

AN OVERVIEW OF THE SECOND HEART ASSIST DEVICE

OVERVIEW

In the U.S. over 6 million people suffer from heart failure with up to 20% suffering from an advanced form of the disease (Class 3 and 4). This results in over 1 million hospitalizations each year that cost the healthcare system over \$30 billion. According to the American Heart Association, the prevalence of heart failure is expected to increase by 46% through 2030, resulting in over 8 million patients.

Currently available circulatory assist devices face a number of significant limitations and drawbacks, including: Low flow rates that do not provide the full assistance patients need. Device-associated thrombosis that can block blood flow to vital organs, potentially resulting in a stroke, myocardial infarction, etc. High impeller speeds that can cause hemolysis and pump migration. Risks and complications associated with invasive implantation procedures that are required to deploy many circulatory assist devices. External equipment can decrease patient comfort and quality of life while limiting the range of activities a patient can participate in (swimming, etc.).

Second Heart is developing a minimally invasive circulatory support platform based on proprietary aortic stent pump technology. The platform will be deployed using low profile catheter-based techniques and will provide either temporary or chronic circulatory support, depending on the specific needs of the patient. Second Heart's initial product will be a catheter-based temporary assist pump to treat patients with acute decompensated heart failure and to provide circulatory support to those undergoing high-risk percutaneous coronary intervention (PCI). The second application will be a wirelessly powered circulatory assist pump that will provide chronic circulatory support for heart failure patients.

THE SECOND HEART ASSIST DEVICE

The device consists of two models: 1) a temporary circulatory assist support pump(s) on the tip of an endovascular aortic catheter and 2) a removable chronic wireless powered implant circulatory assist pump within an aortic stent.

Key features include:

- Pump placement just above the renal arteries will provide additional benefit for heart failure patients with kidney dysfunction.
- A choice of pulsatile or continuous flow to optimize hemodynamics and lessen the risk of thrombosis.
- The only system to use the full inner diameter of the aorta to increase pump stability and reduce pump migration.
- Lower risk of mechanical failure due to simple impeller deployment mechanism, improved bearings, and liquid cooled drive shaft.
- Competing products are more difficult to place, have lower flow rates, and do not provide the improvements in renal function that are anticipated with Second Heart's platform.
- A higher flow (with lower RPMs) rate than other systems at over 7 liters per minute.

PRE-CLINICAL TRIAL DATA

Pre-clinical trial data currently consists of a study from Tufts University featuring swine, Q testing in Ohio featuring a large sheep, enMode Computational Fluid Dynamic testing, and Mock Loop testing from the University of Louisville.

TUFTS

SecondHeart Preclinical Prototype Testing (n=1)

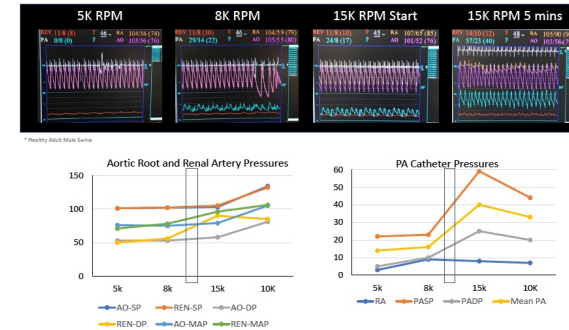


Figure 2



Figure 1: SecondHeartAssist apparatus

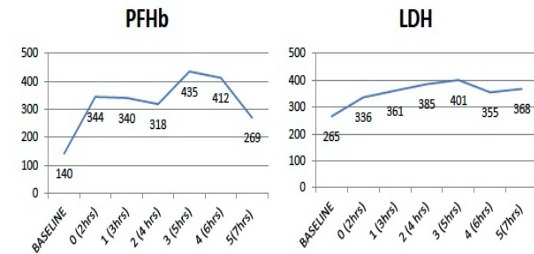


Figure 3: Hemolysis Pig Model n=1 Post Balloon Aortoplasty For Stent Deployment

DISCLOSURE

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Q TESTING

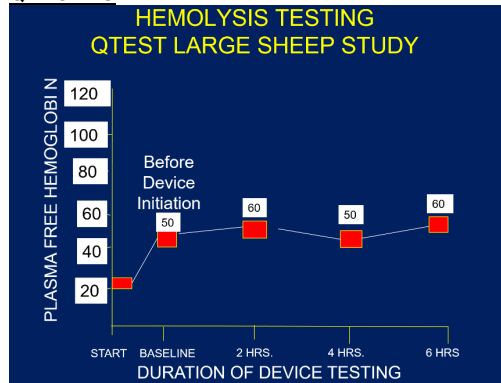


Figure 4

enMODE COMPUTATIONAL FLUID DYNAMIC TESTING

Two impellers, one with blade diameter of 13.5mm and the other 14.5mm, was tested in this study. The impeller was in a tube with the same outer diameter as that of the open stent, i.e. 22.86 mm. Simulations were carried out for constant flow conditions. When the impellers were compared in the study, the 14.5mm impeller presented with a better pressure head compared to the 13.5mm impeller. In regards to the local hydraulic behaviors of each impeller, it was similar. Further analysis & design optimization is needed to improve the device performance of SecondHeartAssist and its blood compatibility.

