COMPUTATIONAL MITRAL VALVE MODELING THROUGH A COMPREHENSIVE MRI-BASED APPROACH

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Introduction

High-fidelity mitral valve (MV) finite element (FE) models based on *in vivo* imaging have been increasingly developed [1,2]. To this aim, 4D echocardiography has been largely used since it provides well time- and space-resolved volumetric data, despite its inter-operator variability [1]. Cardiovascular magnetic resonance (CMR) can also be exploited [2]; it is operator-independent, it offers a better image contrast, but data consist in stacks of 2D images thus requiring a dedicated approach to reconstruct the 3D MV geometry. Also, regardless of imaging modality, chordae tendineae cannot be clearly identified, with uncertainty in their definition heavily hampering the reliability of computational results. Herein, we sought to advance CMR-based MV modelling by combining an improved method for MV 3D reconstruction with a dedicated approach for the calibration of chordae tendineae.

Methods

CMR images were acquired on a Philips Ingenia 1.5T scanner (Philips Medical System) on 18 evenly distributed radial planes [2], and on a stack of short-axis planes encompassing the entire MV. CMR planes were realigned by optimizing their normalized cross correlation, under the hypothesis of pixel-intensity similarity along their intersections [3]. Based on Fourier and NURBS fitting functions, the stress-free MV geometry was reproduced at late diastole (Fig. 1.a) from manual tracing of MV annulus, MV leaflets and papillary muscle (PMs) tips. The model was completed by a functionally equivalent model of chordae tendineae with insertions uniformly distributed over the leaflet surface (15 chordal insertions/cm^2 [4]). Chordae initial length was then calibrated [4]: the mid-systolic leaflet surface was reconstructed from CMR data (Ω_{MS}^{CMR}), and the end-diastolic leaflet computational grid (Ω_{ED}^{GRID}) was morphed onto Ω_{MS}^{CMR} through a preliminary simulation where annulus and MV free edge were displacement-controlled to match the corresponding profiles on Ω_{MS}^{CMR}, and Ω_{ED}^{GRID} was driven to contact Ω_{MS}^{CMR} by a 5 mmHg pressure load, yielding the new position of chordae insertion and hence the calibrated chordae length. The calibrated model was completed including the anisotropic and hyperelastic mechanical response of MV tissues [4]. MV closure from late diastole to peak systole was simulated in Abaqus/Explicit (Dassault Systèmes), retrieving annular and PMs kinematic boundary conditions from CMR data and applying a 120 mmHg pressure on leaflets ventricular surface.

Results

The method was preliminarily tested on a healthy MV. As compared to the initial setting at end-diastole, calibration made 95% of chordae longer, on average by 4.2 mm (+ 12.3%), and made 5% of chordae negligibly shorter, by 0.6 mm (-1.4%) on average. Chordae length calibration allowed for consistency between the simulated mid-systolic leaflet configuration and ground-truth CMR data (Fig. 1.b). At mid-systole, MV leaflets strain pattern (Fig. 1.c) well agreed with previous MV models [1, 4]. Force transferred to PMs reached 20.7 N, redistributed between the single antero-lateral PM (10.0 N) and the two heads of the postero-medial PM (8.5 N and 2.2 N, respectively).

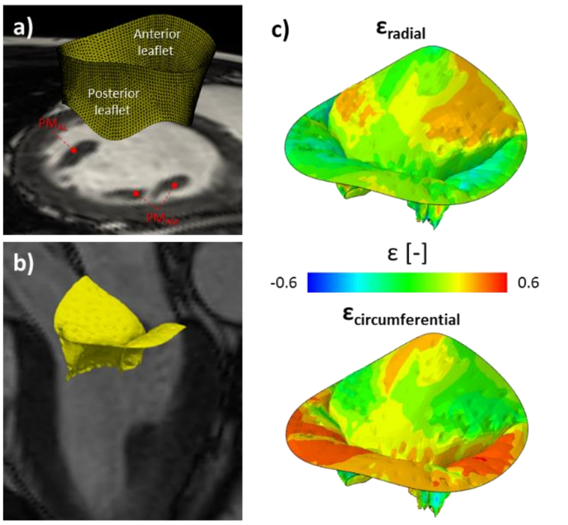

Figure 1: MV model at late diastole (a) and mid-systole (b), c) radial and circumferential strain on MV leaflets

Discussion

We effectively improved our CMR-based MV modeling strategy, which will allow achieving deeper insight into MV function and biomechanical implications involved in MV degenerative prolapse.

References

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3. Carminati *et al*, Comput Biol Med 2014; 46: 42-50
4. Khalighi *et al*, Ann Biomed Eng 2019; 47(1): 60-74

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