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**INITIAL IN VITRO AND IN VIVO CHARACTERIZATION OF A
PEDIATRIC CARDIOPULMONARY ASSIST SYSTEM**

By

**Jeffrey Michael Colyer
B.S., University of Louisville, 2004**

**A Thesis
Submitted to the Faculty of the
University of Louisville
Speed Scientific School
As Partial Fulfillment of the Requirements
For the Professional Degree**

MASTER OF ENGINEERING

Department of Electrical Engineering

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INITIAL IN VITRO AND IN VIVO CHARACTERIZATION OF A PEDIATRIC CARDIOPULMONARY ASSIST SYSTEM

Submitted By: _____

Jeffrey Michael Colyer

A Thesis Approved on

_____ April 21, 2006 _____

By the Following Reading and Examination Committee:

Aly Farag, Thesis Director

George Pantalos

Bruce Alphenaar

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ABSTRACT

Historically in the area of pediatric heart failure, few options have been available that are specifically designed to provide pediatric circulatory support. Extracorporeal Membrane Oxygenation (ECMO) was the traditional method of choice, providing cardiopulmonary support (CPS) for a relatively short time of 3-7 days. The pediatric cardiopulmonary assist system (pCAS) examined in this paper is designed to be able to provide left ventricular assist (LVA), right ventricular assist (RVA), or cardiopulmonary assist to a pediatric patient for a period of 30 days, with the option of device replacement if needed. A specially designed controller allows for both continuous and pulsatile flow assist. This study focuses on an early developmental version of the device which has a 3 inch diameter pump. The system pumping performance is characterized by using various techniques and examining a range of information. Mock circulation loop experiments are evaluated for the pCAS providing LVA, CPS during normal heart conditions, CPS during right ventricular failure, and veno-venous ECMO. Three acute animal studies are evaluated for the pCAS providing LVA. The pCAS ability to provide adequate flow of 100 ml/min/kg and restore acceptable hemodynamics is discussed for each condition. Recommendations for the optimization of pumping performance are given and will be used to guide the next steps in the development of the pCAS.

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NOMENCLATURE

A/D = analog to digital
AoP = aortic pressure
AoPr = aortic root pressure
AoF = aortic flow
AoFr = aortic root flow
bpm = beats per minute
CAF = coronary artery flow
CdAF = carotid artery flow
CDAS = Cardiovascular Data Acquisition Software
CO = cardiac output
cP = centipoise
CPS = cardiopulmonary support
cVAD = continuous ventricular assist device
D = diameter
DAQ = data acquisition
ECG = electrocardiogram
ECMO = extracorporeal membrane oxygenation
Fr = French (size of cannula)
HEART = Hemodynamic Estimation and Analysis Research Tool
IABP = intraaortic balloon pump
kg = kilograms
L = length (only in Poiseuille's equation)
L = liters
Len = length
LAP = left atrial pressure
LPM = liters per minute
LVA = left ventricular assist
LVF = left ventricular failure
LVP = left ventricular pressure
LVPed = end diastolic left ventricular pressure
IN = pCAS inlet pressure
MCS = mock circulation system
mmHg = millimeters of mercury
NHLBI = National Heart, Lung, and Blood Institute
OUT = pCAS outlet pressure
 ρ = density
PAF = pulmonary artery flow
PAP = pulmonary artery pressure
PC = personal computer
pCAS = pediatric cardiopulmonary assist system
pVAD = pulsatile ventricular assist device
Q = flow

R = radius
RAP = right atrial pressure
Re = Reynolds number
RPM = rotations per minute
RVF = right ventricular failure
SV = stroke volume
UofL = University of Louisville
v = velocity
V = volts
Vpk = pCAS peak voltage in pulsatile mode
VAD = ventricular assist device
VADF = ventricular assist device flow
VASF = ventricular assist system flow
VV = veno venous
 ΔP = change in pressure (pressure drop)
 μ = dynamic viscosity

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I. INTRODUCTION

A. Definition of Problem

For infants and small children with heart disease in America today, the options are limited for the kind of treatment available. The need for devices targeted specifically for this age group has become more and more evident. Each year, around 36,000 babies are born in the United States with congenital heart disease. Out of this growing population, 25% of them will need invasive treatment during the first year of their life.¹ The need for pediatric mechanical circulatory support is increasing because of the possibility of corrective operations for heart conditions that previously were inoperable, and due to the success of pediatric heart transplantations which leads to longer waiting times for rare organ donors.⁹ Mechanical circulatory support is frequently needed as treatment to keep these young patients alive while their diseased hearts recover or until the next surgical procedure can be undertaken.

Mechanical circulatory support is performed in a human by a ventricular assist device (VAD). The VAD is attached between the person's heart and the exiting artery with the purpose of helping to circulate blood when the heart is incapable of doing so adequately on its own.⁹ The two most common uses of mechanical circulatory support are left ventricular assist (LVA) and cardiopulmonary support (CPS). LVA is performed by connecting a pump between the left heart and the aorta to bypass the left ventricle. CPS is performed by connecting a pump between the right heart and aorta, bypassing the lungs and providing paracorporeal oxygenation and carbon dioxide removal. Both of these temporary assist techniques are meant to reduce the workload on a failing heart and keep healthy blood moving throughout the body.

Situations requiring pediatric circulatory support include bridge to post-operative recovery, bridge to transplant, support during operation, and certain conditions requiring temporary heart or lung support. Many of these conditions are associated with congenital heart disease, especially hypoplastic left heart syndrome, transposition of the great arteries, tetralogy of Fallot, and anomalous origin of the left coronary artery.^{3,5} Others may be associated with developed ventricular dysfunction, including myocarditis, sepsis, cardiomyopathy, or cardiopulmonary collapse.⁵ Postoperative use of a VAD may be necessary as a bridge to recovery, reducing the work of the heart while allowing it to strengthen until assistance is no longer needed.

In pediatrics, more than 50% of patients needing circulatory support also need pulmonary support.⁸ This percentage is even higher in the smallest infants. This is due to the many congenital ailments in infants which are combined with poorly developed lungs and complex deformities.⁸ The need for both circulatory and pulmonary support is well established.

While there has been some success in the emergency use of adult VADs in children, unique challenges await any designer of a pediatric VAD. First of all, the device may need to support various patient sizes, ranging from neonates and infants to adolescents. Second, in cases of lengthened assistance in infants, the VAD must be able to either adjust for the growth of the child or be replaceable by a larger device. Third, the vasculature of a pediatric patient is much smaller and more friable than adults, requiring unique cannulation strategies. Along with the smaller diameter, the vasculature is also more compliant. Fourth, heart abnormalities are frequently associated with infant heart failure because of the physiological consequences of congenital heart defects. Fifth, high

heart rates make some assist techniques, such as intraaortic balloon pumps, more difficult to use reliably. Finally, the lower circulatory flow causes problems when trying to use adult assist devices by increasing the risk of thromboembolic complications.

In recent years, more effort around the world has been put into developing circulatory assist devices for the pediatric population. In Germany the Berlin Heart VAD (Berlin Heart AG, Berlin, Germany) has been approved and used for pediatric patients. At the Deutsches Herzzentrum Berlin, there have been recorded 45 implantations in patients ranging from 2 days to 16 years old in age. Survival in patients with myocarditis and cardiomyopathy was 66.7% and 71.4%, respectively; overall survival was 48.9%.⁷

The options for pediatric circulatory support in the United States remains more limited, however. The only device approved for clinical use is the intraaortic balloon pump (IABP) from Datascope. This usually either leads to the use of adult sized VADs in patients they were not designed for, emergency or humanitarian approval for the use of officially unapproved VADs, or usually the use of extracorporeal membrane oxygenation (ECMO).

Extracorporeal membrane oxygenation (ECMO) is intended to provide infants and children with circulatory and pulmonary support. An ECMO circuit consists of a centrifugal or roller pump, mechanical ventilator or membrane oxygenator, drainage and return cannulas, and a heat exchanger to warm the blood. This system remains the most commonly used method for mechanical circulatory support.

According to the ECMO registry for Kosair Children's Hospital in Louisville, KY, 333 patients have been treated with ECMO at that facility from January 25, 1995 to February 27, 2006. Of those patients, 298 required veno-arterial ECMO

(cardiopulmonary support) while 40 required veno-venous ECMO (some patient conditions necessitated a change from veno-venous to veno-arterial ECMO during the support duration). Of the 288 patients treated that weighed below 10 kg, 203 patients (70%) survived the ECMO treatment.

While ECMO has proven effective for providing cardiopulmonary support, there are also several very important disadvantages. The complexity of system means more device integration and potential complications, more set up time, and more intensive training for the technicians. The large circuits also require large priming volumes and lead to the blood being out of the body longer, which leads to cooling of the blood and necessitates the blood-warmer. Larger and more complicated circuits require continuous anticoagulation with heparin and also increase the chance of inflammatory response resulting from large biomaterial exposure due to device inefficiencies. Patients have been kept on ECMO systems for up to 30 days, but the probability of complications increases significantly with longer duration of support. The patient is also intubated with very restricted mobility. Especially for infants, this prevents physical rehabilitation and valuable time being cared for by parents.

The intraaortic balloon pump (IABP) consists of a balloon tipped catheter that is inserted into the descending thoracic aorta. The system works by counterpulsation, inflating and deflating the balloon out of phase with the cardiac cycle. The use of an IABP in infants and children has been limited however, due to some complications. It is difficult to insert the balloon and catheter into the small vessels of a child. These vessels, notably the aorta, are also more compliant. This limits the effects of balloon inflation on diastolic pressure. Children also have a much more rapid heart rate than adults, which

makes an IABP difficult to synchronize. As the patient gets smaller with smaller and more compliant vasculature, the less effective is the IABP.

B. History

Recognizing the increase in need and lack of options for mechanical circulatory support in pediatrics, the National Heart, Lung, and Blood Institute (NHLBI) issued a call for the development of circulatory support systems for infants and children from 2 to 25 kg with congenital or acquired cardiovascular disease. Five contracts were awarded, including a five year grant for the pediatric cardiopulmonary assist system (pCAS) discussed in this paper (NHLBI Contract No. HHSN268200449189C). The grant was to Ension Inc. out of Pittsburgh, in collaboration with the University of Louisville, Seare BioMatrix Systems, and Fluent Inc. The University of Louisville is focusing on rheological characterization and functional evaluations of pCAS prototypes.¹ These evaluations include both in vitro and in vivo testing.

The pCAS integrates a centrifugal pump with a membrane oxygenator to provide circulatory support as well as pulmonary support for the patient. This membrane, which acts as a rotor disc, is comprised of microporous hollow fibers similar to the ones used in ECMO circuits.⁸ While spinning, the blood will be forced through these fibers where gas exchange will take place. A unique coating covers the membrane fibers to improve blood-material interaction and reduce the amount of anticoagulation needed. The pCAS has both continuous and pulsatile pumping capabilities.

The advantages to such a system are numerous. The pCAS is a very versatile system, being able to provide either circulatory or cardiopulmonary assist, determined only by whether or not the gas exchange mechanism is hooked up. This makes the

device useful for addressing ailments requiring any form of mechanical circulatory support. The size of the pCAS also is very advantageous, reducing complexity with only one moving part. This leads to smaller priming volumes and less opportunity for thromboemboli to form. The reduction in biomaterial means less stimulus for inflammatory response as is common with ECMO. Increased mobility of the patient is a significant advantage also, as it allows the child to move, cry, nurse, and vocalize. The pCAS makes possible normal development in children with heart disease.⁸

The initial target patients for the pCAS by the end of the contract period are neonates below 10 kg. The focus on these smallest patients is due to the higher need for cardiopulmonary support. After the contract period, the intent is to broaden the system to also cover the needs of children exceeding 10 kg also. The minimum flow requirement of the pump is 100 ml/min/kg. This means that the pump must be capable of flows up to 1 L/min for a 10 kg patient.

