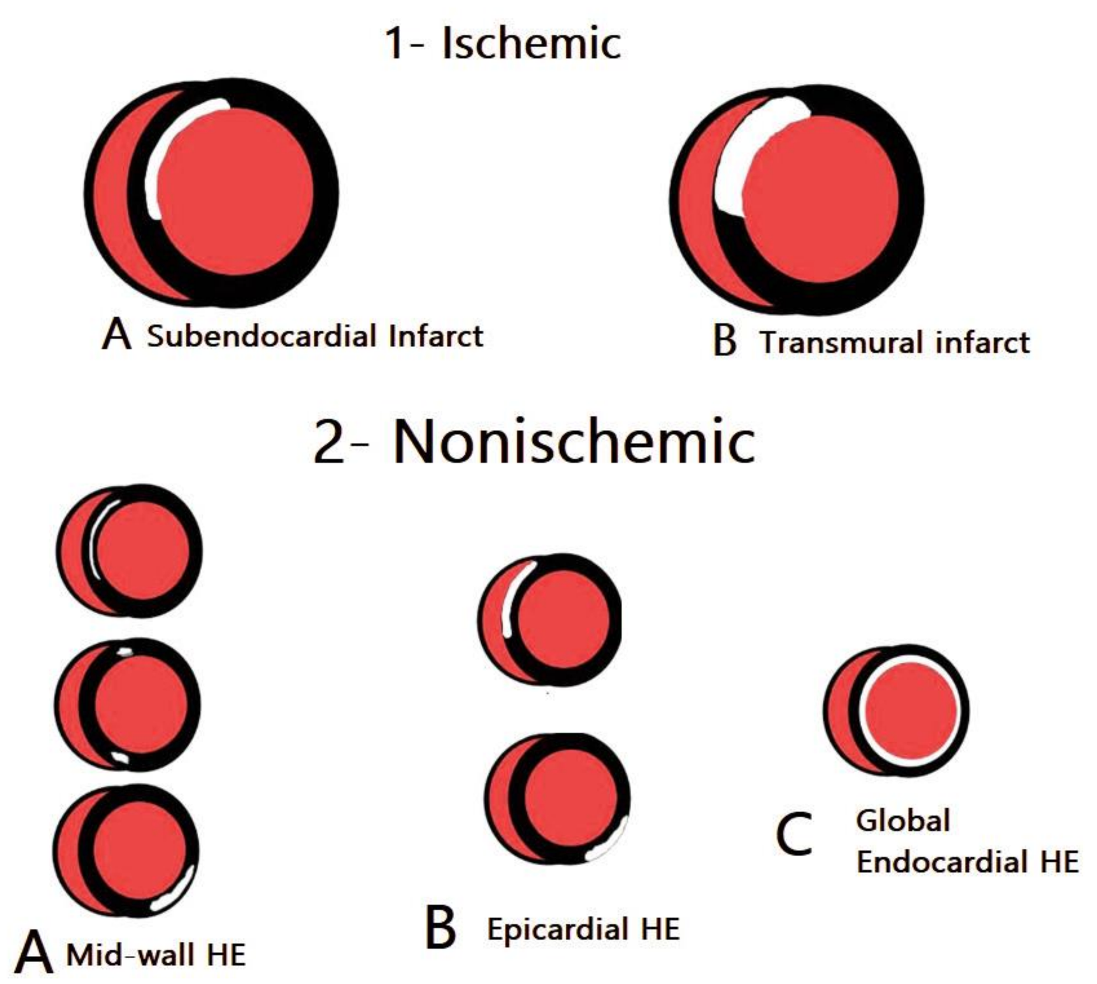
Modeling contrast perfusion and adsorption in the 3D heart

Rodrigo Weber dos Santos, Evandro Dias Gaio, Bernardo Rocha Martins
Universidade Federal de Juiz de Fora

Introduction

Contrast-enhanced Cardiac Magnetic Resonance Imaging (MRI) is an exam used to characterize myocardial perfusion and detect scars or infarct regions via a contrasting agent (CA). The CA assumes a specific contrast on poorly perfused regions or in scars on the MRI images.



The proposed new model can reproduce clinical exams (including Late Gadolinium Enhancement) under normal perfusion or in the presence of ischemia or myocardial infarct. The model provides new information for clinicians. Other than the contrast dynamics, the model presents how it relates to the pressure gradient, perfusion flow and fibrosis or scar in the heart tissue.

