VCU School of Engineering

Biodevices for Circulatory Flow Augmentation Research Lab

MECHANICAL ENGINEERING

3-D Reconstructed Patient-Specific Cavopulmonary Connection with Mechanical Assistance in the Inferior Vena Cava

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Motivation

- The incidence of patients born with functional univentricular physiology is approximately 2 per every 1000 births.
- The Fontan procedure has remained the prominent means of surgical palliation.
- The total cavopulmonary connection (TCPC) is an example of the extracardiac Fontan .This procedure connects the inferior vena cava (IVC) and superior vena cava (SVC) directly to the pulmonary arteries.
- The resulting Fontan configuration of the univentricular anatomy leads to an increased workload on the systemic ventricle due to a loss of kinetic energy from the lack of a subpulmonary ventricle (Figure 1).
- Few therapeutic alternatives exist for the failing Fontan patient beyond medical therapy and ultimately heart transplantation.
- To address this need for novel therapeutic options, we are developing a collapsible, percutaneously inserted, axial flow blood pump to support the TCPC.
- Axial flow blood pump would serve as a bridge-to-transplant, bridge-to-surgical reconstruction, or bridge-to-recover for patients suffering with a Failing Fontan.
- This study evaluated the performance of an intravascular axial flow blood pump for mechanical circulatory support of Fontan circulation (Figure 2).
- Two models of the extra-cardiac, total cavopulmonary connection (TCPC) Fontan anatomy were investigated to formulate numerical predictions.

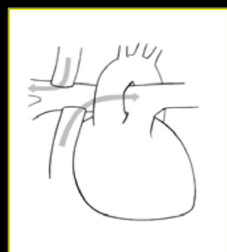
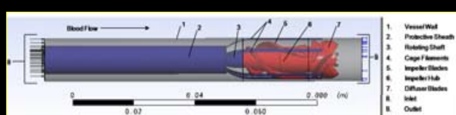


Figure 1: Fontan Total Cavopulmonary Connection. Direct connection from the great veins (IVC and SVC) to the pulmonary arteries.

Figure 2: Intravascular Axial Flow Blood Pump for Cavopulmonary Assist. This assist device consists of a protective sheath, cage filaments, a rotating shaft and catheter, impeller region and diffuser region.



Numerical Methods

TCPC Models

- Two computational models were generated: Idealized TCPC (Figure 3A) and Patient Specific TCPC (Figure 3B)

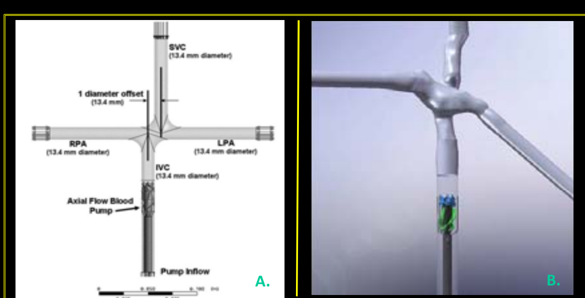


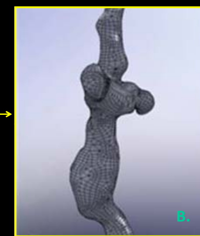
Figure 3: Computational TCPC Models with Blood Pump Placement in IVC. A) Idealized TCPC with a 1-diameter offset between SVC and IVC. B) Patient-specific anatomical model with vascular extensions.

Numerical Methods *(continued)*

Figure 4: Generation of a patient specific computational model.

2D patient MRI transformed into 3D point cloud mesh using *MIMICS* software

3D point cloud imported into *SolidWorks*



Surface Knit and smoothing of counters

Generate solid body model and extend all vasculature

Insert axial flow blood pump into IVC

Computational Fluid Dynamics

- Blood Properties: Newtonian assumption: fluid viscosity of 3.5cP (hematrocrit of 33%) and fluid density of 1050 kg/m^3
- K-ε turbulence model coupled with the scalable wall function to characterize near-wall flow conditions
- Steady flow with constant boundary conditions at the pulmonary arterial outlets and constant velocities. No slip boundary conditions applied to pump housing regions
- Rotating reference frame for impeller and diffuser regions in the counterclockwise direction according to the impeller blade orientation
- Frozen rotor interface linked regions of differing reference frames
- Uniform inflow mass flow rates applied with outflow pressure set a constant and equal pressures of 14 – 22 mmHg and pump operating rotational speeds of 2000 – 5000 RPM