The final diameter size of the centrifugal pump is to be 2". A prototype of a 4" pump has been tested in both in vitro and in vivo experiments with successful results. An intermediate prototype 3" pump has been developed and will be evaluated in this paper.

C. Purpose of Research

The primary purpose of the research conducted in this study is to characterize the 3" pCAS pumping ability using in vitro and in vivo experiments. From this characterization, determinations will be made regarding the capability of the pCAS to provide adequate support for the target age and weight group. Next steps will be suggested based on the results.

The in vitro experiments will be conducted using a unique pediatric mock circulation system (MCS). Continuous improvement and development of this system will be a necessary outcome from carrying out this research. The MCS is able to model the hemodynamic waveforms of a 10 kg human patient and can be adjusted to simulate heart failure. Based on the results, the pCAS will be evaluated for its ability to produce adequate flow and restore acceptable hemodynamics.

In vivo experiments will be performed as acute animal studies on piglets. Left ventricular failure (LVF) will be brought about in these animals and the pCAS will assist the animal in this state. These animal experiments give a valuable indicator of how the pCAS will perform in a human patient. Again, the pCAS will be evaluated in its ability to produce adequate flow and restore acceptable hemodynamics.

For the target population mentioned before of patients 10 kg or less, the pCAS must be able to produce a flow rate of 1 L/min (100 ml/min/kg) while restoring acceptable hemodynamics. Because of the flexibility of the pCAS's potential use, it will need to be evaluated during several heart failure modes: left ventricular assist, cardiopulmonary assist during normal heart conditions, cardiopulmonary assist during right ventricular failure, and veno-venous ECMO. Characterization of the pump under both continuous and pulsatile modes will be necessary.

II. INSTRUMENTATION AND EQUIPMENT

A. Data Acquisition Equipment

In order to successfully characterize the pumping ability of the pCAS, certain parameters were necessary to measure and record. As the pCAS purpose is to restore acceptable hemodynamics to a failing circulatory system, particular pressures and flows associated with the circulatory system were measured. Certain measurements, such as an ECG, are necessary for the animal experiments only. Further measurements were taken on the inlet and outlet pressures of the pCAS, as well as the pCAS flow. A complete listing of the measurements used is found in Table I (MCS) and Table II (acute animal studies). All of these measurements were taken and recorded using the data acquisition equipment described in this section.

1. Pressure catheters

Millar pressure catheters acted as the signal transducers for the pressure signals. Specific models and serial numbers are listed in the experimental data sheets for both the MCS and acute animal experiments. These catheters are unique in that the pressure sensor is incorporated into the tip of the catheter resulting in high-fidelity pressure sensing at the location of physiologic event.

2. Pressure amplifiers

There are six pressure amplifiers (Ectron Model 428) which receive and make necessary amplifications to the incoming pressure transducer signals.

3. Flow probes

Transonic flow probes acted as the signal transducers for the flow signals.

Specific models and serial numbers are listed in the experimental data sheets for both the MCS and acute animal experiments. These flow probes operate on the ultrasonic, transit-time principle.

4. Flow meters

Transonic flow meters, model T206, provide the excitation signal to the crystals in the flow probes and receive the incoming signals from the flow probes. There is a digital readout of each measurement on the flow meter. The flow meter also passes an analog signal on to the signal conditioning and distribution unit.

5. ECG channel

During the acute animal experiments, surface electrodes were used to measure the ECG. These signals were sent to the ECG channel (Gould Instruments) on the data acquisition (DAQ) system, which feeds it to the signal conditioning and distribution unit.

6. Signal conditioning and distribution unit.

This is a key component designed specifically for the integrated DAQ system. This 16-channel signal conditioning and distribution unit receives low level analog outputs (μV or mV) from the amplifiers and signal processor. The unit then needs to be able to drive multiple peripheral monitoring and recording devices while maintaining signal strength and integrity. It was designed with finite, fixed gain and offset to maximize A/D input range, and with low-pass filters to minimize electrical noise and prevent aliasing.¹²

7. Analog-to-digital (A/D) conversion

Mounted on the DAQ is an A/D accessory (Bayonet Nut Connector (BNC)-2090, National Instruments), which routes the analog data to an A/D board located inside a computer (AT-MIO-16E-10 or PCI-MIO-16XE-10, National Instruments). Here, the signal is converted into digital format for the computer to read and display in real-time fashion. The A/D sampling rate is set at 400 Hz, which is sufficient for all the sensed physiologic signals.

8. Measurement Instrumentation

There are several options also available on the DAQ for analog measurement analysis. There is a model 45 digital multi-meter (DMM) from Fluke to read incoming analog signals from various transducers. The DAQ is also fitted with a digital storage oscilloscope (Tektronix model 340A) for additional signal analysis.

9. Cardiovascular Data Acquisition Software (CDAS)

The CDAS program was developed in LabVIEW (National Instruments, Austin, TX) and is made for real-time data acquisition. This software is interfaced with the A/D board to read the data coming in on the different channels, and can present the data with a graphical display. It is configured to run in four different modes of operation to best meet the user's needs.¹²

In mode 1, Measurement and Automation (National Instruments, Austin, TX) is used to assign channels, identify signal names, convert physical values to the physiologically equivalent units, and identify the A/D conversion format. These setting can be saved and reloaded for repeated experiments. Mode 2 is an interface that allows the user to set up the CDAS program to record data at their preference. Important information is entered and stored in the header file of the experiment, such as the date,

study title, DAQ operator, subject number, etc. The graphical display setup is also configured here, assigning waveforms to display windows according to their name.

Mode 3 of the CDAS program is the display window, where the various waveforms are displayed. Here you can view the selected signal by the channel name and see the mean value. Options are available to combine different waveforms in the same window (i.e. LVP, AoP) or freeze the graphs. This window is also where you can capture a data set for a specified amount of time. Mode 4 is a data viewer option that allows users to review previously recorded data sets.¹²

B. HEART Data Analysis Software

The Hemodynamic Estimation and Analysis Research Tool (HEART) is used as the analysis software package for the data recorded in these experiments. Developed in Matlab (MathWorks, Natick, MA), it is meant to allow for researchers to document, load, view, calibrate, and analyze experimental data that have been saved digitally in ASCII or binary format.¹³

In order to be able to analyze the recorded data sets, the HEART program provides the user with the ability to first calibrate the data. Calibration factors are calculated based on calibration data sets taken at the beginning and end of the experiment. HEART also allows the user to automatically or manually pick beats on the data set. Several beat picking algorithms are used for the various hemodynamic signals.¹³ Based on user guidance, these algorithms are also able to distinguish between good and bad beats of the heart. The analysis is performed on each good beat selected.

Analyses for both the left and right heart were run on the experimental data taken from the in vitro and in vivo studies covered in this research. Sophisticated analysis

routines are included in the HEART software to take the recorded digital waveforms and calculated various parameters. These parameters are presented and discussed.

C. Pediatric Mock Circulation System

A pediatric mock circulation system (MCS) was used to create instantaneous physiological pressure and flow conditions that mimic those of an infant or small child.²¹ The MCS uses pneumatically driven 10 ml left and right ventricles to pump the test fluid through the circuit. It is designed with components that mimic the resistance and compliance of different segments for both the systemic and pulmonary circulations. A dynamic coronary resistor, which is actuated by the pneumatic right driveline pressure during left heart diastole, is added to accurately represent the hemodynamic function of the coronary artery. Both the coronary and carotid artery flows can be adjusted by closing or opening the respective variable valves more or less. The primary control for the system is provided by the pinch valve downstream of the aorta, which acts as a way to control the systemic resistance. Figure 1 shows a picture of the mock circulation system with certain components identified (cannulated for left ventricular assist). The right heart components are boxed and labeled in blue while the left heart components are boxed and labeled in red. Figure 2 shows a representation layout of the uncannulated MCS.

FIGURE 1. Picture of the pediatric Mock Circulation System with selected components labeled.

Pediatric Mock Circulation

FIGURE 2. Pediatric Mock Circulation System layout without cannulation.

The system was designed with the capability to be cannulated for LVA, CPS, and VV ECMO. Each of these variations requires different cannulation techniques. The following cannulae were used:

- Left atrium: 20 Fr Research Medical Inc pediatric cannula
- Aorta: 16 Fr Research Medical Inc pediatric cannula
- Right atrium: 8 Fr Medtronic Biomedicus ECMO cannula-CPS
- Right atrium: 14 Fr Origen double lumen cannula-VV ECMO

A variety of Millar pressure catheters were used during the experiments. These catheters are identified by type and serial number in the setup sheets for each experiment. Transonic inline flow probes were used for each of the flows except the VAD flow, where a clamp-on flow probe was used. These probes are also identified by type and serial number in the setup sheets for each experiment.

D. Acute Animal Studies

The instrumentation used on the acute animal studies was similar to that used on the MCS experiments, with a few exceptions. The flow probes were all perivascular Transonic flow probes that fit around the vessel, except for the same pCAS outflow clamp-on flow probe that was used for the MCS experiments. Also added were surface electrodes to monitor an ECG signal.

E. Pediatric Cardiopulmonary Assist System (pCAS)

An intermediate prototype 3" pCAS is used for all the experiments conducted in this research. The pCAS pump is accompanied by a controller, which directs the pump in either continuous or pulsatile mode. This controller, which is also in an intermediate stage, was developed by Ension Inc. especially for the pCAS. The pCAS generates pulsatile flow by cyclically increasing and decreasing the RPM during the pump cycle.

The continuous operation mode is controlled by a manually adjusted dial used to change the pump RPM. A digital readout on the controller case shows the current pCAS RPM. The pulsatile operation mode is controlled by an interface with a PC. A program was developed in LabVIEW by Ension Inc. where the user can control the pCAS pulse frequency, peak voltage, and offset voltage.

III. PROCEDURE

To most accurately characterize the pumping performance of the pCAS, it was necessary to perform both in vitro and in vivo studies. The pediatric mock circulation system described above was used for the in vitro studies, while acute animal experiments were performed for the in vivo studies. Both were useful and complimentary of each other in providing valuable feedback on the ability of the pCAS to restore acceptable hemodynamics in a patient.

Mock circulation systems do not have the purpose of replacing clinical trials. However, they can be an essential step in the design and development of cardiac devices. With a controlled and repeatable environment with user defined test conditions, a MCS can provide valuable insight into potential hemodynamic responses.

There are obviously limitations to in vitro MCS studies also. For instance, the mock circulation cannot mimic conditions involving neurohumoral responses, tissue remodeling, or genetic differences.¹⁰ It does not take into account some physiological aspects such as ventricular septal interaction. While pressure and flow waveforms can be mimicked closely and mean values matched, it is difficult to precisely match a typical signal or account for irregularities. For example, the mock coronary vasculature uses a dynamic resistor to create a response similar to actual coronary flows, but it cannot account for autoregulatory responses and myocardial effects that occur in vivo.¹⁰

In vivo studies are more reliable indicators of the overall performance of a ventricular assist device because they are able to take into account more of the experimental variables found in the body. Unlike MCS experiments, in vivo studies also require numerous experiments because of the possible variation between test subjects.

Variations between test subjects (e.g., age, weight, sex) can cause large variation in physiological parameters (e.g., blood pressure, blood volume, heart rate, stroke volume).¹⁰ There are also variables involved in the experimental preparation, such as anesthesia, drugs given, or the need to surgically modify the procedure.

The in vitro studies in this research are first used to evaluate the pumping performance of the pCAS in a controlled, user-defined environment. These studies also are used to guide further development of a useful in vivo test protocol.

A. In Vitro Studies, Pediatric Mock Circulation System

In vitro studies were performed using the pediatric mock circulation system. The purpose, as stated above, is to evaluate the pumping characteristics of the pCAS in a controlled and user-defined environment, as well as direct further in vivo experimentation. A detailed protocol for the experiments performed is included in Appendix I. Four assist conditions were evaluated in the MCS experimentation.