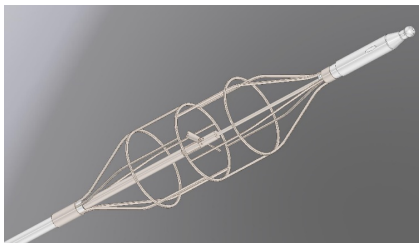


Figure 5: Impeller apparatus

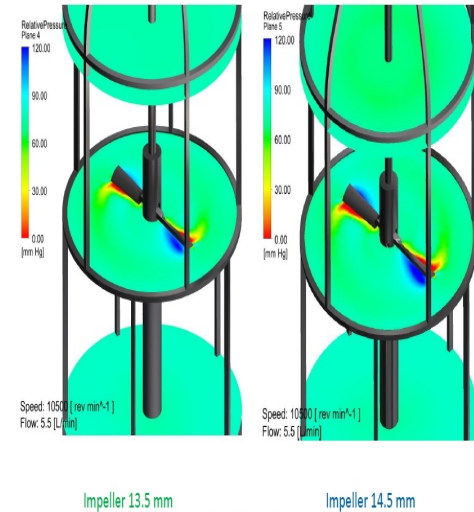


Figure 6

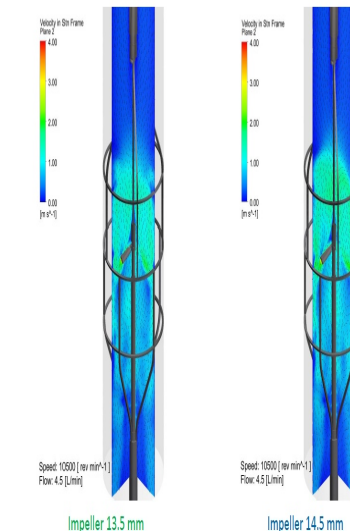


Figure 7

UNIVERSITY OF LOUISVILLE MOCK LOOP TESTING

The University of Louisville conducted a mock circulatory loop (MCL) study to assess the hemodynamic performance of SecondHeartAssist's stent-based percutaneous thoracic assist device. SecondHeartAssist was evaluated in a left heart mock loop that replicated cardiovascular function levels NYHA Class I, II, III, IV. Physiologic test conditions such as normal function, heart failure, hypertension, hypotension, hypervolemia, hypovolemia was tested. The mock loop apparatus is pictured in Figure 3 and included a volume reservoir, venous and arterial compliance chambers, a pneumatically-actuated left ventricle (LV), aorta, and silicone tubing (1/8" to 3/4" inner diameter) to simulate the coronary, carotid, spinal, and renal arteries.

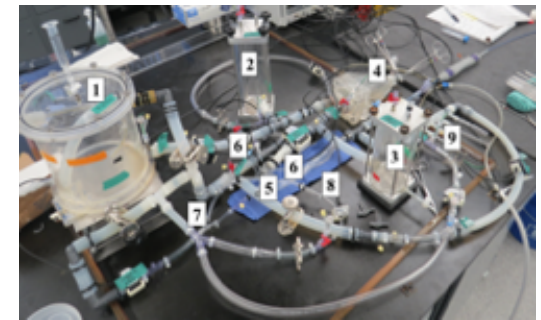


Figure 8: Mock Loop apparatus

Eight pressure catheters (Millar, Houston, TX), one pressure-volume (PV) catheter and nine flow probes (Transonic, Ithaca, NY) were used to instrument the mock loop. A blood analog solution (saline and glycerol) with a viscosity of 3cP (35% hematocrit) was used to prime the loop. Recording ΔP and pump flow over a range of pump speeds (6,000-15,000 RPM) developed static pressure-flow (HQ) curves and hemodynamic data was recorded in 30s epochs (400Hz) for each NYHA Class and physiologic test condition (LabChart, Colorado Springs, CO). Evaluating HQ curves, flow distribution, and volume unloading results determined the pump performance. SecondHeartAssist produced 2.5 L/min flow at 15,000 RPMs against no resistance in the static test condition as shown in the HQ curves (Figure 4). The Second Heart device supplemented renal flow by an average of 0.4 ± 0.02 L/min across all tested conditions with exception of Class I hypervolemic state. There

