode from the tissue, where several biochemical effects occur. We want to understand the impact of contact impedance during a stimulation and quantify the energy actually applied to the tissue.

**ODE – 0D Model**

* Device equation (equivalent RC circuit)

\[
\frac{dI}{dt} + \frac{I}{r} = \frac{1}{C} \left( \frac{V_L}{r_L} + \frac{V_R}{r_R} + \frac{I_{in}}{C_{in}} + \frac{V_m}{r_m} \right)
\]

* Contact equations (tip and ring)

\[
\frac{dV_L}{dt} + \frac{V_L}{r_L} = \frac{I}{C_{in}} + \frac{I_{in}}{C_{in}}
\]

* 0D cell equation with ionic terms from literature

\[
\frac{dV_m}{dt} = \frac{I}{C_m} + \frac{I_{in}}{C_{in}}
\]

* Poisson equation in the blood

\[
\frac{\partial}{\partial x} (\sigma \nabla u) = 0
\]

* At boundaries with electrodes (tip and ring)

\[
\sigma \nabla u \cdot n = j_x
\]

* At external boundaries, a transmissive b.c.

\[
\sigma \nabla u \cdot n = j_x
\]

Proof of existence on the way !

How to choose and determine contact and scaling parameters... ?

**PDE – 3D Model**

* Bidomain equations in the tissue

\[
\frac{\partial}{\partial x} (\sigma \nabla u) = -C_m \partial_t v_m - j_{in}
\]

\[
\frac{\partial}{\partial x} (\sigma \nabla v) = C_m \partial_t u_m + j_{in}
\]

* Poisson equation in the blood

\[
\frac{\partial}{\partial x} (\sigma \nabla u) = 0
\]

* At boundaries with electrodes (tip and ring)

\[
\sigma \nabla u \cdot n = j_x
\]

* At external boundaries, a transmissive b.c.

\[
\sigma \nabla u \cdot n = j_x
\]

How to adjust conductivities, ionic model, all parameters... ?

**Ringer Tests**

**Context**

These experiments were done in a laboratory of the industrial partner company MicroPort.

**Principle**

A lead is submerged in a salt bath, voltage and current passing through between the two electrodes are measured.

**Shape of data obtained**

Discharge: Phase to counterbalance capacitive effects of contacts.

**Optical Mapping**

**Context**

These experiments were done at IHU Liryc with MicroPort leads.

**Principle**

A sheep’s ventricle is placed in a bath with two cameras pointing at it (endocardial and epicardial sides). A lead is then implanted and stimulates the tissue. An activation map is calculated from the fluorescence captured by the cameras.

**Ex-vivo data from 2 animals**

* Activation map by optical mapping.
* Measured voltage at lead terminal.
* Geometries and some tissue characteristics by MRI 9.4T.

**Results**

**Contact calibration**

* Several contact models tested (different ODE systems).
* We are faced with the non identifiability of parameters.
* Still a large variability even with R/C.
* Accurate enough to reproduce measures in saline solution.

**Scaling parameters**

* Great influence of parameter \( S \) (surface membrane).
* \( S \) and \( r_m \) are surrogates of the geometry.

**Lapicique curves**

* Obtained by 2D dichotomy for now.
* Not accurate enough for ex-vivo comparison.
* Order of magnitude and results relevant for exploration.

**No results in 3D for Lapicique studies yet**

But some works on bidomain coupled with an extracardiac domain already done.

**Objectives**

* Reproduce ODE studies in 3D.
* Quantify influence of tissue variability and geometric properties on results.

For that we need to exploit experimental data, and several calibrations will be required.

**All this work to**

* Take into account pacemaker in models.
* Create a web platform with a design tool for lead manufacturers.

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