MCB, vol.16, supplemental 2, pp.56-57, 2019

Tech Science Press

Computational Biomechanical Right Ventricle Modeling with Contracting Bands to Improve Ventricle Cardiac Function for Patient with Repaired Tetralogy of Fallot

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Abstract: Computational biomechanical models are widely used in cardiovascular research for better understanding of mechanisms governing disease development, quantitative diagnostic strategies and improved surgical designs with better outcome. Patients with repaired tetralogy of Fallot (TOF) account for the majority of cases with late onset right ventricle (RV) failure. The current surgical approach, which includes pulmonary valve replacement/insertion (PVR), has yielded mixed results. An innovative PVR surgical approach was proposed using active contracting bands to help ventricle to contract and improve RV function measured by ejection fraction [1]. Muscle active contraction caused by sarcomere shortening leads to change of zero-load configurations. In lieu of experimenting using real surgery, computational simulations (called virtual surgery) were performed to test different band combination and insertion options to identify optimal surgery design and band insertion plan.

Cardiac magnetic resonance (CMR) data were obtained from one TOF patient (sex: m, age: 22.5 y) before pulmonary valve replacement surgery. The RV end-systole volume was 254.49 ml, end-diastole volume was 406.91 ml, and ejection fraction was 37.46%. A total of 15 computational RV/LV/Patch/Band combination models based on (CMR) imaging were constructed to investigate the impact of band insertion surgery. These models included 5 different band insertion models: Model 1 with one band at anterior to the middle of papillary muscle; Model 2 with one band at posterior to the middle of papillary muscle; Model 3 with 2 bands which are the ones from Models 1 & 2 combined; Model 4 with a band at the base of the papillary muscle; Model 5 with 3 bands which is a combination of Models 3 & 4. Simulations will be performed using the 5 models with 3 different band contraction ratio (10%, 15% and 20% band zero-stress length reduction). A pre-shrink process was performed on *in-vivo* begin-filling and end-systole MRI data to obtain diastole and systole zero-load ventricle geometries. An extra 5-8% shrinkage was applied to obtain corresponding systole zero-load geometry reflecting myocardium sarcomere shortening. The nonlinear Mooney-Rivlin model was used to describe the ventricle material properties with their material parameter values adjusted to match MRI data. The band material properties were in the same scale with healthy right ventricle. The RV/LV/Band model construction and solution procedures were the same as described in [1].

Model 5 with band contraction ratio of 20% has the ability to improve RV ejection fraction to 41.07%, which represented a 3.61% absolute improvement, or 9.6% relative improvement using pre-PVR ejection fraction as the baseline number. The ejection fractions for Models 1-4 were 39.28%, 38.87%, 40.34, and 39.47, respectively.

This pilot work demonstrated that the band insertion surgery may have great potential to improve post-PVR RV cardiac function for patients with repaired TOF. Further investigations using *in-vitro* animal experiments and final patient studies are warranted.

Keywords: Heart model; heart failure; tetralogy of fallot; contraction band

Acknowledgement: The research was supported in part by National Sciences Foundation of China grants 11672001, 81571691 and 81771844. The authors happily acknowledge that the valve biaxial testing data was provided by Professor Wei Sun at Georgia Institute of Technology.

Reference

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