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was an inverse correlation between renal artery flow and all other arteries simulated. LV volume unloading was not observed as evidenced by minimal changes in the LV PV loops. Increased renal flow at operating pump speeds between 6,000-15,000 RPMs was demonstrated by SecondHeartAssist. A negative correlation between the renal artery versus the spinal arteries, carotid arteries, and coronary arteries was shown through the flow distribution. Hemolysis testing in the MCL model and feasibility testing in acute animals are future tests that will be conducted.

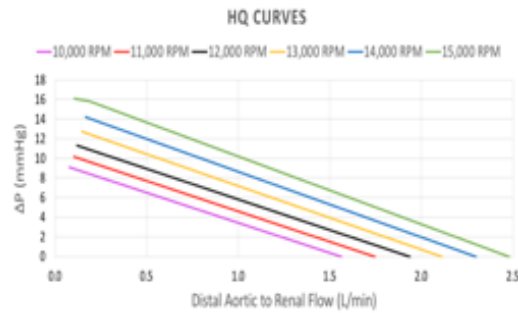


Figure 9: Mock loop data results

COMPETITIVE DEVICES

Cardiobridge's Reitan catheter pump, Procyrion Aortix's pump, Thoratec's HeartMate PHP, and the Parachute device are current competitive devices on the market. We have summarized their capabilities in this white paper.

Parameter	Second Heart	Procyrion	Cardiobridge
FR Size	13.5	18	10
RPM Speed	7,500	18,000	10,000
Hemolysis	0/+	?	0/+
% Aorta filled	110%*	30%	90%
Ease Insert.	++++	++/+++	+++
Reposition	None	??	Rare
Renal Flow	++++	+++	+++
Acute CRS	++++	+++	+++
Chronic HF	Yes	Yes	No

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CARDIOBRIDGE

Cardiobridge assessed the safety of its novel percutaneous circulatory support device, the Reitan catheter pump (RCP), during high-risk percutaneous coronary intervention (PCI). The RCP has a catheter-mounted pump-head with a foldable propeller and surrounding cage. By reducing afterload and enhancing organ perfusion, the pump creates a pressure gradient positioned in the descending aorta. In this study, ten patients in need of circulatory support endured percutaneous coronary intervention. The mean age was 71 ± 9 , LVEF $34\% \pm 11\%$, with a jeopardy score of 8 ± 2.3 . In each patient, the Reitan catheter pump was inserted via the femoral artery. Perclose™ sutures were used to achieve hemostasis, and PCI was performed via the radial artery. In-hospital death, myocardial infarction, stroke, and vascular injury were the reported outcomes. Hemoglobin (Hb), free plasma Hb (fHb), platelets, and creatinine (cre) were measured pre PCI and post RCP removal.

With a median of 79 minutes, nine out of ten cases were successful when the pump was inserted and operated. Propeller rotation at $10,444 \pm 1,424$ rpm maintained an aortic gradient of 9.8 ± 2 mm Hg. Although fHb increased, there was no significant hemolysis (4.7 ± 2.4 mg/dl pre vs. 11.9 ± 10.5 post, $P = 0.04$, reference 20 mg/dl). Platelets were unchanged (pre $257 \pm 74 \times 10^9$ vs. 245 ± 63 , $P = NS$). Renal function improved (cre pre 110 ± 27 μ mol/l vs. 99 ± 28 , $P = 0.004$). No deaths or strokes, one MI, and no vascular complications following pump removal was reported, with all PCI procedures being successful. In conclusion, the RCP can be used safely in high risk PCI patients and may be an alternative to other percutaneous systems when extensive cardiac support is needed.

THORATEC HEARTMATE PHP

Thoratec's HeartMate PHP (Percutaneous Heart Pump) is a 13F catheter-based trans-aortic heart pump with a collapsible distal portion that expands to 24F to provide minimally invasive acute hemodynamic stabilization and left ventricular unloading in both prophylactic and emergent clinical settings. It was created to sustain major organ perfusion, boost coronary perfusion, reduce ventricular loading and myocardial oxygen consumption for High Risk Percutaneous Coronary Intervention (HR-PCI) and Cardiogenic Shock (CS) patients. Thoratec conducted a study in Sunnyvale, CA, to determine how the HeartMate PHP interrelates with the native cardiovascular system via in vitro pulsatile mock loop testing. Obtained from Vivitro Pulse Duplicator of Vivitro Labs Inc., Canada, a custom-

built pulsatile heart simulator was programmed to produce physiological flow pressure waveforms while replicating the preload sensitivity of the native heart.