1. Left ventricular assist (LVA), left heart failure.

LVA is accomplished by inserting the inflow cannula into the left atrium and the outflow cannula into the aorta, thus using the pump to partially or fully bypass a failing left ventricle. The goal is to reduce the workload on the weak heart while restoring adequate blood flow. With this manageable amount of cardiac work, the hope is for the heart to either recover from its failing state or maintain its current state until a transplant can be found. The MCS layout cannulated for left ventricular assist is shown in Figure 3. The inflow and return cannulae are shown in the MCS in Figure 4.

FIGURE 3. Pediatric Mock Circulation System layout with cannulation to perform left ventricular assist.

FIGURE 4. Pediatric MCS cannulations for LVA. A) 20 Fr Research Medical Inc pediatric venous (inflow) cannula into the left atrium. B) 16 Fr Research Medical Inc pediatric arterial (return) cannula into the aorta.

2. Cardiopulmonary support (CPS), normal heart conditions.

In order to perform CPS, the inflow cannula is inserted into the right atrium with the outflow cannula in the aorta. This enables the assist system to bypass both the heart and lungs, and necessitates the ability of the system to provide pulmonary support along with cardiac support. CPS during normal heart conditions is most concerned with the oxygenation ability of the pCAS, which is not evaluated in this study. However, it is essential to analyze the pumping ability of the pCAS in this situation even if the main purpose is to provide oxygen to the circulating blood. The MCS layout cannulated for cardiopulmonary assist is shown in Figure 5. The inflow and return cannulae are shown in the MCS during CPS in Figure 6.

FIGURE 5. Pediatric Mock Circulation System layout with cannulation to perform cardiopulmonary assist.

FIGURE 6. Pediatric MCS cannulations for CPS. A) 8 Fr Medtronic Biomedicus ECMO (inflow) cannula into the right atrium. B) 16 Fr Research Medical Inc pediatric arterial (return) cannula into the aorta.

3. Cardiopulmonary support (CPS), right ventricular failure.

This assist condition is performed in the same manner as CPS with a normal heart, but along with pulmonary support it is concerned with providing cardiac support for a failing right heart. By reducing the work done by the heart, the heart is given the opportunity to recover. The MCS layout is the same as the layout for CPS with normal heart conditions as shown in Figure 3.

4. Veno-Venous ECMO (VV ECMO), normal heart.

For Veno-Venous ECMO, both the inflow and outflow cannulae are placed in the right atrium. In the case of these experiments, a double lumen cannula is used. The purpose of VV ECMO is to take deoxygenated blood from the body and perform the oxygenation and carbon dioxide removal externally. This particular ECMO cannulation strategy is most often used due to respiratory failure rather than cardiac failure. It has

nearly no effect on the hemodynamics. The MCS layout cannulated for veno-venous ECMO is shown in Figure 7. The double lumen cannula is shown in the MCS right atrium in Figure 8.

FIGURE 7. Pediatric Mock Circulation System layout with cannulation to perform veno-venous ECMO.

FIGURE 8. Pediatric MCS cannulations for VV ECMO. 14 Fr Origen double lumen cannula into the right atrium.

5. Measurements recorded

The same measurements were recorded for each in vitro experimental condition.

Table I lists these signals.

TABLE I
MCS PRESSURE AND FLOW SIGNALS MEASURED

Pressure Signals			Flow Signals		
Description	Symbol	Units	Description	Symbol	Units
Aortic Pressure	AoP	mmHg	Aortic Flow	AoF	L/min
Left Atrial Pressure	LAP	mmHg	Pulmonary Artery Flow	PAF	L/min
Right Atrial Pressure	RAP	mmHg	Coronary Artery Flow	CAF	ml/min
Pulmonary Artery Pressure	PAP	mmHg	Carotid Artery Flow	CdAF	ml/min
pCAS Inlet Pressure	IN	MmHg	VAD (pCAS) Flow	VADF	L/min
pCAS Outlet Pressure	OUT	MmHg			

To best represent the circulatory system of an infant, the heart rate was set to 120 beats per minute (bpm) and the systolic/diastolic ratio was set to 50%. The hemodynamic ranges for normal and failing heart function are listed in Table II.

For the experiments performed in this research, normal heart conditions were achieved with a left driveline pressure of 130-135 mmHg and a right driveline pressure of 40 mmHg. To achieve failure mode in the left ventricle the left driveline pressure was dropped to 70 mmHg and more test fluid volume was added to the left atrium to mimic the volume retention of heart failure. For failure mode in the right ventricle, a variable hose clamp was used to limit the amount of driveline pressure to the right ventricle (the right driveline pressure could not be reduced because it is also used for the dynamic coronary resistor) and more test fluid volume was added to the right atrium.

TABLE II

HEMODYNAMIC PARAMETERS USED FOR MCS EXPERIMENTS

Parameter	Normal	Left Heart Failure	Right Heart Failure
Mean AoP	70-75 mmHg	50-55 mmHg	60-70 mmHg
Aortic Flow	800-1000 ml/min	600-700 ml/min	600-700 ml/min
Left Atrial Pressure	10-12 mmHg	18-25 mmHg	8-10 mmHg
Right Atrial Pressure	8-10 mmHg	10-12 mmHg	18-20 mmHg
Pulmonary Art. Pres.	18-22 mmHg	22-27 mmHg	15-19 mmHg
Coronary Flow	45-55 ml/min	35-40 ml/min	30-35 ml/min
Carotid Flow	90-110 ml/min	70-80 ml/min	80-90 ml/min
Left Driveline Pres.	130-140 mmHg	70-75 mmHg	130-140 mmHg
Right Driveline Pres.	40-45 mmHg	40-45 mmHg	40-45 mmHg (clamped)

*heart rate = 120 bpm and systolic/diastolic ratio = 50% for all test conditions

A method was developed to most effectively characterize the pumping ability of the pCAS. As a centrifugal pump, reverse flow will occur if the pump is off or at low RPM. So the first step is to find the zero flow point of the pump where it is rotating at such a speed to produce neither positive or negative net flow. From there, the pCAS RPM (or peak voltage in the case of pulsatile mode operation) is incrementally increased until the desired flows and pressures are reached. Data is recorded at each increment. This gives a very useful performance curve for the pCAS that covers potential usage rates.

B. In Vivo Studies, Acute Animal Experiments

To give a better indication of how the pCAS will perform in a human pediatric patient, a series of acute animal studies were conducted. Piglets were chosen to model the human cardiac response for these experiments. The cardiovascular anatomy and responses of swine have made them a frequently used model for human cardiovascular studies.¹⁴ Porcine hearts have a coronary anatomy similar to that of a human heart. They

tend to develop a low amount of collateral circulation after the induction of a coronary occlusion, making them appealing for the reproduction of left ventricular dysfunction.¹⁵ Swine typically also have a higher heart rate (100-150 bpm), similar cardiac output to human infants, and comparable aortic cell and tissue anatomy. However, blood vessels and the atria in swine tend to be more fragile than other species, especially in neonates.¹⁴

Three 10-13 kg piglets completed the in vivo experimental protocol covered in this research. The protocol through continuous flow measurements was completed in a fourth animal (Pig 020). While hemodynamics were restored successfully in this test subject, the pCAS performance was not characteristic of other in vivo and in vitro experiments due to a suspected off-center pump shaft. For this reason, the Pig 020 test subject data will not be discussed in this paper to characterize the pCAS.

Although the sizes of these piglets represent a population slightly larger than the proposed 10 kg child, the friable swine vasculature and atria advocate the use of an older and more robust animal. The neonatal sized catheters used will help to mimic the desired human neonatal support. This model has been used extensively by UofL in their evaluations of pediatric VADs.⁸

The purpose of these in vivo experiments is to evaluate the pumping characteristics of the pCAS in a living animal model with left ventricular dysfunction. The results will give a valuable indication of how the pump will perform in a human patient. A detailed protocol for the in vivo studies performed is included in Appendix II. The condition evaluated in the acute animal experimentation is left ventricular assist in the presence of left heart failure.

After instrumenting and cannulating the piglet, left ventricular failure was induced in the subject via pharmacologic stabilization of myocardial function and sequential coronary ligation. When hemodynamics achieve a steady state, the pump is evaluated by stepping the speed up incrementally as with the MCS experiments. Unlike the MCS experiments, it is important to the survival of the animal not to let any reverse flow through the centrifugal pCAS. For this reason, instead of slowly adjusting the pump up to a zero flow value, the speed was initially set to a value above the zero flow value as the cannulae are unclamped. Once forward flow is established, the pCAS can then be backed down to a speed that produces zero flow through the pump. From here, the pCAS is incrementally increased until the desired flows and pressures are reached. Data is recorded at each increment. This method gives a very useful performance curve for the pCAS that covers potential usage rates.

Table III lists the signals that were recorded during the three in vivo experiments.

TABLE III
ACUTE ANIMAL STUDY SIGNALS MEASURED

Pressure Signals		
Description	Symbol	Units
Aortic Pressure	AoP	mmHg
Left Ventricular Pressure	LVP	mmHg
Left Atrial Pressure	LAP	mmHg
Right Atrial Pressure	RAP	mmHg
Pulmonary Artery Pressure	PAP	mmHg
pCAS Inlet Pressure*	IN	mmHg
pCAS Outlet Pressure*	OUT	mmHg

* IN & OUT only measured on Pig 25

Flow Signals		
Description	Symbol	Units
Aortic Flow	AoF	L/min
Pulmonary Artery Flow	PAF	L/min
Carotid Artery Flow	CdAF	ml/min
VAD Flow	VADF	L/min

Miscellaneous Signals		
Electrocardiogram	ECG	mV
Heart rate	HR	bpm

C. Cannulae length study

An additional experiment was conducted to evaluate the effect of cannulae and tubing length on the performance of the pCAS. The experimental setup for all of the MCS and acute animal studies mentioned above used an inflow cannulae attached by 60 cm tubing to the pCAS inlet, and an outflow cannulae attached by 60 cm tubing to the pCAS outlet. It is hypothesized that by reducing the length of the tubing the pumping ability of the pCAS will be increased due to the reduced pressure drop (ΔP) across the tubing. Some clinical circumstances may necessitate various positions of the pCAS with respect to the patient, requiring various lengths of tubing. It is important to understand the effects introduced by changes in the tubing length.

This hypothesis was evaluated using the pediatric mock circulation system. The condition of left heart failure was induced in the MCS and LVA was provided. The same protocol is used for the MCS LVA experiment previously described (See Appendix I). The only experimental difference is that both the inflow cannula connection to the pCAS inlet and the outflow cannula connection to the pCAS outlet are bridged by only a 20 cm section of tubing large enough for a pressure catheter inlet to be made. These results are compared with the results from the similar experiment using the 60 cm. tubing.

In each of the in vivo experiments it was necessary to use the 60 cm extension tubing between the pump and the cannulae connections because of position of the test subject and pump. The MCS experiments will give a sufficient indication of the effect of extension tubing length on the performance of the pump.

IV. RESULTS AND DISCUSSION

Results will be presented for each ventricular assist scenario: left ventricular assist with left heart failure, cardiopulmonary support with normal heart conditions, cardiopulmonary support with right heart failure, and veno-venous ECMO with normal heart conditions. Left ventricular assist will be evaluated with both in vitro and in vivo studies, while the other scenarios will be evaluated only with in vitro data. For each experiment the pCAS in continuous flow mode will be described first, followed by the pCAS in pulsatile flow mode.

A. Left ventricular assist

1. In Vitro Study

A mock circulation study with left ventricular assist was performed using the pCAS according to the protocol presented in Appendix I. A complete analysis of the data, showing calibrated values for each hemodynamic parameter, is found in Appendix III.

Figure 9 compares the hemodynamic waveforms produced by the MCS during normal heart conditions and during left ventricular failure.

FIGURE 9. A) MCS with normal heart conditions. B) MCS with left ventricular failure.

The parameters for the normal heart match the criteria described in Table II. The parameters for left heart failure also match the criteria set forth for this condition, with several noticeable differences in the hemodynamic waveforms. These waveforms are typical of an enlarged heart with depressed function.

