

Ventricle Stress/Strain Comparison Between Models Using Different Zero-Load Diastole and Systole Morphologies and Models Using Only One Zero-Load Morphologies

Han Yu¹, Pedro J. del Nido², Tal Geva³, Chun Yang⁴, Zheyang Wu⁴, Rahul H. Rathod³, Xueying Huang⁵, Kristen L. Billiar⁶ and Dalin Tang^{1,4,*}

Abstract: Ventricle mechanical stress and strain calculations play an important role in cardiovascular investigations. Patients with repaired tetralogy of Fallot (TOF) account for the majority of cases with late onset right ventricular (RV) failure. The current surgical approach, including pulmonary valve replacement (PVR), has yielded mixed results with some patients recover RV function after pulmonary valve insertion with or without concomitant RV remodeling surgery but some do not [Therrien, Siu and McLaughlin (2000);]. Cardiac magnetic resonance (CMR) data were collected from 6 healthy volunteers and 12 Tetralogy of Fallot (TOF) patients before PVR with consent obtained. 12 patients were divided into two groups depending on right ventricle post-surgery recover (6 for each group). 3D patient-specific CMR-based ventricle models with different zero-load diastole and systole geometries were constructed to qualify right ventricle (RV) stress and strain values at begin-filling, end-filling, begin-ejection, and end-ejection, respectively. The models are solved with ADINA. Our new models (called 2G models) could provide end-diastole and end-systole stress/strain values which the old models with only one zero-load geometries (called 1G models) could not provide [Tang, Del Nido, Yang et al. (2016)]. Logistic regression with 5-fold cross validation was adopted to predict pulmonary valve replacement outcome. The results showed 2G mean end-ejection stress value from the 18 participants was 321.4% higher than that from 1G models ($p=0.0002$). 2G mean strain values was 230% higher than that of 1G models ($p=0.0002$). TOF group (TG) end-ejection mean stress value was 105.4% higher than that of healthy group (HG) (17.54 ± 7.42 kPa vs. 8.54 ± 0.92 kPa, $p=0.0245$). Worse outcome group (WG) begin-ejection mean stress was 57.4% higher than that of better outcome group (BG, 86.94 ± 26.29 vs. 52.93 ± 22.86 kPa; $p=0.041$). Among 7 chosen parameters (stress, strain, age, gender, right volume end-diastole volume index, right volume end-

¹ School of Biological Science & Medical Engineering, Southeast University, Nanjing, China.

² Department of Cardiac Surgery, Boston Children's Hospital, Dept of Surgery, Harvard Medical School, Boston, MA USA.

³ Department of Cardiology, Boston Children's Hospital, Department of Pediatrics, Harvard Medical School, Boston, MA USA.

⁴ Mathematical Sciences Department, Worcester Polytechnic Institute, Worcester, MA USA.

⁵ School of Mathematical Sciences, Xiamen University, Xiamen, Fujian, China.

⁶ Department of Biomedical Engineering, Worcester Polytechnic Institute, MA, USA.

* Corresponding Author: Dalin Tang. Email: dtang@wpi.edu.

systole volume index and ejection fraction), end-filling stress was the best predictor to differentiate BG patients from WG patients with prediction accuracy=0.8208. 2G models may provide more accurate stress/strain results than 1G models and be applied in clinical situation, potentially. Large scale studies are still needed for validation.

Keywords: Tetralogy of Fallot, pulmonary valve replacement, active contraction, right ventricle model, risk factor.

Acknowledgement: This research was supported in part by NIH-1R01-HL 089269 (del Nido, Tang, Geva) and NIH-NHLBI 5P50HL074734 (Geva). Tang's research was also supported in part by National Sciences Foundation of China grants 11672001, 81571691.

References

Tang, D.; Del Nido, P. J.; Yang, C.; Zuo, H.; Huang, X. Y. et al. (2016): Patient-specific mri-based right ventricle models using different zero-load diastole and systole geometries for better cardiac stress and strain calculations and pulmonary valve replacement surgical outcome predictions. *PLoS One*, e0162986.

Therrien, J.; Siu, S. C.; McLaughlin, P. R. (2000): Pulmonary valve replacement in adults late after repair of tetralogy of Fallot: are we operating too late? *Journal of the American College of Cardiology*, vol. 36, pp.1670-1675.