The HeartMate PHP expanded and mounted across the aortic valve. The systemic vascular impedance of the PLVS was adjusted to simulate typical pre-op hemodynamics HR-PCI and CS patients. Ultrasonic flow sensors and pressure transducers were used to measure total cardiac output and pressures. From there, ventricular unloading is characterized by analyzing pressure-volume (PV) loops, and derived cardiac indices at 16k, 18k and 20.5k RPM pump speeds.

Total CO increased by 0.8 ± 0.3 LPM and MP by 29 ± 4 mm Hg from baseline HR-PCI hemodynamics at the maximum speed setting, and the ventricle was unloaded by substantially reducing all cardiac indices (EDV: 9%, SV: 21%, SW: 22% and PVA: 17%, $p < 0.05$) from baseline HR-PCI state. Furthermore, the ventricle workload was reduced drastically (lowering SV: 53%, SW: 54%, PVA: 33%, $p < 0.05$). The ventricle workload was lowered significantly when the HeartMate PHP was under CS settings, which allowed for the hypotensive state to resolve by increasing MAP 66 ± 2 to 95 ± 4 mm Hg and increased the total CO by 0.7 LPM from the baseline.

This study was able to prove that the Heartmate PHP improves systemic hemodynamics and ventricular unloading ability of the device under clinically relevant pulsatile loading conditions of HR-PCI and CS. The study indicates that the device replenishes the total CO (+1 LPM) and increases the aortic pressure (+30 mm Hg) to enhance the end organ perfusion and coronary perfusion. The total mechanical energy consumption via the native heart (SW, PVA) was significantly reduced by the HeartMate PHP. HeartMate PHP decreased the contribution of the native heart's forward flow (up to 90%) while sustaining the elevated total CO mainly through the pump flow.

PROCYRION AORTIX

Procyrion's catheter-deployed, partial circulatory support device Aortix was assessed in a porcine acute heart failure (HF) model in this study. Long-term circulatory support (LTCS) is only allowed for use in NYHA Class IV HF patients and is limited to large devices with invasive and risky surgical implantations. Procyrion's Aortix is an intra-aortic micro-axial entrainment pump that is implanted with cath-lab techniques and is intended for LTCS in earlier stage HF patients. The study initiated with the pump being positioned into the thoracic aorta and secured with self-expanding struts. Via a continuous esmolol infusion, acute cardiac

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dysfunction was induced until cardiac contractility was 50% of the pre-esmolol baseline. A pressure-volume catheter (left ventricle), a flow probe (renal artery) and pressure catheters (aorta and renal artery) were utilized to record hemodynamic effects. Cardiac output, stroke volume, ejection fraction, and renal flow and pressure all experienced an increase, while cardiac stroke work, afterload and end-diastolic pressure all experienced a decrease as a result from the intra-aortic pump. Procyrion's study was able to reflect that acute HF hemodynamics were improved through this catheter based intra-aortic fluid entrainment pump. HF treatment may improve with improved renal perfusion, while disrupting cardiorenal syndrome. HF outcomes and quality-of-life by heart rest, reverse remodeling and augmentation of end-organ perfusion are all potential benefits of the pump.

- Reduce risks associated with percutaneous catheterization interventions (High Risk PCI).
- Help patients on amputation list to recover their limbs when used in combination with limb regeneration technologies such as bioelectric protein release and stem cell/growth factor composition injections (Limb Salvage).

SUMMARY

In summary, the SecondHeartAssist aortic stent pump is superior to its competition on the market and can potentially provide these benefits:

- Super Easy Aorta Position Insertion
- Stable Over Time
- Provides hemodynamic support in minutes.
- Designed to minimize heart valve damage.
- Designed to minimize coronary re-perfusion injury.
- Low shear stress on blood. Minimizes hemolysis.
- Only circulatory assist pump with VibroCell vibrational energy designed to reduce thrombosis risk reduction.
- Wireless power option designed to reduce infection risk compared to external drive line systems.
- Wireless power designed to improve patient quality of life.
- Designed to reduce end diastolic pressure.
- Designed to reduce end diastolic volume.
- Designed to reduce oxygen demand of myocardium.
- *5 to 6 liters of flow per minute depending on aorta diameter and impeller speed.
- Reduce heart work load and improve perfusion.
- Improve renal function.
- Get acute decompensating heart failure patients back to normal hemodynamics.
- Support heart regeneration procedures.
- Help patients recover from cardiogenic shock.

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