The afterload of the heart in the left heart failure model has decreased. This is shown by the low perfusion pressure (AoPmean) caused by the weakened left ventricle (left driveline pressure lowered). As a result of this failing ventricle, the stroke volume (SV) has decreased from 6.6 ml to 5.5 ml and the cardiac output (CO) has decreased from

0.80 L/min to 0.66 L/min. The lower aortic pressure pulsatility and peak aortic flow are also indicative of the reduced contractility of the weakened heart. CAF and CdAF have also decreased in mean value and pulsatility.

Along with reduced afterload comes elevated filling pressures and an increased ventricular preload. The mean LAP has increased from 13 mmHg during normal heart conditions to 23 mmHg during left heart failure. Increased LAP raises the pulmonary capillary hydrostatic pressure which could lead to pulmonary congestion and edema. It could also lead to right ventricular failure (RVF).^{9,16}

The right heart parameters and waveforms have adjusted in response to the high filling pressures of the left heart. The mean pulmonary artery pressure has increased from 17 mmHg to 24 mmHg, demonstrating the increased pulmonary congestion. As a result, the right atrial pressure has also increased from 7 mmHg to 11 mmHg, creating a higher preload on the right ventricle. Thus, the failing left ventricle also has a negative effect on the right ventricle.

Once left ventricular failure had been established, the VAD inlet and outlet tubing were unclamped and the VAD was first tested with continuous flow. The speed was incrementally stepped up from the zero flow point (where the pump is rotating at such a speed as to provide neither positive nor negative net flow through the cannulae) to maximum assist. Figure 10 shows the pCAS performing continuous left ventricular assist at 0%, 50%, and 100% of maximum assist.

FIGURE 10. MCS. pCAS performing continuous LVA at A) 0% B) 50% C) 100% of maximum assist.

From left heart failure, the pCAS has been able to restore acceptable hemodynamics while providing an adequate amount of flow. The left atrial pressure has been significantly lowered, resulting in a reduced preload on the heart. At 100% bypass, the aortic root flow is essentially zero as the left ventricle is being completely bypassed. The aortic pressure has been raised, but nearly all pulsatility is gone due to the amount of flow coming from the continuous pCAS. The coronary artery flow and carotid artery flow were also increased back to normal levels with the loss of pulsatility.

The pumping ability of the pCAS was well-proven in this continuous left ventricular assist condition. The VAD was able to provide 0.99 L/min flow at 1600 RPM, which is above the original cardiac output at normal heart conditions (0.80 L/min). This satisfies the requirement of the pCAS to pump 100 ml/min/kg, as the MCS ventricles and vasculature is to represent that of a 10kg child. Figure 11 shows the pCAS flow and LAP as a function of RPM. The pCAS is able to successfully reduce the filling pressure to the ventricle and maintain adequate flow to the rest of the body.

FIGURE 11. MCS LVA continuous pCAS flow and LAP as a function of RPM.

In order to more completely analyze the pumping ability of the pCAS, pressure ports were placed at the pump inlet and outlet so that a change in pressure (ΔP) could be measured across the pump. A centrifugal pump's performance is highly dependant on this pressure drop across the pump (head pressure). In a centrifugal pump, the inlet is at the center of the top of the pump. The rotating pump results in reduced pressure at the inlet which establishes a pressure drop in the atrial (venous) cannula. This pressure drop draws flow into the pump. As the pump spins, the hollow membrane fibers act as the impeller to provide centrifugal acceleration. As the centrifugal force moves the liquid outward away from the eye of the impeller, a low-pressure area is created causing more liquid to flow from the cannula toward the inlet. The kinetic energy of this fluid in centrifugal motion is harnessed by creating a resistance to the flow. This resistance is created by the pump volute that catches the fluid to slow it down and the discharge nozzle.¹⁷

An increase in pCAS ΔP during the pCAS LVA experiments can easily be seen in the IN/OUT plots in Figure 14 as the two signals separate with increasing flow. Figure 12 shows this pressure drop across the pump as a function of flow rate. The pressure drop here almost takes an exponential curve. The peak outlet pressure and minimum inlet pressure measured during the experiment were 156 mmHg and -28 mmHg, respectively. Care must be taken to keep the inlet pressure above excessive negative values or excessive hemolysis could occur and air could be entrained through a connector leak. Some researchers have identifies hemolysis and blood traumatization to occur at negative inlet pressure values exceeding -20 mmHg.¹⁶

FIGURE 12. MCS. The pressure drop across the pCAS during continuous LVA.

The pCAS was also evaluated in pulsatile mode for its ability to provide ventricular assist during left ventricular failure. It was evaluated at both 100 bpm and 140 bpm to cover potential ranges of use. Similar to the continuous assist experiments, a zero flow peak drive voltage (which corresponds to peak pump speed) was established first and then the speed was incrementally increased to maximum assist. Incremental waveforms for the pulsatile assist experiments can be seen in Figure 13 and Figure 14.

FIGURE 13. MCS. pCAS performing 100bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 14. MCS. pCAS performing 140bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

In both of the pulsatile assist modes, the pCAS was able to restore acceptable hemodynamics while providing an adequate amount of flow. The left atrial pressure was reduced significantly. The aortic pressure was increased back to normal levels while maintaining most of its pulsatility. However, at 100% bypass the pulsatility of the aortic pressure mimics the pulsatility of the pCAS because the left ventricle is essentially providing no flow. This pulsatile assist is believed to aid in preventing the vasculature, especially the aorta, from becoming stiff during the assist period. The advantages and disadvantages of continuous and pulsatile assist are discussed further in the recommendations section of this paper.

Between the 100 bpm and 140 bpm pCAS LVA experiments, similar results were experienced. One difference between the two is that, expectedly, a higher peak voltage was necessary for the pCAS at 100 bpm to provide the desired 1 L/min of flow. At a peak voltage of 4.00 V, the pCAS at 100 bpm was able to provide a flow of 0.97 L/min. The pCAS at 140 bpm was able to provide a flow of 1.03 L/min at a peak voltage of 3.90 V. Because the frequency of the pump pulses was less, in order to have the same mean flow required a larger peak flow, as can be seen in the waveforms. The peak positive flow for the pCAS at 100 bpm was 2.35 L/min, while the peak positive flow for the pCAS at 140 bpm was 1.84 L/min. It is observed in both instances that the offset voltage of 0.1 V is sufficient to avoid periods of reverse pCAS flow. This is seen in the VASF waveforms in Figure 13 and Figure 14, where the flow waveforms are consistently above the red zero line.

As a result of this requirement of more volume per pulse with the pCAS at 100 bpm, the ΔP plots (Figure 15) between the two vary slightly. While the curves take a

similar near-exponential pattern, the pCAS at 100bpm has higher ΔP values at the same flow rates.

FIGURE 15. MCS. The pressure drop across the pCAS during pulsatile LVA. A) 100 bpm. B) 140 bpm.

In the same way, the pCAS flow and LAP plots as a function of peak voltage show that the pCAS at 140 bpm decreases the LAP at a lesser peak voltage. This is due to the increased flow rate at that peak voltage. Both are successful in reducing this preload on the left ventricle back down to acceptable levels.

FIGURE 16. MCS. Pulsatile pCAS flow and LAP as a function of peak voltage. A) 100 bpm. B) 140 bpm.

2. In Vivo Study

A series of acute animal studies with left ventricular assist were performed using the pCAS according to the protocol presented in Appendix II. For these experiments, pCAS inflow was drawn from a cannula inserted into the left atrium and the outflow was returned via a cannula inserted into the descending aortic arch. The entire experimental procedure was successfully performed on three piglets: Pig 019, Pig 022, and Pig 025. For a description of the pCAS's effect on the animal hemodynamics, Pig 025 will be

discussed here in detail. Any significant discrepancies between test subjects will be noted. Complete analyses of data for each pig, showing calibrated values for each hemodynamic parameter, are found in Appendices IV - VI. All the waveforms and plots shown for Pig 025 in this discussion have been completed for all test subjects and can be found in Appendices XI - XIX. It is anticipated that the results of pCAS use in an animal model will provide valuable predictors of how the pCAS will perform in a human pediatric patient.

Figure 17 compares the hemodynamic waveforms taken from the test subject during normal heart conditions and during left ventricular failure. Left ventricular failure was induced in the subject via pharmacologic stabilization of myocardial function and sequential coronary ligation.

FIGURE 17. A) Pig 025 with normal heart conditions. B) Pig 025 with left ventricular failure.

There are several notable differences in the hemodynamic waveforms of the normal heart and the heart with induced left ventricular failure. Indicative of a failing left ventricle, the filling pressures have increased, the afterload on the heart (aortic pressure) has decreased, and the cardiac output (aortic flow) has decreased.

The mean LAP has increased from 10 mmHg to 15 mmHg during left heart failure. The left ventricular end diastolic pressure (LVPed) has also increased from 22 mmHg to 25 mmHg. The increases in these filling pressures are due to the weakening of the left ventricle which causes reduced contractility and results in greater end-diastolic

volumes. The ventricle is not strong enough to empty itself of a necessary amount of volume and pump blood throughout the body. The left ventricular SV has decreased from 16.5 ml to 11.6 ml and the CO has decreased from 1.8 L/min to 1.3 L/min.

The increase in left heart filling pressures also has an effect on the right heart hemodynamics. The pulmonary artery pressure has increased from 16 mmHg during normal heart conditions to 19 mmHg during left heart failure. This pulmonary congestion will eventually lead to higher filling pressures for the right ventricle and a greater chance of reducing right ventricular function.

Also due to the reduced strength of the left ventricle, the afterload on the heart has been decreased. The mean aortic pressure has decreased from 67 mmHg to 58 mmHg. A noticeable decrease in the aortic flow has occurred, both in the mean AoF (1.84 L/min to 1.28 L/min) and in the pulsatility (7.82 L/min pulse to 6.28 L/min pulse). While the CdAF pulsatility has increased from 192 ml/min pulse to 244 ml/min pulse during LVF, the mean CdAF has decreased from 135 ml/min to 119 ml/min. A decrease of blood flow to the brain for an extended period of time can have significant consequences.

After the pCAS had been primed with blood, cleared of air bubbles, and connected to the inflow and outflow cannulae, the pCAS tubing was unclamped and immediately brought to a flow level above the zero flow point. This was to prevent any possibility of reverse flow through the centrifugal pump. After reducing the pCAS RPM to create a pump zero flow situation and recording data, the RPM was incrementally increased until near 100% bypass was achieved. Data was recorded at each of these intervals. Figure 18 shows the pCAS performing continuous left ventricular assist at 0%, 50%, and 100% maximum assist.

FIGURE 18. Pig 025. pCAS performing continuous LVA at A) 0% B) 50% C) 100% of maximum assist.

From left heart failure, the pCAS is able to restore acceptable hemodynamics while providing an adequate amount of flow to the circulation. The ventricular filling pressures have been reduced, decreasing the preload on the left ventricle. The left atrial pressure, which was at 10 mmHg during normal heart conditions, has been reduced from 15 mmHg during left heart failure down to 9 mmHg. The left ventricular end diastolic pressure has been reduced from 25 mmHg during left heart failure to 12 mmHg at 100% of maximum assist. These parameters show that the work required of the left ventricle is being greatly reduced by the pCAS. The calculated external work of the ventricle actually decreased from 1059 mmHg-ml at 0% assist to 29 mmHg-ml at 100% of maximum assist. This reduction in workload will provide conditions that promote heart recovery from its weakened state.

At 100% of maximum assist, the pCAS is able to provide 1.92 L/min of flow. A reduction in the pulsatility of the aortic pressure and aortic flow can be seen with increasing RPM as more flow is provided by the continuous pCAS and less flow is provided by the beating heart. The pulsatility of the CdAF has decreased for the same reason, but the mean flow has increased from 119 mmHg during left heart failure to 178 mmHg during 100% of maximum assist.

