Mitral Valve Models Reconstructor: a Python based GUI software in a HPC environment for patient-specific FEM structural analysis

A. Arnoldi[a], A. Invernizzi[b], R. Ponzini[b], E.Votta[a], E.G. Caiani[a], A. Redaelli[a]

[a]Bioengineering Department, Politecnico di Milano, Milan, Italy
[b]CILEA, Milan, Italy
arnoldialice@hotmail.com

Abstract- A new approach in the biomechanical analysis of the mitral valve (MV) focusing on patient-specific modelling has recently been pursued. The aim is to provide a useful tool to be used in clinic for hypotheses testing in pre-operative surgical planning and post-operative follow-up prediction. In particular, the integration of finite element models (FEMs) with 4D echocardiographic advanced images processing seems to be the key turn in patient-specific modelling. The development of this approach is quite slow and hard, due to three main limitations: i) the time needed for FEM preparation; ii) the high computational costs of FEM calculation; iii) the long learning curve needed to complete the analysis without a unified integrated tool which is not currently available.

In this context, the purpose of this work is to present a novel Python-based graphic user interface (GUI) software working in a high performance computing (HPC) environment, implemented to overcome the above mentioned limitations. The Mitral Valve Models Reconstructor (MVMR) integrates all the steps needed to simulate the dynamic closure of a MV through a structural model based on human in vivo experimental data. MVMR enables the FEM reconstruction of the MV by means of efficient scientific routines, which ensure a very small time consuming and make the model easily maintainable. Results on a single case study reveal that both FEM building and structural computation are notably reduced with this new approach. The time needed for the FEM implementation is reduced by 1900% with respect to the previous manual procedure, while the time originally needed for the numerical simulation on a single CPU is decreased by 980% through parallel computing using 32 CPUs. Moreover the user-friendly graphic interface provides a great usability also for non-technical personnel like clinicians and bio-researchers, thus removing the need for a long learning curve.

I. Introduction

The mitral valve (MV) is a complex apparatus inserted on the valvular plane through the mitral annulus (MA), which is the support site of two leaflets. The valve is connected to the ventricular myocardium through a net of several branched chordae tendineae that converge into two papillary muscles (PMs). In the last two decades the high prevalence of MV pathologies has induced a growing need for quantitative and patient-specific information on MV biomechanics; these information should be available to cardiac surgeons and useful for an objective assessment of MV diseases and for surgical planning. As compared to traditional engineering in-vitro and animal models, finite element models (FEMs) are an innovative tool able to provide more detailed information on MV biomechanics and, if validated, may be more suitable to predict the characteristics of a given clinical scenario. These features make them a potential turn key in wide range hypothesis testing: thanks to such potential FEMs have already been applied to study the MV normal function [1-3], the biomechanics underlying MV diseases [1] and the effects of surgical corrections [4-7]. However, none of the mentioned studies captures all of the four aspects that drive MV function: morphology, tissues mechanical response, dynamic boundary conditions, and the interaction among MV components and between the MV and the surrounding blood. Nowadays, published models propose idealized geometries and boundary conditions of the MV, in contrast to the complexity and the variability of the MV morphology and dynamics.

Recently, a realistic FEM of a physiological MV has been obtained by the integration of quantitative information from in vivo real time 3D echocardiography (RT3DE), including a detailed mechanical properties description [8].
The model has been successfully tested to simulate the MV closure from end-diastole (ED) to systolic peak (SP), obtaining interesting results. However, the applicability of the procedure presented in [8] would be very limited due to high computational costs of FEM reconstruction and dynamic simulation; moreover the large complexity of manual integration of the modelling procedures restricts to very few people the usability of the new approach.

The present work consists of a possible graphic user interface (GUI) software implementation able to: i) build the FEM of the MV starting from patient-specific RT3DE pre-processed data, ii) perform FEM computation in high performance environment (HPC), iii) analyse FEM results.

II. Design considerations

The Mitral Valve Models Reconstructor (MVMR) is an interactive and automated tool built in HPC environment. The user accesses to the software by connecting to a high

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