Numerical Results

- Idealized TCPC: For flow rates of 1 to 7.5 LPM and pump rotational speeds of 3000 to 8000 RPM, the pump delivered a range of pressure rises from 2 to 26 mmHg (Figure 5).
- Patient-specific Anatomical TCPC: For flow rates of 1 to 5 LPM and pump rotational speeds of 2000 to 5000 RPM the pump delivered a range of pressure rises from 1 to 7 mmHg (Figure 6).
- The pump in the patient-specific TCPC was found to generate a lower pressure rise across the pump as compared to the idealized TCPC model.
- Pressure rise across the pump increased with an increase in rotational speed and decreased with an increase in flow rate, as to be expected.
- Maximum energy gain: Idealized = 45 mW, Patient-specific Anatomical TCPC = 27 mW

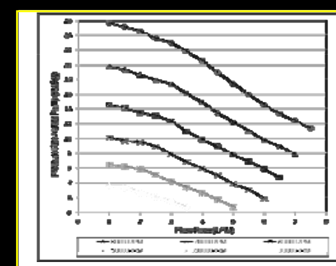


Figure 5: CFD predictions of the hydraulic performance of the blood pump in the Idealized TCPC model. Pressure generation across the axial flow blood pump. Simulations were completed with flow rates of 1 to 7.5 *LPM*, rotational speeds of 3000 to 8000 *RPM*, and pulmonary arterial pressure set at 14 mmHg.

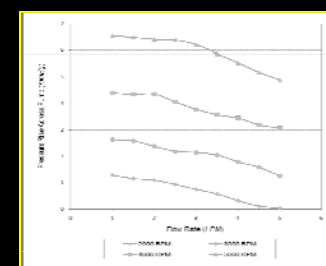
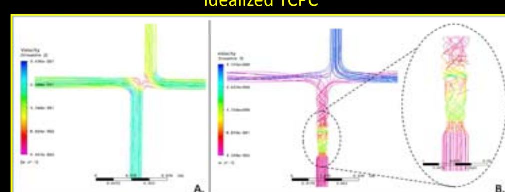
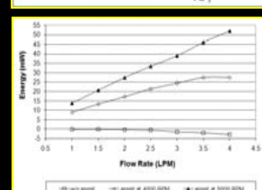


Figure 6: CFD predictions of the hydraulic performance of the blood pump in the Patient Specific TCPC model. Pressure generation across the axial flow blood pump. Data represents simulations conducted at LPA=RPA=14 *mmHg* for flow rates of 1 to 5 *LPM* and pump rotational speeds of 2000 to 5000 *RPM*.

Idealized TCPC

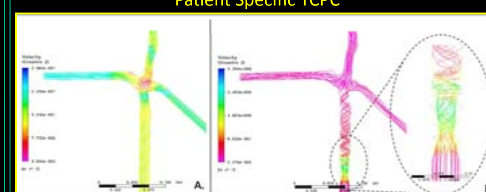


(above) **Figure 8: Fluid streamlines.** (A) Model without pump displays high velocity turns at the outer boundaries TCPC connection points. (B) Velocity increases at IVC outlet due to axial flow pump.

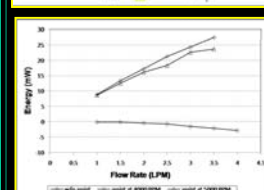


(left) **Figure 9: Energy Gain due to mechanical assistance of a blood pump in the IVC.**

Patient Specific TCPC



(above) **Figure 10: (A) Fluid streamlines.** Lowest fluid velocities are observed at the inner boundaries of the TCPC. (B) Increased fluid particle velocities observed due to axial flow blood pump.



(left) **Figure 11. Energy Gain due to mechanical assistance of a blood pump in the IVC.**

Acknowledgments

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