The pumping ability of the pCAS was well proven in this continuous left ventricular assist application. The VAD was able to provide 1.92 L/min of flow at 2000 RPM. This satisfies the requirement of the pCAS to pump 100 ml/min/kg, as the weight of pig 025 was 12.4 kg. To meet the 100 ml/min/kg requirement a flow rate of 1.24 L/min would have been required, which was easily met at 1600 RPM. Figure 19 shows

the pCAS flow and LAP as a function of RPM. The pCAS is able to successfully reduce the filling pressures of the ventricle and maintain adequate flow to the rest of the body.

FIGURE 19. Pig 025. Continuous pCAS flow and LAP as a function of RPM.

For the animal experiments performed, only the pCAS assisting Pig 025 was instrumented with pressure catheters to measure the pump inlet and outlet pressures. As a result, an analysis of the pCAS pressure head (ΔP) is only done on Pig 025. The plot of the pressure drop across the pump as a function of flow rate for this pig is shown in Figure 20. The peak outlet pressure seen during the experiment was 201 mmHg (mean of 154 mmHg), while the peak negative inlet pressure was -65 mmHg (mean of -27 mmHg). As discussed before, this low inlet pressure is of concern because it could lead to blood damage and the introduction of air into the system through a connector leak.

FIGURE 20. Pig 025. The pressure drop across the pCAS during continuous LVA as a function of flow rate.

In each of the animal experiments, the pCAS was also evaluated in pulsatile mode operation for its ability to restore acceptable hemodynamics during left ventricular failure. The pCAS generated pulsatile flow by cyclically increasing and decreasing the RPM during the pump cycle. The progression of 0% to 100% of maximum assist can be seen for the pCAS operating at 100 bpm and at 140 bpm in Figure 21 and Figure 22, respectively.

FIGURE 21. Pig 025. pCAS performing 100bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 22. Pig 025. pCAS performing 140bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

For both rates of pulsatility, the pCAS was able to restore acceptable hemodynamics while providing adequate blood flow. The filling pressures are reduced so that the heart would be able to begin a process of recovery. Most of the pulsatility of the aortic pressure is maintained with the pCAS operating in pulsatile assist mode.

With the test subject's heart rate ranging between 120 and 130 bpm, the peak flow points of the pCAS interacted at different times with the peak flow points of the natural heart. This is the reason for some of the variability in waveforms found in Figure 21 and Figure 22. If the peak flow of the pCAS happens during natural left ventricular diastole, then the pulsatility of the aortic pressure and flow waveforms will be small (seen in seconds 2-4 of the AoPr waveform in Figure 22c). If the peak flow of the pCAS happens during natural left ventricular systole, then the pulsatility of the aortic pressure and flow waveforms will be summed and the pulses will be magnified (seen in seconds 1-2 of the AoPr waveform in Figure 22c). This altering of the waveforms can also be seen in the pCAS VASF shown in Figure 21 and Figure 22. The VASF waveforms in Fig 019 and Fig 022 were not altered in this way, mostly due to the reduced aortic pressures or heart rates and cycle synchronization closer to the pCAS pulses (see Appendices XI and XII).

While the pCAS was providing pulsatile assist at 140 bpm, it is noticed that the mean aortic pressure is much higher throughout the experiment than during the experiments with continuous assist and pulsatile assist at 100 bpm. AoP values range from 92 mmHg at zero flow to 108 mmHg at 1.35 L/min pCAS flow. This may be attributed to the trauma the heart has experienced through the previous two sequences of letting the heart fall to failure mode and then bringing it back to normal conditions. It

also may have been due to a reduction in pharmacologic stabilization administered during the experiment.

As seen with the MCS experiments, the pCAS at 140 bpm is expected to provide a greater flow rate at a lesser peak voltage. This was proven true in Pig 019, where the pCAS at a peak voltage of 1.60 V was able to provide 1.09 L/min of flow at 100 bpm and 1.30 L/min flow at 140 bpm. In Pig 025, however, the pCAS at 140 bpm does not provide greater rates of flow as a function of peak voltage than the pCAS at 100 bpm. At a peak voltage of 4.80 V, the pCAS at 100 bpm was able to provide a flow of 1.85 L/min. At a peak voltage of 4.40 V, the pCAS at 140 bpm was able to provide 1.58 L/min. The reason for this is due to the high aortic pressure that was seen in Pig 025 during LVA with the pCAS at 140 bpm. This created a higher pressure at the outlet of the pCAS, thus increasing the resistance and making it more difficult to pump. The outlet pressure of the pCAS at 100 bpm while providing 1.85 L/min of flow ($V_{pk} = 4.85$ V) was 158 mmHg. The outlet pressure of the pCAS at 140 bpm while proving a lesser flow of 1.58 L/min ($V_{pk} = 4.40$ V) was 166 mmHg. This effect is shown in Figure 23, which plots ΔP and AoP as a function of pCAS flow.

FIGURE 23. Pig 025. Pig 025 ΔP and AoP as a function of pCAS flow.

Because of this increased outlet pressure due to a high AoP, the pCAS at 140 bpm in Pig 025 did not provide a greater rate of flow as a function of peak voltage. While the data for Pig 019 was as expected during pulsatile mode, the data for Pig 022 followed the same pattern as Pig 025. Upon further review of the hemodynamic data, the AoP for Pig 022 was an average of 20 mmHg higher throughout the experimental sequence for the pCAS at 140 bpm than for the pCAS at 100 bpm. An analysis is shown in Figure 24. Pig 019 and Pig 022 could not be directly compared with Pig 025 because of the removal of an op-amp from the controller before the experiment on Pig 025, effecting the peak voltage values (this change had no effect on the performance of the pump, but only on the value of the peak voltage sent from the computer to the controller).

FIGURE 24. Acute animal studies. Comparison of pCAS flow rate as a function of peak voltage for the three pig test subjects.

As a result of the pCAS at 140 bpm pumping against a greater resistance because of a higher AoP, the inlet pressure also did not get as low as with the pCAS at 100 bpm. This affected the pCAS pressure drop in that the pCAS at 100 bpm has lower ΔP values at the same flow rates as the pCAS at 140 bpm, seen in Figure 25. The MCS experiments, as expected, showed that the pCAS at 100 bpm had higher ΔP values than the pCAS at 140 bpm at the same flow rates (see Figure 15). The difference in Pig 025,

again, is due to the increased aortic pressure effecting the outlet pressure and inlet pressure of the pCAS. Since pCAS inlet and outlet pressures were not measured with Pig 019 and Pig 022, no ΔP comparisons can be made with these test subjects. The lesson to be learned from this analysis of the pCAS and the varying aortic pressures is that the pumping performance will be influenced by the patient's hemodynamic parameters. As the hemodynamics of a patient are subject to change, so the pCAS must be able to adjust to meet the blood flow needs at the time. The pCAS has proven this ability by providing an adequate amount of flow to restore acceptable hemodynamics for all test subjects.

FIGURE 25. Pig 025. The pressure drop across the pCAS during pulsatile LVA. A) 100 bpm. B) 140 bpm.

The pCAS at both pulsatile assist rates were able to reduce the left atrial pressure while pump flow increased. This is shown in Figure 26, which displays the pCAS flow and LAP plots as a function of peak voltage.

FIGURE 26. Pig 025. Pulsatile pCAS flow and LAP as a function of peak voltage. A) 100 bpm. B) 140 bpm.

The pCAS was able to provide the required 100 ml/min/kg flow to all test subjects in all conditions, with the exception of Pig 022 during operation in continuous and 100 bpm pulsatile modes. The results for each test subject are shown in Table IV. Even in the case of Pig 022 where the 100 ml/min/kg flow was not reached, the patient

hemodynamics were properly restored. The pCAS successfully provided left ventricular assist for all three pig test subjects in continuous and pulsatile modes.

TABLE IV

MAXIMUM FLOW RATES DURING LVA FOR EACH IN VIVO TEST SUBJECT

Piglet Number	Piglet Weight (kg)	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF mean (ml/min/kg)
019	10.5	CF	1700	-	1.24	118
019	10.5	PF	100	1.60 / 0.1	1.09	104
019	10.5	PF	140	1.60 / 0.1	1.30	124
022	12	CF	1600	-	1.06	88
022	12	PF	100	1.50 / 0.9	1.14	95
022	12	PF	140	1.55 / 0.9	1.31	109
025	12.4	CF	2000*	-	1.92	155
025	12.4	PF	100	4.80 / 0.1	1.85	149
025	12.4	PF	140	4.40 / 0.1	1.58	127

B. Cardiopulmonary support (CPS) with normal heart conditions

A mock circulation study was performed according to the protocol presented in Appendix I to evaluate the pumping ability of the pCAS while providing cardiopulmonary assist during normal heart conditions. For this test, pCAS inflow is drawn from the right atrium through an 8 Fr Medtronic Biomedicus ECMO cannula and pCAS outflow is returned to the aorta through a 16 Fr Research Medical Inc. cannula. A complete analysis of the data, showing calibrated values for each hemodynamic parameter, is found in Appendix VII.

Figure 27 shows the hemodynamic waveforms recorded from the MCS during normal heart conditions. The parameters for the normal heart condition match the criteria described in Table II (note that in all the CPS recordings, the PAF probe indicated half of the true value. This was adjusted in the calculation of PAF parameters).

FIGURE 27. MCS with normal heart conditions

The purpose for providing cardiopulmonary assist in the presence of a healthy heart is to provide oxygenation and remove carbon dioxide removal in the blood because of respiratory failure. So the primary concern is not restoring acceptable hemodynamics while reducing the workload of the heart as with LVA, but rather assisting or completely bypassing the lungs so as to maintain oxygenated blood flow throughout the body.

In the same manner as the LVA experiments, the pCAS was brought to a zero flow point and then the speed was incrementally stepped up. Figure 28 shows the pCAS in continuous mode at different levels of assist.

FIGURE 28. MCS. pCAS performing continuous CPS during normal heart conditions at A) 0% B) 50% C) 100% of maximum assist.

Several important effects can be seen from the progression of hemodynamics shown in Figure 28. It is evident that the heart is being partially bypassed. This is seen by the reduced mean aortic flow from 0.84 L/min to 0.40 L/min and mean pulmonary artery flow from 0.71 L/min to 0.49 L/min. The pulsatility of these signals has also decreased as less volume is available to pump by the left and right ventricles. The left ventricular stroke volume has been reduced from 7.0 ml to 4.0 ml and the right ventricular stroke volume has been reduced from 7.8 ml to 4.3 ml.

The pVAD flow is increased to 0.61 L/min at 2000 RPM. At this amount of flow, the aortic pressure reached 112 mmHg with the combined strength of the pCAS and a healthy left ventricle. The systemic vascular resistance was not adjusted on the MCS as the AoP was increased above normal levels as would be possible in clinical use by vasodilatory drugs. Because of this high aortic pressure and low pCAS inlet pressure, the pCAS speed was not increased any further to provide additional flow. A significant pressure drop across the pCAS can be observed in the pCAS inlet and outlet pressure plots in Figure 28c. The pressure drop across the pump as a function of flow rate is shown in Figure 29.

FIGURE 29. MCS. The pressure drop across the pCAS for continuous CPS during normal heart conditions.

The ΔP values during this CPS experiment are higher than the ΔP values during the MCS LVA experiment, yet the flow provided by the pCAS is less. This is due primarily to the smaller inflow cannula used in the CPS experiments, changing in size from a 20 Fr cannula in the left atrium for LVA to an 8 Fr cannula in the right atrium for CPS. The 8 Fr cannula was used as a worse case scenario of clinical pediatric cannulation of the jugular vein for CPS. Depending on the patient size and cannulation site, the cannula could range from 8 Fr to 20 Fr. This small cannula size caused a mean pCAS inlet pressure of -86 mmHg while providing 1.62 L/min flow at 2000 RPM, with a peak negative inlet pressure recorded at -116 mmHg. Along with the option of changing the inflow cannula size, the inlet pressure could also be increased by reducing the size of the 20 Fr return cannula to create a greater resistance on the pCAS outlet.

