Mitral valve finite element modeling from cardiac magnetic resonance imaging: patient-specific quantitative analysis

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Introduction

Finite element models (FEMs) has proven to be useful and accurate in the assessment of mitral valve (MV) biomechanics. Previously proposed MV FEMs, mostly based on animal or ex vivo measurements, lay over simplifying assumptions on MV symmetrical shape, idealize leaflets profile and disregard contraction.

Thus, our goal was to develop a framework for the quantitative analysis of time-varying MV geometry from cardiac magnetic resonance (CMR) imaging, and to integrate these data in patient-specific simulations of MV closure from end diastole to peak systole.

Materials and methods

CMR imaging of 18 evenly rotated long-axis cut-planes (one every 10 degrees) was performed on a healthy subject with a temporal resolution of 55 time-frames per cardiac cycle. Three-dimensional MV annulus geometry, leaflets surface and papillary muscles (PMs) position were manually obtained using custom software. Leaflets extent and orientation were set consistently with MRI-derived leaflets free-edge profile. Branched chordae tendineae of three orders were defined in accordance to ex vivo findings (Figure 1).

All tissues were assumed non-linear and elastic. Their mechanical response was described by means of proper strain energy potentials. Leaflets behaviour was described through the hyperelastic and transversely isotropic constitutive model proposed by May-Newman¹. Chordae tendineae response was assumed isotropic and described through a polynomial strain energy function, whose parameters were defined via interpolation of data from the literature.

The dynamic contraction of mitral annulus and PMs was modeled via kinematic boundary conditions, i.e. imposing time-dependent nodal displacements, derived from annular nodes position at each time-frame. A physiological transvalvular pressure drop, up to 120 mmHg, was applied on the leaflets. The numerical simulations were performed within the finite element commercial code ABAQUS/Explicit 6.9-1 (SIMULIA, Dassault Systèmes).

Results and discussion

In the studied subject, full valve closure occurred at a 15 mmHg transvalvular pressure drop, accordingly with in vitro observations.

Leaflets maximum principal stresses were computed (Figure 2). The anterior leaflet resulted more stressed than the posterior one; peak values of 500 kPa were computed next to the fibrous trigones on the mitral annulus, consistently with their functional role of anchoring structures for the surrounding soft tissues.

Conclusion

In this study, we introduced a novel approach for developing a FE model of the MV based on patient-specific data obtained from CMR. This technique allows for high time-resolution imaging in adequately large field of view, even in subjects with enlarged annulus due to MV pathologies. Although further tests are mandatory, this approach could constitute the basis for an accurate evaluation of MV pathologic conditions and for the planning of surgical procedures.

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References