In vitro assessment of bioprosthetic valves in clinical models of right ventricular outflow tracts

Nicole Schiavone, Christopher Elkins, Doff McElhinney, John K. Eaton, Alison Marsden
Stanford University

Introduction: Tetralogy of Fallot (ToF), the most common type of cyanotic congenital heart defect, affects 1 in every 2500 newborns annually. A typical surgical procedure for ToF repairs the right ventricular outflow tract (RVOT) and often necessitates a pulmonary valve replacement. Prosthetic replacement valves are subject to dysfunction, but valve longevity is highly variable [1]. There is little understanding of blood flow patterns local to the valve and which factors of the anatomy and hemodynamic environment may lead to valve dysfunction. This study’s objective is to experimentally assess the performance of bioprosthetic pulmonary valves in healthy and diseased RVOT geometries to determine optimal valve placements for long-term function.

Materials and Methods: The experimental method consists of two main steps: 1) using patient data to construct physical models of the RVOT using 3D printing, and 2) using Magnetic Resonance Velocity (MRV) to measure the velocity fields in the models using a blood-analog fluid [2]. Two models are presented in the current work: an idealized RVOT based on magnetic resonance imaging (MRI) measurements of pulmonary anatomies from six healthy subjects and a generalized diseased ToF anatomy with a 150% dilation in vessel diameter immediately downstream of the pulmonary valve. We use a St. Jude Medical Epic valve (a porcine bioprosthetic) with a 25mm diameter and scale our models to match. The model designs allow for rotation of the valve, to examine the effect of its orientation on hemodynamics. A custom experimental flow loop was designed to capture the key features in physiological flow and pressure waveforms. 3D, three-component, phase-averaged velocity fields in the models are measured over the cardiac cycle using MRV. The current work examines the flow fields in both models, each with a native and a rotated valve orientation.

Results and Discussion: Flow features are shown to be strongly affected by RVOT geometries and valve orientations. These features, such as vortex formation and stagnation regions, may impact valve performance by affecting how the leaflets open and close or providing an environment more prone to valve calcification. Figure 1 shows the streamwise velocity downstream of the valve for the healthy and the diseased RVOT geometries, both with the valve in native orientation. There are distinct differences in the size and location of the reverse flow regions, most notably below the high speed region in the diseased case, where the flow stagnates instead of moving back towards the valve. Additionally, the in-plane vectors show similar secondary flow structures, but the vortices are more coherent in the diseased case, where fluid can flow around the valve structure. The full 3D flow fields for both geometries and valve orientations reveal additional differences in flow patterns.

Translational Impact: Significant differences in hemodynamics caused by RVOT geometry and bioprosthetic valve position can impact valve leaflet motion and overall performance. More comprehensive knowledge of bioprosthetic valve performance and leaflet dynamics may aid clinicians in selecting the best location and orientation for the valve to prevent dysfunction and eventual failure. This experimental setup can be expanded to patient-specific models, whose selection will be based on a retrospective clinical study associating RVOT geometry with eventual valve dysfunction. In addition, the experimental data will provide a gold standard validation data set for simulations of valve motion and the resulting blood flow fields.

Disclosure Statement: The authors have no conflicts of interest to disclose.

Acknowledgements: This research is made possible by funding from the Children’s Health Research Institute.