MCB, vol. 16, supplemental 1, pp.69-70, 2019

Papillary Muscle Related Biomechanical Properties of Mitral Valve Chordae Tendineae

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Keywords: Chordae tendineae, mitral valve, heart, biomechanical property, papillary muscle.

1 Introduction

Mitral valve is a complex structure including the annulus, the anterior leaflet, the posterior leaflet, the papillary muscles (PM), and the chordae tendineae connecting the leaflets and PM. The mechanical properties of the chordae play an important role in the normal functioning of the mitral valve: the chordae assists in maintaining the opening and closing configuration of the valve during cardiac cycle. Failure of certain chordae may lead to failure of the mitral valve and in severe cases, will lead to heart disease and mortality. In some cases, the ruptured chord needs to be corrected by repair or replacement. Therefore, there has been high interest in the analysis of the function, mechanical properties and shape features of the mitral apparatus to improve the surgical effect.

Chordae can be distinguished by leaflet location insertion as primary and secondary chordae. These finger-like chords connect the mitral valve to either anterolateral papillary muscle (APM) or posteromedial papillary muscle (PPM). The PPM has a higher risk to necrose and rupture in myocardial ischemia and infarction in clinic, but it is underlying mechanism is still unknown. Previous studies have shown importance in maintaining the asymmetric structure and realistic material property of the mitral valve for physiological load condition, but simplified the chord as symmetric structure, which is not true. In this study, the porcine heart chords were classified and measured according to the attached PMs. The uniaxial tensile test was utilized to analyze the biomechanical properties of the papillary muscle related chordae and histology observation was carried out for microstructure analysis. This study aims to analyze the anatomical and mechanical property differences in chords based on PMs which may help to understand the mitral valve function and to optimize the design of the artificial implantation or repair.

2 Methods and materials

Studies have shown that porcine valve was identified as an appropriate model for further investigation of the mitral valve system when considering the rarity of human valve.

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A total of 16 fresh porcine hearts were collected, infused in 4°C PBS buffer and infiltrated in physiological saline during the experiment, 9 of which were used for tensile testing, 6 for histological section staining, and 1 for TEM scanning. Based on insert position to PM (APM or PPM) and leaflets (primary on free edge and secondary on belly), the chord were divided into the APM primary chord, APM secondary chord, and PPM primary chord, and PPM secondary chord. The chords were separated from the valve, and the chordae diameter and length were measured via microscope, Markers were added at the target area of the chord for strain measurement. The sample was then fixed on an Instron1000 uniaxial tensile test machine with sandpaper. Before the experiment, the specimens were preload from 0 N to 2 N until the displacement curves were substantially coincident, and then tensile test. The sensor is used to record the stress change, and the CCD camera synchronously collects the displacement footage of the markers on target area until the chord sample is broken or slipped from tensile test machine. The MATLAB code was used to perform imaging processing and to obtain the stress-strain curve.

Histological samples were fixed in 4% glutaraldehyde in PO4 buffer (pH 7.4) for 5 hours, dehydrated with graduated concentrations of ethanol and embedded in paraffin. Radial sections were cut to 5 µm thick, masson stained and photos were then taken with microscope (ZEISS Stemi 2000-C) and camera (ZEISS AxioCam ICc5). The cross-sectional area ratio of collagen fibers and the amount of micro-vessel were observed. The microstructure sample was processed for transmission electron microscopy (TEM) observation. They were trimmed and fixed with 2.5% glutaraldehyde, post-fixed with 1% Osmium Tetroxide for 1 hour, 1% uranyl acetate in Maleate buffer for 1 hour, and dehydrated with ethanol and propylene oxide, and then embedded in Epon. The difference in the configuration of collagen fibers was observed by TEM scanning.

3 Result and conclusion

There was no significant difference in the number of chord on each PM, and the PPM chord was longer. The Green strain-Cauchy stress curve showed that the Tangent Modulus (TM) of the PPM secondary chord was larger than that of the APM secondary chord. The number of blood vessels on APM primary chord was more than that of PPM primary chord, there was no significant difference in the area ratio of collagen fiber on chord of each PM. In our research, the Ogden nonlinear strain energy function was used to fit the experimental stress-strain data and to obtain material parameters. It provides a theoretical basis for the subsequent dynamic simulation using finite element method.