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Standardized numerical simulations of cardiac electrical stimulation devices



SIM
CARDIO
TEST

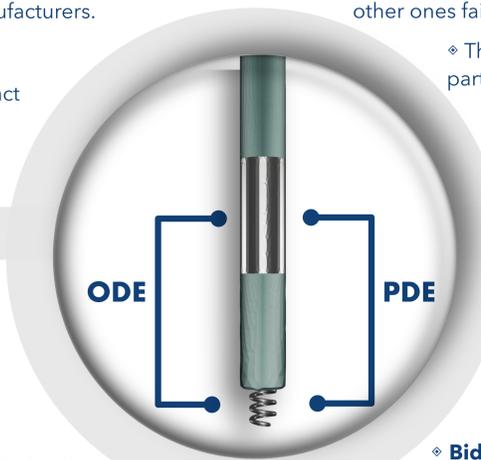
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Université de Bordeaux, IMB, Inria and IHU Liryc

CONTEXT

The **SimCardioTest** project aims to improve the interest and benefits of **insilico 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.



STIMULATIONS

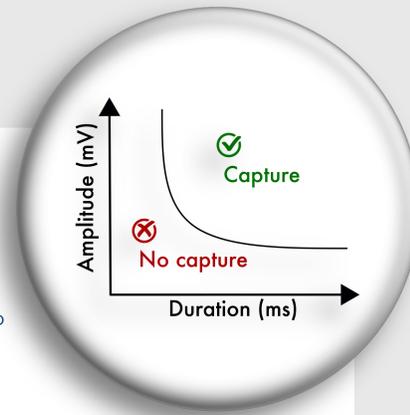
Parametrized by their **amplitude** and **duration** of pulse.

◊ Efficient stimulations lead to a capture, and the other ones fail.

◊ The plane of stimulations is splitted in two parts by the **Lapicque** curve

$$A(d) = A_{rh} \left(1 + \frac{t_{ch}}{d} \right)$$

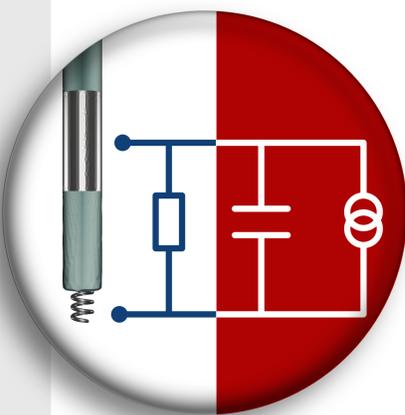
with two parameters called rheobase and chronaxie.



ODE – 0D MODEL

Why

- Basic study on electrical properties of **contacts**.
- Test some algorithms, and simplified **nonlinear** effects.
- First comparison with **experimental** data.



◊ **Device** equation (equivalent RC circuit)

$$\frac{dI}{dt} + \frac{I}{\tau} = \frac{1}{R} \left(\frac{V_1}{\tau_1} + \frac{V_2}{\tau_2} + \frac{I_{ion}}{C_m} + \frac{V_m}{\tau_m} \right)$$

◊ **Contact** equations (tip and ring)

$$\frac{dV_i}{dt} + \frac{V_i}{\tau_i} = \frac{I}{C_i}$$

◊ **0D cell** equation with **ionic terms** from literature

$$\frac{dV_m}{dt} + \frac{I_{ion}}{C_m} + \frac{V_m}{\tau_m} = \frac{I}{SC_m}$$

$$\frac{dh}{dt} + g(v_m, h) = 0$$

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

PDE – 3D MODEL

Why

- Take geometry into account (electrode distances, front wave propagation...).
- Compare **experimental** data with our solution.

