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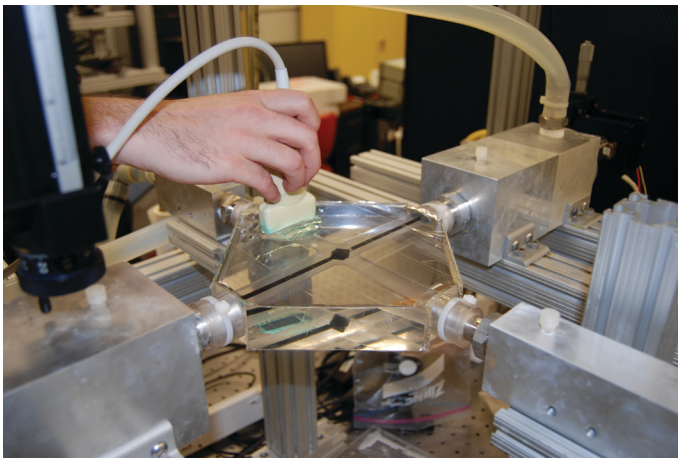
Treating Congenital Heart Disease: In Vitro Ultrasound Imaging of a Powered Total Cavopulmonary Connection

Student researcher: Benjamin P. Iliff, Senior

Three-staged Fontan surgery is often performed on children suffering from congenital heart disease where only one ventricle is working correctly. The Fontan procedure reroutes blood from the vena cava directly to the pulmonary arteries, creating a circulation known as total cavopulmonary connection (TCPC). A novel cavopulmonary assist device, the viscous impeller pump (VIP), is currently being developed to reduce the workload on the single ventricle. Hemodynamic, or blood flow, efficacy of the VIP previously has been studied using computational fluid dynamics (CFD) and stereoscopic particle imaging velocimetry (SPIV). This study is the first to use ultrasound imaging to visualize complex flow patterns in powered and unpowered in vitro Fontan circulation. The idealized TCPC was modeled with a silicone mold and flowing glycerol seeded with 10-µm glass beads to mimic blood. B-mode, color Doppler (CD), and pulsed-wave Doppler (PW Doppler) images were used to quantify complex flow patterns in the idealized TCPC with (1) no VIP, (2) stationary VIP, and powered VIP at (3) 500 and (4) 2,000 RPM. PW Doppler data showed higher mean velocities and greater variance in the outlets relative to the larger inlets. The ratio of the means of maximum outlet velocity to maximum inlet velocity for no VIP, 0 RPM, 500 RPM, and 2,000 RPM decreased from 1.96 to 1.48, 1.29, and 1.15, respectively. These data indicate that both the placement and rotation of the VIP help improve hemodynamics. Oscillating vortices were observed in the outlets of the powered and unpowered idealized TCPC, agreeing with previous CFD and SPIV studies. The results of this study suggest that measuring complex flow patterns with ultrasound in vivo could be used clinically to optimize positioning and VIP rotation rate during and after implantation.

Research advisor Craig Goergen writes, "Ben's project using ultrasound to study a novel blood pump is important as it may one day lead to improved care for children with severe forms of congenital heart disease. The current surgical treatments often lead to circulatory systems that create a tremendous amount of work for the heart. A viscous impeller pump could be a breakthrough for these children and lead to substantial improvements in their quality of life. His findings lay the groundwork for the use of noninvasive imaging as a tool to help optimize pump speed and placement in these kids."



In vitro ultrasound imaging experimental setup.

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