Similar results were seen with the pCAS providing pulsatile CPS during normal heart conditions. The hemodynamic waveform progressions for the pCAS in 100 bpm and 140 bpm pulsatile modes are shown in Figure 30 and Figure 31, respectively.

FIGURE 30. MCS. pCAS performing 100 bpm pulsatile CPS during normal heart conditions at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 31. MCS. pCAS performing 140 bpm pulsatile CPS during normal heart conditions at A) 0% B) 50% C) 100% of maximum assist.

Similarly to the cardiopulmonary assist provided by the pCAS in continuous mode, the aortic flow and pulmonary artery flow have been reduced significantly due to the partial bypassing of the heart. The aortic pressure is increased again to a high level. For the pCAS providing 0.43 L/min flow at 100 bpm, the mean AoP reaches 104 mmHg. For the pCAS providing 0.44 L/min flow at 140 bpm, the mean AoP reaches 106 mmHg.

The peak negative inlet pressure reaches below -200 mmHg as early as 0.26 L/min mean flow with a peak voltage of 3.95 V for the pCAS at 100 bpm. The inlet pressure was only set to measure between -200 and +200 mmHg, so clipping occurred on both the inlet and outlet pressure signals on all files after the peak voltage = 3.95 V. This clipping also affects the mean inlet and outlet pressure recorded in pulsatile mode, resulting in the true mean inlet pressure values at the maximum flow rate being slightly more negative than the -63 mmHg (100 bpm) and -71 mmHg (140 bpm) recorded. It is clear that the peak negative inlet pressure becomes more negative with the pCAS in pulsatile mode as compared with continuous mode.

This low negative inlet pressure caused by the small catheter increases the risk of excessive hemolysis and the entrainment of air through a connector leak. During the pulsatile experiments, air bubbles could be seen entering and exiting the pump. Whether this air was leaking through a connector or coming out of the solution was not clear. This occurred with the pCAS at 100 bpm at a flow rate of 0.38 L/min and a peak voltage of 4.25 V (mean inlet pressure = -59 mmHg, peak negative inlet pressure = -200+). It occurred with the pCAS at 140 bpm at a flow rate of 0.36 L/min and a peak voltage of 4.10 V (mean inlet pressure = -58 mmHg, peak negative inlet pressure = -200+). Air bubbles were also noticed with the pCAS in continuous mode. In comparison, air

bubbles were noticed with the pCAS in continuous mode at a flow rate of 0.55 L/min at 1900 RPM (mean inlet pressure = -71 mmHg, peak negative inlet pressure = -107 mmHg). The excessive peak negative inlet pressure caused by the pCAS in pulsatile mode leads to a greater probability of the introduction of air into the system through connector leaks.

The ΔP as a function of pCAS flow can be seen in Figure 32. As discussed previously, the pCAS at 100 bpm requires more volume per pulse to pump the same flow rate as the pCAS at 140 bpm. The ΔP plots, shown in Figure 32, display this slight difference. The pCAS at 100bpm has higher ΔP values than the pCAS at 140 bpm at the same flow rates. The ΔP values corresponding to flow rates above 0.26 L/min are less than the true values because of clipping that occurred on the inlet and outlet pressure signals. As a result, a slope reduction of the plots in Figure 32 can be seen as the flow rate increases above 0.26 L/min.

FIGURE 32. MCS. The pressure drop across the pCAS for pulsatile CPS during normal heart conditions. A) 100 bpm. B) 140 bpm.

The pCAS VASF waveforms in Figure 31 show that there are periods of pCAS flow below the red zero flow line. These periods of negative flow can be explained by the high aortic pressure creating a greater resistance to the pump flow and insufficient minimum pCAS RPM during the pCAS pumping cycle. The pCAS offset voltage of 0.1 V was not set high enough to counter this effect and should have been increased until the negative flow was eliminated, as was demonstrated and accomplished in the animal experiment for Pig 022 (offset voltage = 0.9 V).

C. Cardiopulmonary support (CPS) with right ventricular failure

A mock circulation study was performed according to the protocol presented in Appendix I to evaluate the pumping ability of the pCAS while providing cardiopulmonary assist during right ventricular failure. A complete analysis of the data, showing calibrated values for each hemodynamic parameter, is found in Appendix VIII.

Providing cardiopulmonary support in the presence of right ventricular failure is necessary for conditions where the right ventricle has been weakened and lost contractility. The pCAS is responsible in this situation to provide sufficient amounts of blood flow and restore acceptable hemodynamics to the body. Because the lungs are bypassed, it is also necessary for the pCAS to provide oxygenation and carbon dioxide removal for the blood.

Figure 33 shows the hemodynamic waveforms recorded from the MCS during normal heart conditions and during right ventricular failure (note that in all the CPS recordings, the PAF probe indicated half of the true value. This was adjusted in the calculation of PAF parameters).

FIGURE 33. MCS with A) normal heart conditions. B) right ventricular failure.

The hemodynamics produced by the MCS for right ventricular failure are consistent with the values presented in Table II. The right atrial pressure has increased from 7 mmHg during normal heart conditions to 19 mmHg during right ventricular failure. This increase in ventricular preload is indicative of a weakened ventricle that has lost contractility and the ability to pump an adequate amount of blood volume. The weakening of the right ventricle is simulated in the MCS by partially clamping the right driveline pressure to reduce the metered pulse of compressed air pressurizing the ventricle diaphragm.

The weakened heart also results in a reduction in right ventricular cardiac output and stroke volume. The mean pulmonary artery flow has decreased from 0.65 L/min to 0.56 L/min during right ventricular failure. The PAF pulsatility has decreased from 4.13 L/min pulse to 2.06 L/min pulse, showing the decrease in perfusion pressure of the ventricle. The PAP has seen a slight decrease in mean pressure from 15 mmHg to 14 mmHg but a significant decrease in pulsatility from 36 mmHg pulse to 21 mmHg pulse.

The left heart parameters are affected by the weakened right ventricle also. Because of the lessened amount of flow from the right heart, the aortic flow from the left heart has been decreased (0.77 L/min to 0.66 L/min). The reduction in volume has led to a reduced preload on the left ventricle, causing the mean LAP to decrease from 13 mmHg during normal heart conditions to 8 mmHg during right ventricular failure. The reduction in aortic pressure from 73 mmHg to 66 mmHg also indicates the reduction in left ventricular stroke volume caused by right ventricular failure. The pulsatility of the left heart hemodynamics has not been significantly affected, however, due to the maintained contractility of the healthy left ventricle.

Figure 34 shows the progression of the pCAS in continuous mode at different levels of assist.

FIGURE 34. MCS. pCAS performing continuous CPS during right ventricular failure at A) 0% B) 50% C) 100% of maximum assist.

The pCAS has decreased the workload on the weakened right ventricle. The ventricular preload has been significantly reduced. The mean RAP has decreased from 19 mmHg at right ventricular failure to 12 mmHg at a pCAS flow rate of 0.69 L/min (2000 RPM). The systolic RAP is reduced from 28 mmHg to 22 mmHg while the diastolic RAP is reduced from 5 mmHg to 2 mmHg. This support will provide an atmosphere for the right ventricle to recover. The continuous pCAS flow and RAP as a function of RPM is shown in Figure 35.

It is also evident that the heart is being partially bypassed by the pCAS. The mean aortic flow has decreased from 0.68 L/min to 0.22 L/min, and the mean pulmonary artery flow has decreased from 0.55 L/min to 0.29 L/min. This is caused by the pCAS pumping a portion of the blood volume, which also decreases the pulsatility of these flow signals. The heart is doing less work because it is being forced to pump less volume.

FIGURE 35. MCS. Continuous pCAS flow and RAP as a function of RPM.

Because of the combined strength of the pCAS and the left ventricle, the aortic pressure was increased to 101 mmHg while the pCAS was providing 0.69 L/min flow at 2000 RPM. The systemic vascular resistance again was not adjusted on the MCS as the AoP was increased above normal levels. This would be possible in clinical use by vasodilatory drugs that reduce systemic vascular resistance. Although the pCAS flow while providing cardiopulmonary support during right heart failure was able to be increased higher than with CPS during normal heart conditions, the flow was not further increased because of the high aortic pressure and low pCAS inlet pressure.

A similar pattern is seen in the pCAS inlet and outlet pressure measurements as was seen in the pCAS while providing CPS during normal heart conditions. The same 8 Fr inflow cannula was used, so the pCAS inlet pressure was low. The plot of ΔP relating to flow rate is shown in Figure 36. Because the pCAS began its pumping during right ventricular failure where the RAP is up and the AoP is down, the pCAS inlet pressure started higher and the outlet pressure started lower than the support with normal heart conditions. As a result, the pCAS during right ventricular failure was able to provide a greater flow at the same ΔP values. This effect also caused the zero flow point during right heart failure to occur at 960 RPM, as compared to 1140 RPM during normal heart conditions.

FIGURE 36. MCS. The pressure drop across the pCAS for continuous CPS during right ventricular failure.

A right ventricular failure baseline was taken between each transition from continuous to 100 bpm pulsatile to 140 bpm pulsatile assist. An experimental error was discovered upon reviewing the hemodynamic data for CPS during right heart failure with the pCAS providing pulsatile assist at 100 bpm. The technique for inducing ventricular failure in the right heart is to partially close off a variable clamp on the right driveline pressure line. During the assist with the pCAS at 100 bpm, this line was closed off too much so that the right ventricle was not receiving enough driveline pressure to represent a right ventricle in the failure state. The mean pressure and flow parameters of the left and right heart measured very similar to the previous right ventricular failure baseline, but the right heart waveforms were too depressed. This effect was not noticed during the experimentation. Figure 37 shows the RVF baseline before the 100 bpm pCAS assist as compared to the RVF baseline before the 140 bpm pCAS assist.

FIGURE 37. MCS. Right ventricular failure baseline taken before CPS experiments with the pCAS operating at A) 100 bpm. B) 140 bpm.

By observing the right heart hemodynamic waveforms (PAP, PAF, RAP) in the experiment with the pCAS at 100 bpm, it can be determined that the right driveline pressure was clamped off too much so as not to allow for sufficient drive pressure to the right ventricle. Nearly all pulsatility has been lost in these signals. Also, as the pCAS flow increased, the right atrial pressure did not decrease as seen in the continuous and 140 bpm experiments because of the lack of work being done by the right ventricle. The RAP with the pCAS at 100 bpm decreased only from 20 mmHg at right ventricular

failure to 18 mmHg with the pCAS providing 0.45 L/min flow at a peak voltage of 4.10 V.

Because of the experimental error mentioned above regarding the pCAS assist at 100 bpm, only the data set with the pCAS at 140 bpm will be considered as valid in this research for the pulsatile pCAS providing CPS during RVF. Comparisons between these two rates of pulsatile assist have already been established in previous assist conditions. Evaluation of the pCAS at 140 bpm alone will be sufficient to characterize pulsatile assist during CPS with right ventricular failure. The hemodynamic waveform progression for the pCAS at 140 bpm is shown in Figure 38.

FIGURE 38. MCS. pCAS performing 140 bpm pulsatile CPS during right ventricular failure at A) 0% B) 50% C) 100% of maximum assist.

These results are similar to the results of the cardiopulmonary assist provided by the pCAS in continuous mode. The aortic flow and pulmonary artery flow have been reduced significantly due to the partial bypassing of the heart with the consequence of a high aortic pressure. The right atrial pressure was also successfully reduced from 18 mmHg at right ventricular failure to 12 mmHg while the pCAS was providing 0.50 L/min flow at a peak voltage of 4.10. The pCAS flow and RAP as a function of peak voltage can be seen in Figure 39. This plot follows a similar pattern as with the pCAS in continuous mode and proves the ability of the pCAS to reduce the preload on the right heart while providing CPS.

FIGURE 39. Pulsatile 140 bpm pCAS flow and RAP as a function of RPM.