◊ **Bidomain** equations in the tissue

$$-\text{div}(\sigma_i \nabla u_i) = -C_m \partial_t v_m - j_{ion}$$

$$-\text{div}(\sigma_e \nabla u_e) = C_m \partial_t v_m + j_{ion}$$

$$\partial_t h + g(v_m, h) = 0$$

◊ **Poisson** equation in the blood

$$-\text{div}(\sigma_e \nabla u_e) = 0$$

◊ At **boundaries** with **electrodes** (tip and ring)

$$-\sigma_e \nabla u_e \cdot \mathbf{n} = j_-$$

$$-\sigma_e \nabla u_e \cdot \mathbf{n} = j_+$$

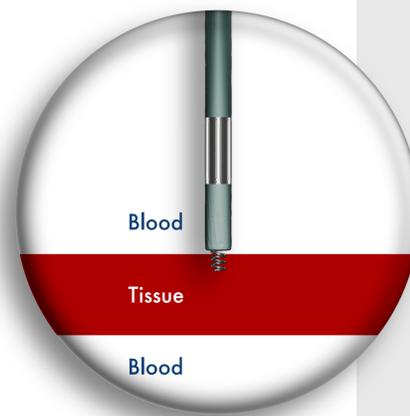
◊ At **exterior boundaries**, a transmissive b.c.

$$-\sigma_e \nabla u_e \cdot \mathbf{n} = \mu_e u_e$$

$$-\sigma_i \nabla u_i \cdot \mathbf{n} = \mu_i u_i$$

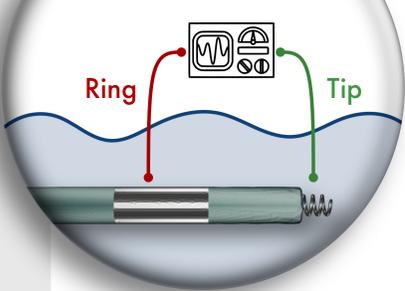
Proof of existence on the way !

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



RINGER TESTS

Measurements in saline solution



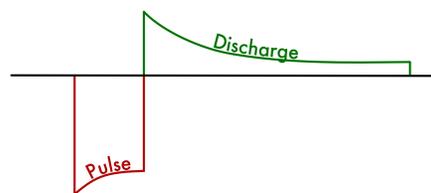
CONTEXT

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

PRINCIPLE

A lead is **submersed** 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.

CONTEXT

These experiments were done at **IHU Liryc** with MicroPort leads.

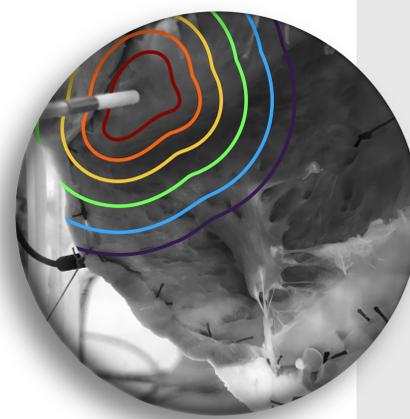
PRINCIPLE

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.

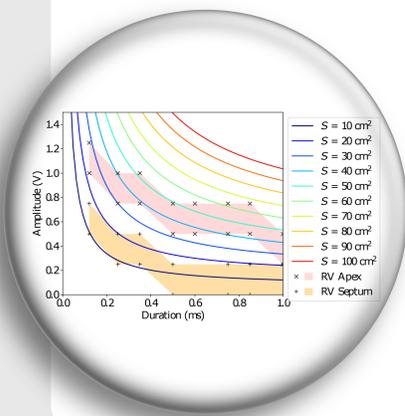
EX-VIVO DATA FROM 2 ANIMALS

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

OPTICAL MAPPING



RESULTS



CONTACT CALIBRATION

- ◊ Several **contact models** tested (different ODE systems).
- ◊ We are confronted 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 **T_m** are **surrogates** of the geometry.

LAPICQUE 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 LAPICQUE STUDIES YET

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

OBJECTIVES

- ◊ Reproduce 0D 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.

RESULTS