Methodology

The perfusion and CA adsoption is modeled via a reaction-diffusion-advection system in porous media.

- **Porous Media Flow in the Intravascular Domain**

$$\mathbf{v} = -\mathbf{K}\nabla p, \quad \text{in } \Omega, \qquad \nabla \cdot \mathbf{v} = \alpha, \quad \text{in } \Omega, \qquad \mathbf{K} = K_t\mathbf{I} + (K_l - K_t)\mathbf{f} \otimes \mathbf{f}$$

- **Contrast Agent Dynamics in the Intra- and Extravascular Domains**

$$\frac{\partial(\phi C_i)}{\partial t} + \nabla \cdot (\mathbf{v}C_i) - \phi\nabla \cdot (\mathbf{D}_i\nabla C_i) + f = 0, \quad \text{in } \Omega_i,$$

$$\frac{\partial((1-\phi)\lambda C_e)}{\partial t} - (1-\phi)\lambda\nabla \cdot (\mathbf{D}_e\nabla C_e) - f + (1-\phi)\lambda k_e C_e + g = 0, \text{in } \Omega_e,$$

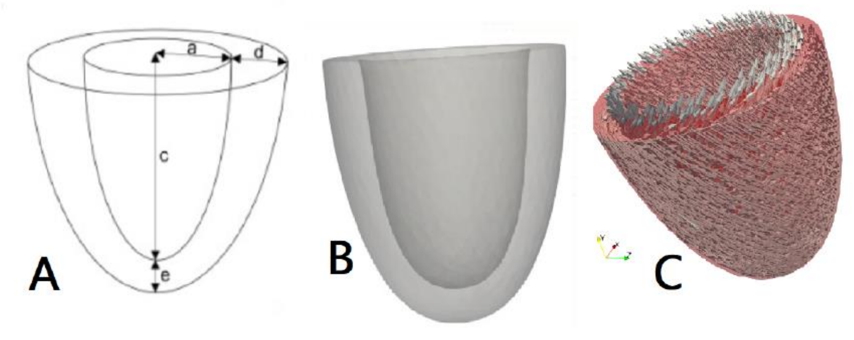
- **Contrast Agent Adsorption**

$$\frac{\partial((1-\phi)\lambda\lambda_f C_f)}{\partial t} + (1-\phi)\lambda\lambda_f k_f C_f - g = 0, \quad \text{em} \quad \Omega_f,$$

- **Initial and boundary conditions**

$$p = p_o, \ \text{on} \ \Gamma_{epi}, \qquad p = p_i, \ \text{on} \ \Gamma_{endo}. \qquad \mathbf{v}C_i - \mathbf{D}_i\nabla C_i = \mathbf{v}Q(t), \ \text{on} \ \Gamma_{epi}, \qquad Q(t) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{t-t_{peak}}{\sigma}\right)} + X(t, \vec{x}),$$

