Post-doc Position
Statistical degradation modelling of heart bioprosthetic valves

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Starting date: between 1/09/2022 and 1/12/2022
Duration: 12 mois
Salary: between 2466€ Brut (1982€ net) and 2891 € Brut (2323 € net)

CONTEXTE

Human heart can be seen as a formidable engineering machine, acting as a central pump, and beating from birth to death to set into motion the circulatory system, thus ensuring oxygen supplies to the organs and removing carbon dioxide and wastes. It relies on the beating of four valves, ensuring that the blood flows unidirectionally through the pump, and preventing backward flows. Dysfunctions of these valves are at the origin of a myriad of pathologies, possibly with genetic origins (congenital cardiac pathologies) and it is estimated that more than 200000 surgical replacements are performed per year worldwide only for the aortic valve. Mechanical valves were first introduced starting from 1950, made of strong and durable materials [2] but due to post-surgery problems linked to the aging of patients and the need of anti-coagulants, they are now almost entirely replaced by bioprosthetic valves, made of biological tissues (porcine or bovine). These valves do not suffer from the drawbacks of mechanical valves, which considerably improves the post-surgery quality of life of patients. However, as all biological tissues they are subjected to decay, calcification, and tearing of leaflets. Thus, to provide a long-lasting solution to heart valves dysfunctions, the crucial point is to understand and improve valves durability (which should in theory be longer that the life expectancy of the patients).
To address this major issue of cardiac surgery, identifying the mechanical stresses exerted on the tissues and using engineering approaches, in particular in-silico strategies, is a cutting-edge approach. Often, the degradation phenomenon is very complex and its modeling would require the consideration of many factors within the framework of a multidimensional temporal model taking into account the fluid stresses on the walls and the structural properties of the tissues over time. The exact modeling of these phenomena is therefore very costly in computing time, and moreover very difficult due to the great variability of the geometries and physiological parameters of the human heart. To overcome these limits, two tracks are delivered, namely dimension reduction and the use of random models.

Scientific Positioning

To study the durability of the valves, markers with a physical or statistical interpretation will be identified, based on:
- digital tools developed at the M2P2 allowing in particular to simulate the fluid stresses exerted on the walls of the valves [4, 5]
- the expertise of cardiac surgeons [6]
- statistical and data processing tools developed at M2P2 [7]
- imaging performed on a micro-tomograph to quantify tissue deformations under physiological pressure conditions [8-10]

These markers may be of a geometric nature (shape of the valves), kinematics (opening and closing movements of the valves) or dynamic (parietal forces). For example, the thickness of the valve influencing the flutter, the elasticity of the materials as well as the non-isotropy of the tissues induced by the orientation of the fibers can also be considered as a marker. These markers, in principle of smaller dimension than the degradation model, will be modeled by a statistical model taking into account the hazard in the phases of data collection, data processing, modeling as well as the uncertainty and variability of the settings. Methods for reducing the dimensions of the

problem could make it possible to propose indicators derived from markers using Principal Component Analysis (PCA) type methods.
After data processing, stochastic models will be used for temporal modeling of the degradation indicator (marker). This model, well calibrated, should make it possible to predict the future evolution of the marker and to anticipate states of strong degradation and non-functionality. The prediction, based on a random (stochastic) model, will propose confidence bounds and a distribution on the future state of the marker and will not be limited to a scalar value. Thus, the prediction will be able to support the experts (surgeons) for decision-making by indicating the level of underlying risk in order to guide them in their therapeutic valve replacement strategy.

Objective and methodology

The objective of the postdoc is therefore to build, from statistical methods and stochastic models, a predictive model of long-term fatigue of heart valve bio-prostheses, by modeling the evolution over time of valve markers.
The methodology will be as follows:
• Global analysis of available digital, imaging and clinical data
• Identification of markers with or without physical interpretation
• First analysis of data in terms of classification, relevance, identification of extreme values
• Proposal of a statistical model for the temporal modeling of the trajectories of one or more markers
• Integration of the hazard in the model parameters
• Prediction of the temporal evolution of the marker
• Analysis of the uncertainty on the prediction
• Feedback of results with experts (surgeons) and other field data.

Candidate profile

- Data-scientist or knowledge of statistical data processing
- R or Python software
- Experience in Bio-statistics or reliability appreciated
- Appetite for numerical modeling

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