Proposition stage de master WP5 LabEx PRIMES: Investigation of lumped parameter models associated with MRI for the study of ischemia-reperfusion impact.

Supervision : P. Clarysse (DR CNRS, équipe MYRIAD, CREATIS, Lyon)
In collaboration with J. Ohayon (PU, équipe BiomécaMot, TIMC, Grenoble).

Context:

In the context of STEMI, early reperfusion (percutaneous coronary intervention, PCI) is currently the most effective treatment to reduce infarct size (IS) resulting from Myocardial Infarction (MI). Although reperfusion reduces IS, it causes additional myocardial damage by itself. This process is called ischemia-reperfusion (I/R) injury [Bochaton, et al., 2021]. There is therefore a clear need to identify biomarkers to stratify MI patients at high risk of poor cardiac recovery [Berezin and Berezin, 2020], [Aimo, et al., 2019]. Although the utility of left ventricular ejection fraction (LVEF) in risk prediction has been extensively reviewed, deformation imaging as a more appropriate approach for overall myocardial functional and risk assessment [Smiseth Otto, et al., 2025] has not yet find its way into routine clinical imaging.

Approaches using computational models have also been considered. In a cardiac modeling study, the statistical analysis of STEMI patients revealed that the required patient-specific contractility, normalized active tension and the systolic myofilament kinematics have the strongest explanatory power for identifying the myocardial function changes post-MI [Gao, et al., 2017]. Rumindo et al. studied ranges of subject-specific in vivo myocardial stiffness and contractility from 21 healthy volunteers [Rumindo, et al., 2020]. In his PhD thesis, Rumindo also investigated the impact of lesions onto the myocardial biomechanical properties [Rumindo, 2019]. Such biomechanical-based approaches use imaging data for the personalization and make assumption about the myocardial tissue, notably the fiber organization within the heart, and the pressure conditions. The complexity of those approaches requires to solve for a huge number of parameters within a complex optimization requiring large memory and computing power.

Low-order models (0D/1D) offer an alternative to these complex calculation chains. They focus on physiological function without the need of detailed anatomical models. For instance, the CircAdapt model enables simulation of blood pressures, volumes, and flows in heart and circulation on a beat-to-beat basis [Arts, et al., 2005], [van Osta, et al., 2025]. The model is composed of modules, such as heart chambers, valves, blood vessel tubes and peripheral microcirculations. CircAdapt was notably used to generate imaging-based Digital Twins (DTs) of patients with LV mechanical discoordination [Koopsen, et al., 2024].

In a previous work placement (Master 1), Omar ATIEA deeply investigated the CircAdapt model, its components (modules) and their interactions, as well as the calculation chain that links the mechanical properties of the myocardium to pressures, volumes and flow rates [Atiea, 2026].

Objective:

Based on the prior study the CircAdapt model, the objective of the project is to investigate its adaptability to STEMI patients studied in MRI and its potential utility to predict recovery following reperfusion. In a multi-segments configuration, we will identify a selection of parameters and measurements required to individualize the models to a patient in a clinical setting. The approach introduced in [Seemann, et al., 2019] to estimate patient specific pressure-volume (PV) loops from MRI volumes and brachial pressure could be considered as a source to the lumped parameter model. Derived parameters from CMR (volumes, strains) and the CircAdapt model (e.g stiffness) will be analyzed collectively in their ability to stratify MI patients.

Proposed Methodology:

- Bibliography study and getting started with the CircAdapt model
- Methodology: investigation of a personalization approach for the CircAdapt model
- Practical work: application of the approach to available MRI data
- Evaluation of the subject-specific MRI-based PV loop method to be combined with the lumped parameter model
- Analysis of output parameters with longitudinal data.

Profile:

- Knowledge in computer modeling, numerical analysis, image analysis
- Programming skills in Python, and specialized libraries for data processing and analysis

Practical Information:

- 6 months from February-March 2027, ~650€ / month, Doua-LyonTech site.
- Possible collaboration with the group developing the CircAdapt Model (CARIM, Maastricht University, The Netherlands)
- Possibility of pursuing a doctoral degree, depending on fundings.