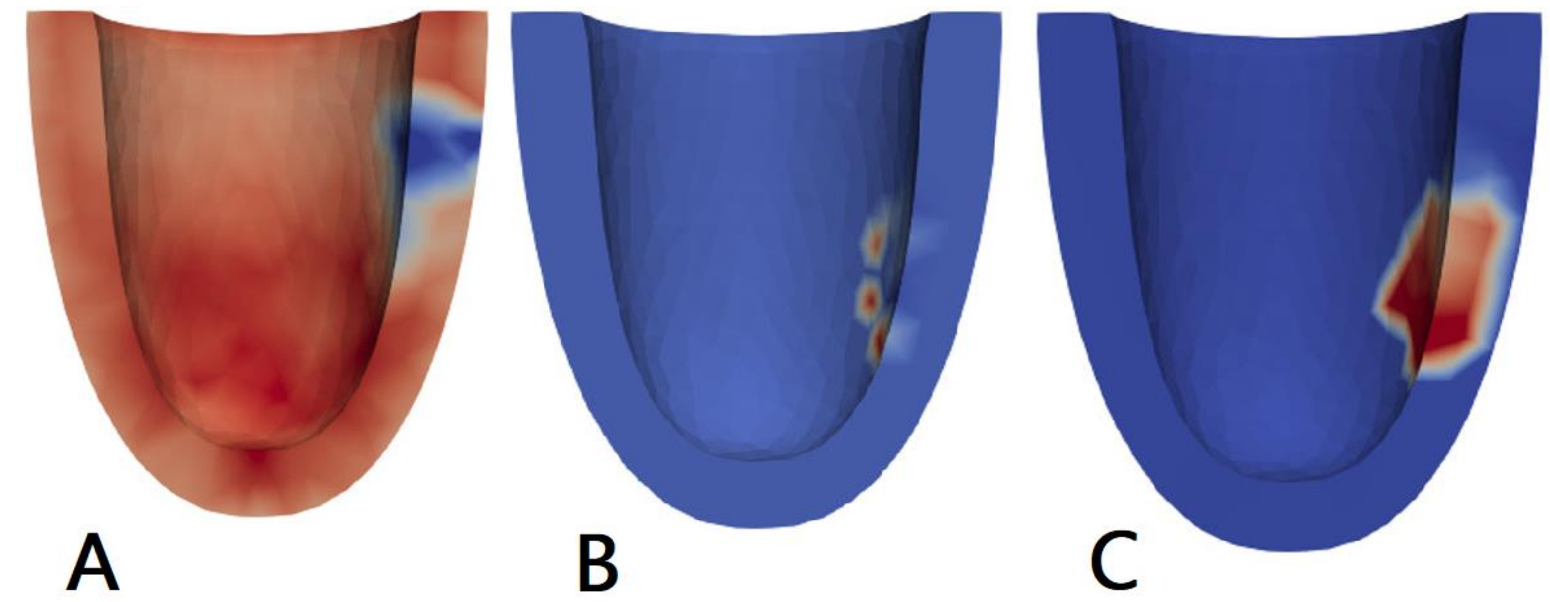
- **Left Ventricular Geometry Models**

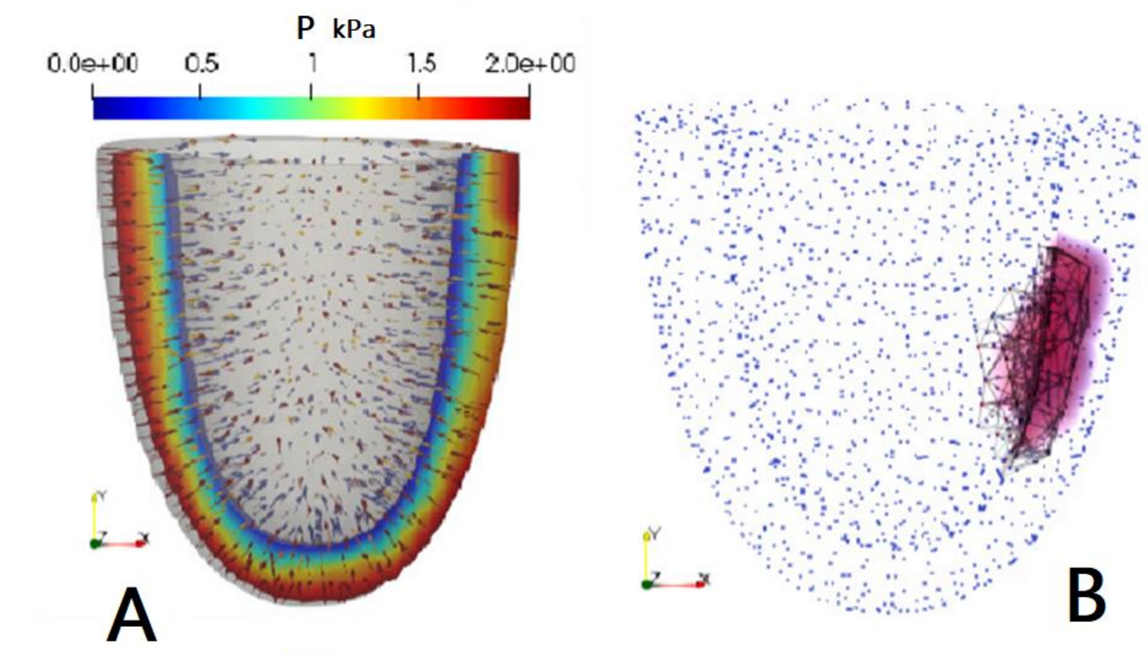


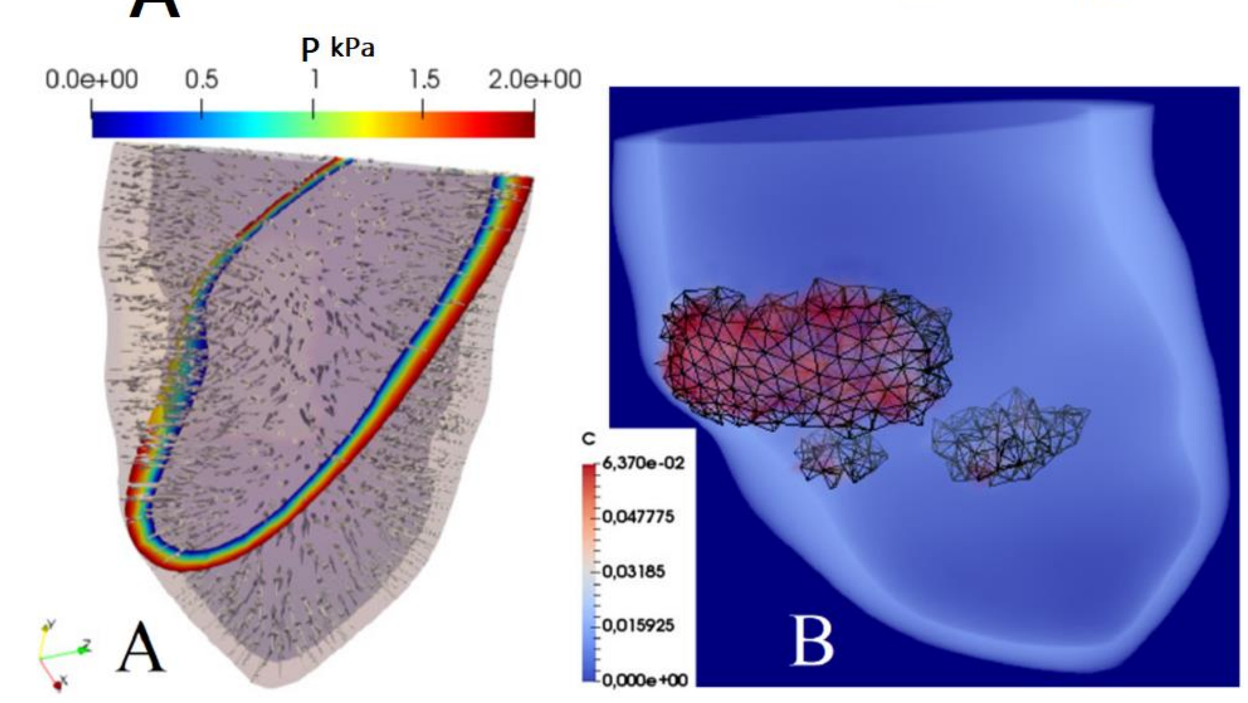
- **Numerical methods**

Darcy's problem is solved using a mixed formulation and stable choice of finite element spaces, the Brezzi-Douglas-Marini elements of polynomial order one with discontinuous Lagrange elements of order 0. The transient CA transport equations were discretized with the Crank-Nicolson scheme and the Streamline upwind Petrov–Galerkin (SUPG) method.