For the pCAS providing 0.50 L/min flow at 140 bpm, the mean AoP reached 93 mmHg. Because of the high AoP and excessive peak negative inlet pressure at this peak voltage, the pCAS speed was not increased any further to provide additional flow. As in the CPS experiment with normal heart conditions, the inlet and outlet pressures were set

to measure between -200 and +200 mmHg. Clipping was seen in the inlet and outlet pressure signals starting with a peak voltage of 3.80 V and a flow rate of 0.39 L/min. While the mean values for the pressures were similar to those measured for the pCAS in continuous mode, the peak negative inlet and peak positive outlet pressures in pulsatile mode exceeded the +/- 200 mmHg range. This causes the mean inlet and outlet pressures recorded for the files with pCAS flow greater than 0.39 L/min (peak voltage = 3.80 V) to be less than their true value, which causes the calculated ΔP values for these files to be low as well. The ΔP plot as a function of flow is shown in Figure 40.

FIGURE 40. MCS. The pressure drop across the pCAS for 140 bpm pulsatile CPS during right ventricular failure.

Air bubbles were noticed in the 140 bpm pulsatile experiment with the pCAS flow at 0.45 L/min at a peak voltage of 3.95 V. At this rate, the pCAS peak negative inlet pressure was less than -200 mmHg. The mean inlet pressure for this rate was recorded as -60 mmHg, though the actual value was somewhat more negative due to clipping. With the pCAS in continuous mode, air bubbles were noticed in the system with the pCAS

pumping 0.62 L/min at 1900 RPM. Because of the high pressure signal peaks, the pCAS in pulsatile mode did not allow as much flow using the 8 Fr inflow cannula during CPS without the introduction of air bubbles as the pCAS in continuous mode.

D. Venovenous ECMO (VV ECMO)

A mock circulation study was performed according to the protocol presented in Appendix I to evaluate the pumping ability of the pCAS while providing venovenous ECMO during normal heart conditions. A complete analysis of the data, showing calibrated values for each hemodynamic parameter, is found in Appendix IX.

Figure 41 shows the hemodynamic waveforms recorded from the MCS during normal heart conditions. The parameters for the normal heart condition match the criteria described in Table II (note that in all the VV ECMO recordings, the PAF probe indicated half of the true value. This was adjusted in the calculation of PAF parameters).

FIGURE 41. MCS with normal heart conditions

Veno-venous ECMO is performed in patients by drawing blood out of the right atrium, oxygenating and removing carbon dioxide from the blood, and then pumping it back into the right atrium. This type of assist is performed on patients with respiratory malfunction but normal heart conditions. Because the blood is taken out and put back in the same vessel, there is little hemodynamic effect. It is important, however, for the pCAS to pump an adequate amount of flow to oxygenate a sufficient amount of blood. A 14 Fr double lumen cannula (OriGen Biomedical) was used for the inflow and outflow of the pCAS. This double lumen cannula will have a significant effect on the ΔP of the pCAS.

Since the inflow and return are both in the right atrium, ΔP is zero and there is no reverse flow through the pump. So the zero flow point of the pCAS during VV ECMO is 0 RPM. Figure 42 shows the pCAS in continuous mode at different levels of assist.

FIGURE 42. MCS. pCAS performing continuous VV ECMO at A) 0% B) 50% C) 100% of maximum assist.

The hemodynamic waveforms remain essentially unaffected by the veno-venous assist provided by the pCAS, as is expected. The pCAS was able to provide 0.97 L/min flow at 3900 RPM. The RPM could be increased very high because of the lack of low negative inlet pressure and the lack of effects on hemodynamics. Under normal clinical circumstances this would be an adequate amount of flow needed to be provided for a patient 10 kg or less, as defined by the 100 ml/min/kg requirement.

The mean inlet pressure reached -29 mmHg at 3900 RPM, with a peak negative pressure at this rate of -72 mmHg. The pCAS outlet pressure was adjusted to measure up to 400 mmHg, but the peak measurements rose above this limit with the pCAS at 2700 RPM and providing 0.64 L/min flow. The outlet pressure signal shown in Figure 42c is completely above 400 mmHg and so only shows as a line. The ΔP plot as a function of pCAS flow is shown in Figure 43.

FIGURE 43. MCS. The pressure drop across the pCAS for continuous VV ECMO.

The ΔP for the pCAS starts at zero and increases at a non-linear rate. For the measurements above 0.64 L/min, the outlet pressure no longer is measured above 400 mmHg. So the only increase in ΔP is due to the decrease in the mean inlet pressure. The high outlet pressure is indicative of the very high outflow resistance caused by the double lumen cannula. This high outlet pressure also helps to keep the inlet pressure higher at high RPM or peak voltage.

The pCAS controller at the time of the VV ECMO experiments had been modified so that an op-amp was removed that boosted the signal coming from the PC DAQ card to the controller. This is why the pulsatile experiments for Fig 019 and Fig 022 have much lower peak voltage values than the pulsatile experiments for Fig 025 and the mock circulation system. The pCAS peak voltage was only able to reach 5V, which hadn't been a problem in previous experiments but proved to be a limitation in the VV ECMO experiments.

While the hemodynamics do not change, it is important to see the effect of the pCAS pulsatility on the inlet and outlet pressure and pCAS flow during VV ECMO. Figure 44 and Figure 45 show the pCAS in pulsatile mode at different levels of assist for 100 bpm and 140 bpm, respectively.

FIGURE 44. MCS. pCAS performing 100 bpm pulsatile VV ECMO at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 45. MCS. pCAS performing 140 bpm pulsatile VV ECMO at A) 0% B) 50% C) 100% of maximum assist.

The maximum flow reached during pulsatile assist with the pCAS peak voltage maxed at 5V was 0.50 L/min at 100 bpm and 0.53 L/min at 140 bpm. Given the results with the pCAS in continuous mode, it can be assumed that the pCAS in pulsatile mode would have been able to provide a greater flow rate given the chance to pump at a greater peak voltage.

For the pCAS at 100 bpm, the mean inlet pressure reached -11 mmHg at 0.50 L/min flow with a peak negative value of -160 mmHg. For the pCAS at 140 bpm, the mean inlet pressure reached -12 mmHg at 0.53 L/min flow with a peak negative inlet value of -184 mmHg. This can be compared to the continuous assist, where a similar flow rate of 0.51 L/min produced a mean inlet pressure of -5 mmHg with a peak negative value of -27 mmHg. No air bubbles were noticed entering or exiting the pump during either the pulsatile or continuous experiments.

Because of the pulsatility in the outlet pressure, clipping occurred (instantaneous outlet pressure exceeded 400 mmHg) on all files after the peak voltage reached 4.00 V for the pCAS at 100 bpm and at 140 bpm. Clipping is displayed in the outlet pressure plots in Figure 44c and Figure 45c. Again, this causes the mean values for the outlet pressure in these files to be less than their true value. The ΔP plots for the pCAS at 100 bpm and at 140 bpm are shown in Figure 46. The clipping has caused the reduction in slope on the values with flow rates greater than 0.32 L/min at 100 bpm and 0.36 L/min at 140 bpm.

FIGURE 46. MCS. The pressure drop across the pCAS for pulsatile VV ECMO with the pCAS set at A) 100 bpm. B) 140 bpm.

While the pulsatile pCAS was not able to provide all of its potential flow due to the maximum peak voltage being set at 5V, the experiment gives a good idea of the pump's ability in a veno-venous assist condition. The high peaks in negative outlet pressure will be important to monitor as the pCAS flow is increased more in pulsatile mode.

E. Left Ventricular Assist with 20 cm connection tubing.

An important factor in the pumping performance of the pCAS is the size and length of cannulae used to connect the pump-oxygenator to the patient. A variety of cannulae may be necessary because of patient size, type of assist needed, physical cannulation site, and physiological abnormalities. One example of the effects of different cannula sizes is seen by observing the LVA and CPS experiments, where the inlet cannulae between these two differed from 20 Fr to 8 Fr. The effect of a double lumen cannula has also been shown in the VV ECMO experiments. Additional studies have been done by Ension⁸ and the University of Louisville²⁰ to characterize the manufacturer, style, and size of cannulae used.

Along with understanding the effects of cannulae used, it is also important to understand the effect of the length of tubing used to connect the inflow and return cannulae to the pCAS. Traditional ECMO circuits use an extensive amount of tubing on the inlet and outlet sides of the pump because of the number of instruments involved and the position of the pump with regards to the patient. The pCAS is able to greatly reduce the length of tubing between the cannulae and pump because of the lack of additional support equipment and mobility of the system. However, even between pCAS experiments this length could vary depending on patient size, patient mobility, and cannulation site on the body.

For these reasons it is important to understand how changes in the tubing length affect the ability of the pCAS to provide an adequate amount of flow while restoring acceptable hemodynamics. For each of the previous experiments mentioned in this research, both in vitro and in vivo studies, 60 cm tubing sections were used to connect the

inflow cannula to the pCAS inlet and the outflow cannula to the pCAS outlet. To evaluate the effect of altering this tubing length, an additional mock circulation study was performed by providing left ventricular assist with only 20 cm tubing sections connecting the inlet and outlet of the pCAS to the cannulae. These 20 cm sections were the minimum necessary because of the connectors used for inlet and outlet pressure catheters. The procedure follows the protocol for LVA presented in Appendix I and matches the procedure used for the LVA experiment with 60 cm tubing. A complete analysis of the data, showing calibrated values for each hemodynamic parameter, is found in Appendix X.

Figure 47 shows the pCAS performing continuous left ventricular assist at 0%, 50%, and 100% of maximum assist.

FIGURE 47. MCS. pCAS performing continuous LVA with 20 cm tubing at A) 0% B) 50% C) 100% of maximum assist.

The pCAS with 20 cm tubing was able to provide an adequate amount of flow and restore acceptable hemodynamics. The hemodynamic waveforms shown here compare very closely to the waveforms produced by the pCAS with 60 cm tubing, shown in Figure 10. The difference is that with 20 cm tubing, the pCAS was able to provide more flow at a lesser RPM. With 20 cm tubing, the pCAS produced 0.99 L/min flow at 1400 RPM. With 60 cm tubing, the pCAS needed 1600 RPM to produce the same flow rate of 0.99 L/min.

The pumping ability of the pCAS itself has not changed during this time. This is shown by Figure 48, where the pCAS inlet/outlet ΔP is nearly unchanged as a function of RPM. At 900 RPM, the pCAS with 60 cm tubing had a ΔP of 37 mmHg while the pCAS with 20 cm tubing had a ΔP of 41 mmHg. Similarly at 1400 RPM, the pCAS with 60 cm tubing had a ΔP of 94 mmHg while the pCAS with 20 cm tubing had a ΔP of 98 mmHg. This shows that the effect of increasing flow as a function of RPM is due to the reduction in tubing and not to the pCAS itself.

The ΔP of the pCAS as a function of flow is affected. By reducing the length of the tubing, the resistance of the tubing is also decreased. This causes the pressure drop across the shorter tubing to be less for the same flow rate. Because the reduction in tubing length causes a greater flow to occur as a function of pressure drop across the tubing, a greater flow will also occur as a function of pressure drop across the pCAS. By losing a lesser amount of pressure across the outlet tubing, the outlet pressure of the pCAS will not need to be as high to pump the same amount of fluid. And by losing a lesser amount of pressure across the inlet tubing from the LAP, the pCAS inlet pressure will not have dropped as low.

The relationships of pCAS flow to ΔP for the tubing lengths are compared in Figure 49. At low flows, the tubing length has little effect due to the greater effect of the AoP and LAP on the inlet and outlet pressure values. But as the flow increases and the inlet and outlet pressures rise, the pCAS with 20 cm tubing is proven to be able to provide a greater flow rate at a lesser ΔP value. The benefit of a greater flow rate at a lesser ΔP grows as pump flow increases, as shown by the increasing separation of the plots in Figure 49. The use of shorter connecting tubing has made more efficient use of the pump by allowing it to produce the same output while performing a reduced amount of work.

FIGURE 48. MCS. The pressure drop across the pCAS as a function of RPM during continuous LVA for different tubing lengths.

