Blood flow simulation and magnetohydrodynamics effects in MRI

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In order to improve the quality of the images provided by Magnetic Resonance Imaging (MRI), the magnetic field used in MRI is getting larger and larger: from $3T$ nowadays, it might increase in the future up to $10T$ in clinical scanners. The impact of such a large magnetic field on health is still in debate. We focus in this study on the perturbations induced by the magnetic field on the electrocardiogram (ECG). Indeed, the blood flow (containing charged particles) immersed in the magnetic field induces an electric field that may alter the electric potential measured during ECG. In particular, the induced electric field may increase the T-wave in the ECG. We investigate this phenomenon and try to simulate such an effect.

Some MHD effects of the magnetic field on blood flows were already discussed in the literature in a stationary case in a 2D configuration. We believe that the geometry and the time dependence may affect significantly the conclusions. We therefore propose to solve the following 3D model.

In the context of blood flows, the magnetohydrodynamics (MHD) equations can be reduced to a coupling between the Navier-Stokes equations with a Lorentz force depending on the electrical potential Φ, and a Laplace equation for the potential Φ with a source term depending on the velocity $\boldsymbol{u}$:

$$\begin{cases} \dfrac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{u} - \dfrac{1}{Re}\Delta\,\boldsymbol{u} + \boldsymbol{\nabla} p = -\dfrac{Ha^2}{Re}\boldsymbol{\nabla}\Phi \times \boldsymbol{B} + \dfrac{Ha^2}{Re}\left(\boldsymbol{u}\times\boldsymbol{B}\right)\times\boldsymbol{B}, \\ \mathrm{div}\boldsymbol{u} = 0, \\ \mathrm{div}\left(\sigma\boldsymbol{\nabla}\Phi\right) = \mathrm{div}\left(\sigma\boldsymbol{u}\times\boldsymbol{B}\right). \end{cases}$$

In this equation, $\boldsymbol{B}$ denotes the constant magnetic field, σ the electrical conductivity, p the fluid pressure, Ha the Hartmann number and Re the Reynolds number.

To go further, these equations have to be solved in the aorta and coupled on the one hand to a model for the electrical activity of the heart (bidomain equations) and on the other hand to a Laplace equation in the torso.

With this model, solved on a realistic geometry, our goal is to assess the impact of the magnetic field on the ECG, the impact of the Lorentz force on the flow and the amount of induced electric current in the aorta.

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