Results

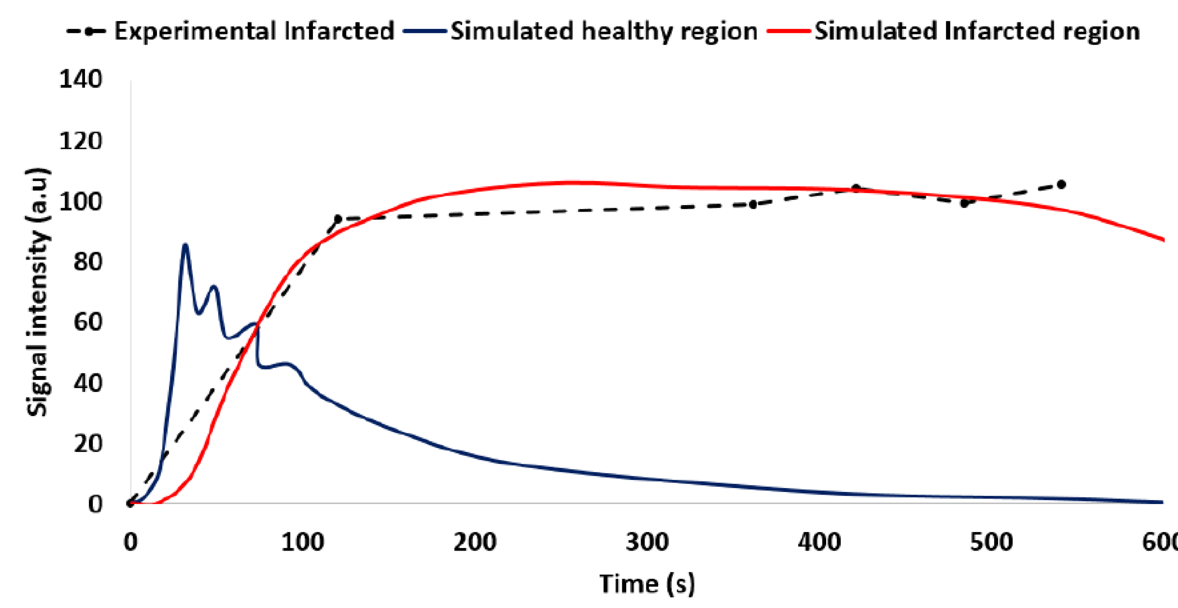


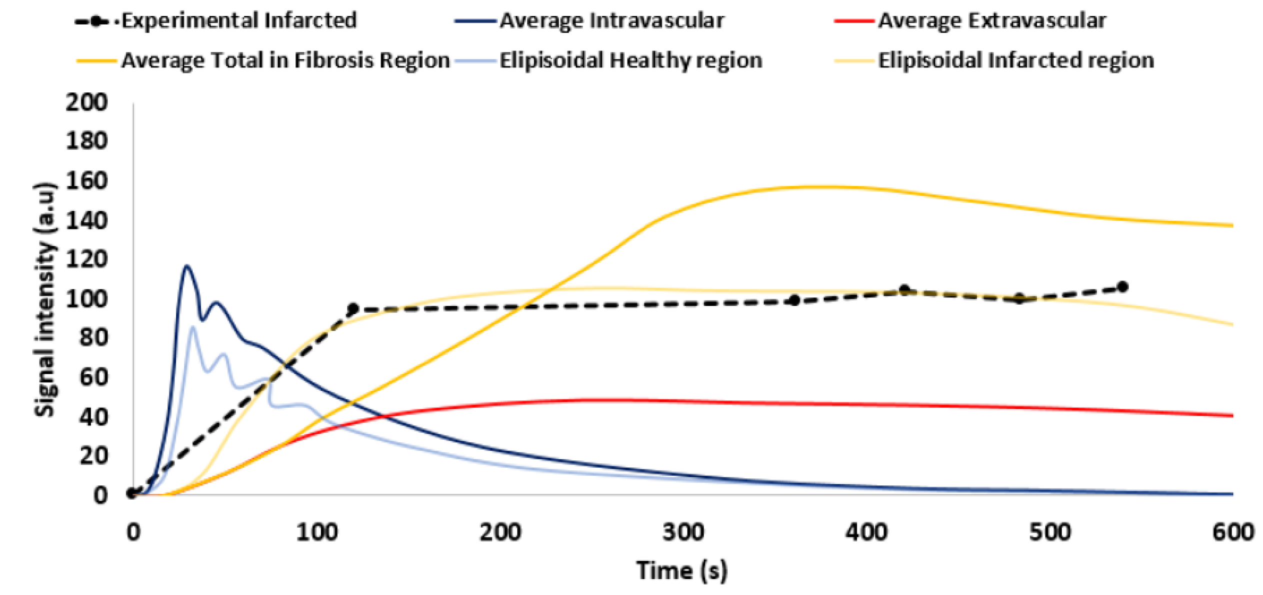




Conclusion

The simulations of the 3D patient-specific model agree with the literature and the available clinical data. This study has a potentially high impact since it provides new information for clinicians based on patient-specific models calibrated with MRI exams.





Acknowledgements

This work was supported by UFJF, CAPES, CNPq (Grants 310722/2021-7, 315267/2020-8), and FAPEMIG (Grants APQ-01340-18, APQ 02489/21).

References

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