Application:

Send CV, motivation letter, and academic results to: patrick.clarysse@creatis.insa-lyon.fr

References

[Aimo, et al., 2019] A. Aimo, K. Gaggin Hanna, A. Barison, M. Emdin, and L. Januzzi James, "Imaging, Biomarker, and Clinical Predictors of Cardiac Remodeling in Heart Failure With Reduced Ejection Fraction," *JACC: Heart Failure,* vol. 7, no. 9, pp. 782-794, 2019.

[Arts, et al., 2005] T. Arts, T. Delhass, P. H. M. Bovendeerd, X. Verbeek, and F. W. Printzen, "Adaptation to mechanical load determines shape and properties of heart and circulation: the CircAdapt model," *Am. J. Physiol. Heart circ. Physiol.,* vol. 288, pp. H1943-H1954, 2005.

[Atiea, 2026] O. Atiea, "Investigation de modèles à paramètres concentrés associés à l'IRM pour l'étude de l'impact de l'ischémie-reperfusion," INSA, Lyon, France, Master 1, 2026.

[Berezin and Berezin, 2020] A. E. Berezin and A. A. Berezin, "Adverse Cardiac Remodelling after Acute Myocardial Infarction: Old and New Biomarkers," *Disease Markers,* vol. 2020, no. 1, p. 1215802, 2020.

[Bochaton, et al., 2021] T. Bochaton, J. Lassus, A. Paccalet, F. Derimay, G. Rioufol, C. Prieur, E. Bonnefoy-Cudraz, C. Crola Da Silva, H. Bernelin, C. Amaz, S. Espanet, C. de Bourguignon, N. Dufay, R. Cartier, P. Croisille, M. Ovize, and N. Mewton, "Association of myocardial hemorrhage and persistent microvascular obstruction with circulating inflammatory biomarkers in STEMI patients," *PLOS ONE,* vol. 16, no. 1, p. e0245684, 2021.

[Gao, et al., 2017] H. Gao, A. Aderhold, K. Mangion, X. Luo, D. Husmeier, and C. Berry, "Changes and classification in myocardial contractile function in the left ventricle following acute myocardial infarction," *J R Soc Interface,* vol. 14, no. 132, 2017.

[Koopsen, et al., 2024] T. Koopsen, N. van Osta, T. van Loon, R. Meiburg, W. Huberts, A. S. Beela, F. P. Kirkels, B. R. van Klarenbosch, A. J. Teske, M. J. Cramer, G. P. Bijvoet, A. van Stipdonk, K. Vernooy, T. Delhaas, and J. Lumens, "Parameter subset reduction for imaging-based digital twin generation of patients with left ventricular mechanical discoordination," *BioMedical Engineering OnLine,* vol. 23, no. 1, p. 46, 2024.

[Rumindo, 2019] G. K. Rumindo, "Predictive cardiac modelling for the study of myocardial injuries," PhD PhD, INSA Lyon, Université de Lyon, 2019.

[Rumindo, et al., 2020] G. K. Rumindo, J. Ohayon, P. Croisille, and P. Clarysse, "In vivo estimation of normal left ventricular stiffness and contractility based on routine cine MR acquisition," *Medical Engineering & Physics,* vol. 85, pp. 16-26, 2020.

[Seemann, et al., 2019] F. Seemann, P. Arvidsson, D. Nordlund, S. Kopic, M. Carlsson, H. Arheden, and E. Heiberg, "Noninvasive Quantification of Pressure-Volume Loops From Brachial Pressure and Cardiovascular Magnetic Resonance," *Circulation: Cardiovascular Imaging,* vol. 12, no. 1, p. e008493, 2019.

[Smiseth Otto, et al., 2025] A. Smiseth Otto, O. Rider, M. Cvijic, L. Valkovič, W. Remme Espen, and J.-U. Voigt, "Myocardial Strain Imaging," *JACC: Cardiovascular Imaging,* vol. 18, no. 3, pp. 340-381, 2025.

[van Osta, et al., 2025] N. van Osta, G. van den Acker, T. van Loon, T. Arts, T. Delhaas, and J. Lumens, "Numerical accuracy of closed-loop steady state in a zero-dimensional cardiovascular model," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* vol. 383, no. 2293, p. 20240208, 2025.