

FINITE ELEMENT MODELING OF TRANSAPICAL MITRAL VALVE REPAIR

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1. Introduction

The mitral valve (MV) presents a biological membrane consisting of two leaflets anchored to the papillary muscles (PMs) by the chordae tendineae, a group of cord-like tendons. From the mechanical point of view, these leaflets play the role of the valve which opens and closes during the cardiac cycle and ensures unidirectional blood flow. MV prolapse is one of the most common valvular abnormalities, affecting 2-3% of the general population [1]. It is a condition in which MV does not close smoothly during heart contraction. In some cases, the prolapsed MV lets a small amount of blood flow backward. This abnormal reversal flow of blood is called mitral regurgitation (MR), which, if untreated, can lead to a life-threatening condition, such as heart failure. Both MV prolapse and MR are usually caused by the rupture of chordae tendineae. Due to different heart and valvular diseases, mechanical properties of chordae can change, and rupture of one or more chordae occurs.

MR caused by chordae tendineae rupture is typically corrected by the chordae replacement with expanded polytetrafluoroethylene (ePTFE) sutures [2]. Transapical off-pump MV repair with neochordae implantation is a novel surgical technique, allowing to correct MR without stopping the heart [3]. The procedure is performed under the guidance of echocardiography, therefore, the exact neochordal length to eliminate prolapse while preventing additional restriction of the leaflet can only be assumed [4]. For this reason, finite element modeling is proposed to evaluate the effects of neochordal length on the post-repair MV function.

2. Materials and Methods

The MV was modeled as thin-walled structure fixed to moving supports by elastic connectors. Geometry was reconstructed from echocardiographic data using custom platform developed in MATLAB (Mathworks) by Biomechanics Research Group of Politecnico di Milano (Italy) [5]. Positions of MV leaflets and PM tips were traced during the closure of the valve, i.e. the time frame between end-diastole, when MV can be assumed as approximately unloaded, and peak systole, when the transvalvular pressure reaches its maximum. The geometry of MV leaflets with a branched network of chordae tendineae connecting PM tips and valve leaflets was then created. Mechanical behavior of MV leaflets was assumed non-linear and anisotropic, and described through a constitutive model, proposed by Lee *et al.* [6]. Mechanical behavior of the chordae tendineae was assumed non-linear and isotropic, and different types of chordae were modeled as 2nd order polynomial and 5th order Ogden hyperelastic materials.

Prolapse of MV was simulated by removing chordae inserted into the middle segment of posterior leaflet (PL). In order to evaluate the effect of neochordal length on post-repair MV function, a total of four virtual repairs using 4 neochordae of different length were performed. The annular contraction was applied as nodal displacements to MV annulus and a time-dependent physiologic transvalvular pressure curve increasing from 0 to 119 mmHg was applied on the ventricular surface of the leaflets. MV leaflets were meshed into 3-node shell elements, while chordae tendineae was modeled as truss elements (Fig 1a). The function of MV before and after virtual repairs for the time frame between end-diastole and peak systole was simulated in Abaqus/Explicit (Dassault Systèmes).

3. Results

All virtual repair procedures eliminated prolapse and significantly increased the coaptation area. However, while virtual repair restored the different level of coaptation length on the septal-lateral diameter of MV, this

length was insufficient (less than 5 mm [7]) after implantation of the shortest and the longest neochordae (Fig. 1b). After virtual repair with the shortest neochordae movement of PL was partially restricted, preventing leaflet apposition, while the implantation of the longest neochordae caused the opposite effect – the movement of the PL was not restricted enough and MV prolapse remained.

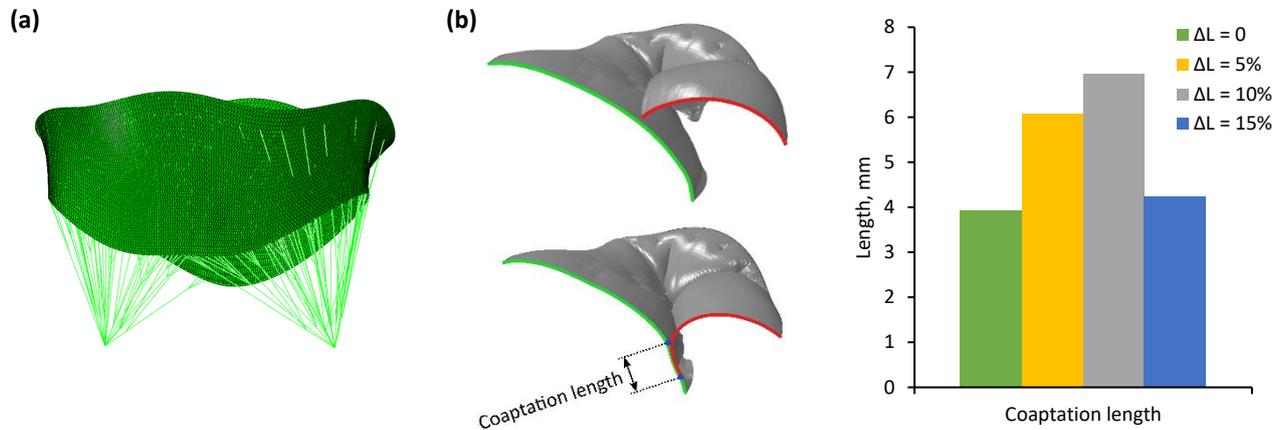


Figure 1. Finite element model of MV leaflets and chordae tendineae (a); evaluation of virtual MV repair in terms of coaptation length (b)

4. Conclusions

In the present study, finite element modeling of the outcomes of transapical MV repair with neochordae implantation was introduced. The evaluation of the effect of neochordal length on post-repair MV function showed that the length of implanted neochordae has a significant impact on the correction of MR caused by chordae tendineae rupture.

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