Thermoelectrical Modelling of Intestine using COMSOL Multiphysics

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1 Introduction

Paralysis of the intestine or paralytic ileus (PI), is an inevitable aftermath of major abdominal and nonabdominal surgeries. PI prevents the passage of food throughout the lumen, causing accumulation of gas and secretions and leading consequently to bloating, distension, emesis and pain. Although improvements in supportive measures have been achieved, no useful therapy to specifically reduce or eliminate these motility disorders has been developed yet [1]. Because there is a lack in scientific literature, PI remains an important clinical problem. Here we draw a plausible mathematical scenario, physiologically fine tuned, which explains a possible cause of PI. Thermal coupling is introduced to study the influence of temperature variations, one of the most important external factors occurred on intestine tissue during surgery in operating theater. In Fig. 1 a schematic diagram of the adopted 3D domain, as modelled by COMSOL Multiphysics, is shown. Model details are presented and discussed according to a physiological point of view in Ref.[2].

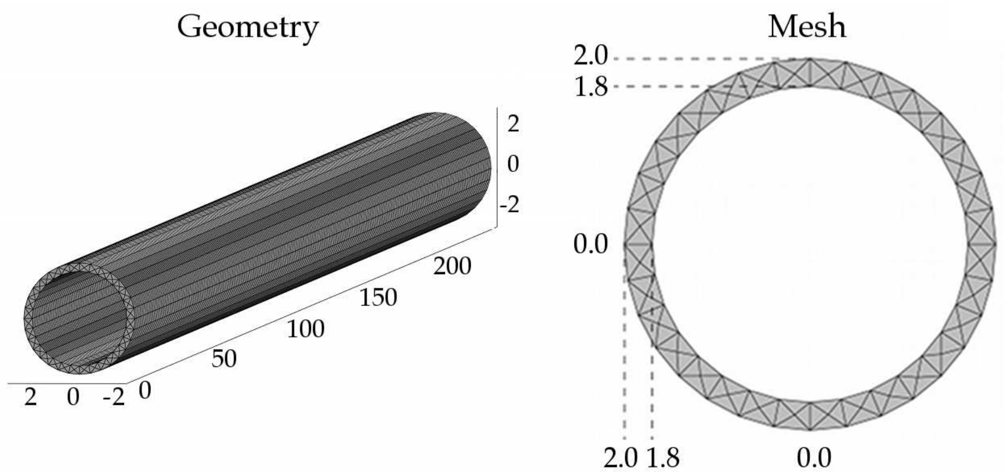

Fig. 1: 3D geometry, physical dimensions (cm) and mesh. A thin cylindrical layer ($[240 \times 10 \times 0.2]\,cm$ corresponding to duodenum length, mean circumference and thickness) is discretized through an adapted mesh method that leads to about 3×10^4 nonlinear quadratic elements and about 8×10^5 degrees of freedom.

2 PDE Modelling in COMSOL Multiphysics

The thermoelectrical and electrophysiologically fine tuned model here adopted combines the electrical activity of small intestine [3] with Pennes bio-heat equation [4] to take into account thermal effects during intestinal surgery. The ionic model is based on a FitzHugh-Nagumo equation set and it's characterized by temperature-dependent parameters of excitability repeated for the two tissue layers and characterized by a longitudinal space-varying excitability parameter. Zero flux Neumann boundary conditions and uniform fields as initial values are imposed. The thermal problem is addressed by the modified scalar heat equation, fine tuned on human values, with time-dependent Dirichlet boundary conditions for the internal and external duodenal temperature. The model is explored specifically through a General Form and Time-dependent COMSOL Multiphysics code. We adopted Lagrange quadratic tetrahedral elements with Linear system Geometric Multigrid solver and a BDF method to minimize the amount of RAM required.

3 Results and Conclusions

We have observed that cooling heat acted like an deformans, destabilizing and external factor against the physiological electrical duodenal activity and these actions leaded to persistent rotating spiral waves. These pathological behaviors should occur not only in PI [1], but also in other major surgeries. The model could be seen as a first level analysis towards biomedical engineering applications developed for reducing PI discomfort.

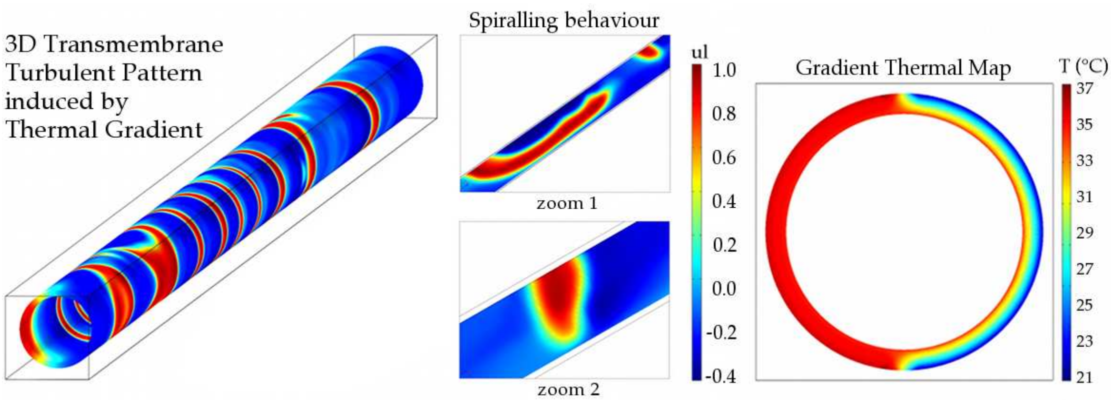

Fig. 2: 3D model obtained by FEM numerical integration of the complete thermoelectric model in COMSOL Multiphysics: the thermal gradient imposed on the domain boundaries leads to irregular and turbulent transmembrane potentials and in particular to electrical spiral waves.

References

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