FIGURE 49. MCS. The pressure drop across the pCAS as a function of flow during continuous LVA for different tubing lengths.

The pCAS flow through the ¼" diameter tubing experiences both laminar and transitional flow during the MCS experiment. The Reynolds number (Re) has been calculated for the pCAS in continuous mode for all mean flow values with the equation:

$$Re = \frac{\rho v D}{\mu}$$

where ρ is the fluid density (.998 g/cm³ for water at 20°C), v is the fluid velocity (calculated from $Q = vA$, where A is the tubing cross-sectional area), D is the tubing diameter, and μ is the fluid viscosity (1 cP for water). The calculated Reynolds numbers are shown in Table V. Laminar flow through a pipe is indicated by a Reynolds number below 2300 and turbulent flow is represented by a Reynolds number above 4000. Fluid flow with a Re value between 2300 and 4000 is considered transitional flow, where the

flow is transitioning from laminar to turbulent and fluid behavior is frequently unpredictable.

TABLE V
REYNOLDS NUMBERS FOR MCS LVA WITH 20 CM CONNECTION TUBING

pCAS RPM	pCAS Mean Flow (L/min)	Re
818	0.00	0
900	0.22	713
1000	0.45	1485
1100	0.60	1997
1200	0.75	2494
1300	0.90	2963
1400	0.99	3277

The flow produced by the pCAS up to 0.60 L/min is laminar flow as indicated by the calculated Reynolds numbers. This fluid flow can be described by Poiseuille's equation, which relates flow (Q), the pressure drop across the tubing (ΔP), viscosity (μ), and the geometry of the tubing (radius (R), length (L)). Laminar flow through tubing is described by Poiseuille's equation, shown below:

$$Q = \frac{\pi(\Delta P)R^4}{8\mu L}$$

The tubing radius ($\frac{1}{4}$ ") and viscosity of the test fluid (water) stay constant in the experiment, which means the flow rate at the same pressure drop across the tubing will have an inverse linear relationship to the length of the tubing. Thus, by reducing the tubing length, the flow will be increased for the same tubing ΔP .

The period of transitional flow as indicated by the calculated Reynolds numbers occurs for the mean flow values above 0.60 L/min. During these periods of flow, it seems that the pCAS with the 20 cm connection tubing has a greater impact on the

efficiency of the pump. This is seen in Figure 49, where the separation between the plots for ΔP versus pCAS flow for the two experiments widens after the flow increases above 0.60 L/min. The increasing separation during the periods of transitional flow indicates that the shorter tubing has a greater effect on the efficiency of the pump during transitional flow than during laminar flow. The flow rate was not increased high enough to experience turbulent flow, as indicated by the Reynolds numbers.

As explained previously, this increase in efficiency from the shorter connection tubing will have a positive effect on the pCAS inlet/outlet ΔP . This effect and increased efficiency show up in the relationship between pCAS flow and RPM, shown in Figure 50. The pCAS in continuous mode is able to consistently provide a greater flow at a reduced RPM for the experiment with the shorter tubing.

FIGURE 50. MCS. pCAS flow as a function of RPM during continuous LVA for different tubing lengths.

The pCAS in pulsatile mode for LVA with the 20 cm tubing experienced similar results as the pCAS in continuous mode. The pCAS was able to provide an adequate amount of flow and restore acceptable hemodynamics. Figure 51 and Figure 52 show the pCAS performing continuous left ventricular assist at 0%, 50%, and 100% of maximum assist for 100 bpm and 140 bpm, respectively. Upon comparing these waveforms to the experiments with 60 cm tubing in Figure 13 and Figure 14, the hemodynamic effects are very similar. As found in the continuous pCAS assist, the pump in pulsatile mode with 20 cm tubing was able to provide a greater flow rate at a lesser peak voltage than with 60 cm tubing. With 20 cm tubing, the pCAS at 100 bpm was able to provide 0.99 L/min flow at 3.80 Vpk. With 60 cm tubing, the pCAS at 100 bpm needed 4.00 Vpk to provide a similar flow of 0.97 L/min. Similarly with the 20 cm tubing, the pCAS at 140 bpm was able to provide 0.97 L/min flow at 3.60 Vpk. With 60 cm tubing, the pCAS at 140 bpm needed a 3.90 Vpk to provide a similar flow of 1.03 L/min.

FIGURE 51. MCS. pCAS performing 100 bpm pulsatile LVA with 20 cm tubing at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 52. MCS. pCAS performing 140 bpm pulsatile LVA with 20 cm tubing at A) 0% B) 50% C) 100% of maximum assist.

The pulsatile pCAS ΔP as a function of peak voltage proved to be almost identical to the numbers recorded during the pCAS experiment with 60 cm tubing. This again shows the increase in pumping efficiency is due to the reduction in tubing and not to the pCAS itself.

The reduction in the tubing has had a positive impact on the pCAS ΔP as it relates to flow. Because of the reduced resistance in the shorter tubing, the inlet pressure is not as low and the outlet pressure does not have to be as high to pump the same amount of fluid as with the 60 cm tubing. This is shown in Figure 53, which shows plots relating pulsatile pCAS flow to inlet/outlet ΔP . As seen with the continuous assist, the separation of the two plots begins increasing significantly as the flow rate increases above approximately 0.60 L/min. Because of the pulsatile nature of the flow, the Reynolds number was not calculated. A Reynolds number calculated for the mean flow rate would not be indicative of the actual pCAS flow. The use of shorter connecting tubing has made more efficient use of the pump by allowing it to produce the same output while performing a reduced amount of work.

The increased efficiency can be seen in the relationship between pCAS flow and peak voltage, shown in Figure 54. The pCAS in 100 bpm and 140 bpm pulsatile modes is able to consistently provide a greater flow at a reduced peak voltage for the experiment with the shorter tubing.

FIGURE 53. MCS. The pressure drop across the pCAS as a function of flow during pulsatile LVA for two tubing lengths A) 100 bpm. B) 140 bpm.

FIGURE 54. MCS. pCAS flow as a function of RPM during pulsatile LVA for different tubing lengths for A) 100 bpm. B) 140 bpm.

The use of shorter tubing during the left ventricular assist condition proved to increase the pumping system efficiency, especially at higher flow rates causing increased fluid turbulence. Turbulent flow was most likely experienced in the pulsatile flow experiments as peak flow rates reached as high as 1.88 L/min, giving a calculated Reynolds number of 6210. As flow becomes turbulent, more energy is required to pump the fluid through the tubing. The relationship between the pressure drop across the tubing and the flow rate becomes non-linear, requiring a greater ΔP for the same increase in flow. This means that at higher flow rates where turbulent flow is likely to occur, the shorter tubing will have an even more pronounced positive effect on the efficiency of the pCAS. The test fluid used for these experiments was distilled water, but the same effect will be seen with blood as the fluid pumped. Blood, however, will not reach transitional or turbulent flow as quickly as water because of its increased viscosity. Laminar flow will remain for higher flow rates with blood being pumped instead of water.

Whenever possible, the clinical operator of the pCAS should use a minimal amount of tubing. Along with greater pumping efficiency, a few more advantages of shorter inlet and outlet tubing are found in reducing the risk of embolisms forming, reducing the priming volume, and reducing the temperature loss to the blood while out of the body⁹. Other requirements may necessitate the use of longer tubing, for which the pCAS using 60 cm tubing has also been proven successful in restoring acceptable hemodynamics. The reduced tubing is not a necessity for successful use of the pCAS, but if the situation enables for shorter tubing then it should be used.

V. SUMMARY AND CONCLUSIONS

Results have been presented for each ventricular assist scenario: left ventricular assist with left heart failure, cardiopulmonary support with normal heart conditions, cardiopulmonary support with right heart failure, and veno-venous ECMO with normal heart conditions. Left ventricular assist has been evaluated both in vitro and in vivo, while the other scenarios have been evaluated only in vitro. The pCAS was characterized in continuous and pulsatile mode for each condition.

The mock circulation system was able to accurately simulate left ventricular failure by reducing the left driveline pressure to weaken the ventricle and adding volume to the left atrium to mimic the volume retention of heart failure. The goal of left ventricular assist with the pCAS is to reduce the left ventricular preload and increase flow throughout the body. This would provide an opportunity for the heart to recover from its failing state by reducing the required work and ventricular distension. The pCAS was to be able to provide 100 ml/min/kg in this condition, which is 1 L/min for the MCS which mimics the heart and vasculature of a 10 kg child.

The pCAS in continuous mode provided 0.99 L/min flow at 1600 RPM. The pCAS in 100 bpm pulsatile mode provided 0.97 L/min flow at 4.00 Vpk and the pCAS in 140 bpm pulsatile mode provided 1.03 L/min flow at 3.90 Vpk. The pCAS met the requirement of providing adequate flow to the body while restoring acceptable hemodynamics. In both continuous and pulsatile modes, the pCAS was able to decrease the preload on the heart by reducing the left atrial pressure.

Three acute animal studies were completed successfully according to the protocol presented in Appendix II. For all three of the piglet test subjects, the pCAS was able to

provide an adequate amount of flow and restore acceptable hemodynamics. Pig 022 was the only test subject not to meet the requirement of 100 ml/min/kg for all conditions, but acceptable hemodynamics were still restored in this case. For each subject, the filling pressures were brought down to ease the preload on the failing left heart.

Pig 025 was the only animal test subject where the pCAS inlet and outlet pressures were taken. The pCAS flow increased at approximately a linear rate as a function of ΔP across the pump. The effects of hemodynamics on pCAS performance were seen, as the aortic pressure increased 20-30 mmHg during the 100 bpm pCAS experiment and the 140 bpm pCAS experiment. This high AoP increased the resistance against the pump and had an impact on the outlet pressure, making the pCAS work harder to provide the same flow rate. The pCAS needed to be versatile enough to adjust for varying hemodynamics, which it was able to do and still provide 127 ml/min/kg flow.

Cardiopulmonary assist during normal heart conditions was successfully performed on the mock circulation system. The primary goal of CPS during normal heart conditions is to provide oxygenation and remove carbon dioxide in the blood because of respiratory failure. The pCAS in this situation must be able to pump enough test fluid to assist or completely bypass the lungs while maintaining appropriate hemodynamics.

The maximum flow rates provided by the pCAS for CPS with normal heart conditions were 0.61 L/min at 2000 RPM in continuous mode, 0.43 L/min L/min at 4.40 Vpk in 100 bpm pulsatile mode, and 0.44 L/min at 4.25 Vpk in 140 bpm pulsatile mode. These values fall short of the 100 ml/min/kg requirement for total CPS for a 10 kg patient but may be sufficient for a patient requiring only respiratory support. The flow values were limited by high aortic pressure and low peak negative inlet pressure which led to the

introduction of air bubbles possibly through connector leaks. In a clinical experiment the aortic pressure could have been reduced by vasodilatory drugs, allowing the pCAS to pump additional flow. This regulating of the systemic vascular resistance was not simulated during this set of experiments using the mock circulation system.

The low peak negative inlet pressure was caused primarily by the 8 Fr inflow cannula. This cannula was used to represent the potentially smallest cannula to be used in CPS, and it gave a good indication of the risks and limitations associated with varying cannula sizes. The pulsatile experiments exhibited a much more negative peak negative inlet pressure, reaching well below -200 mmHg while providing only 0.30 to 0.40 L/min flow. The peak negative inlet pressure for the pCAS in continuous mode reached as low as -116 mmHg at 0.61 L/min, but it never reached the levels measured from the pulsatile experiments. Along with increasing the size of the inlet cannula, another option to lessen this risk of low negative inlet pressure is to reduce the size of the outlet cannula. This would increase the outlet pressure by creating more resistance, and in turn would raise the inlet pressure. Because of the risk of excessive hemolysis and the entrainment of air in the system, negative inlet pressure must be monitored closely and eliminated.

Cardiopulmonary assist during right ventricular failure was also successfully performed on the MCS. The mock circulation system was able to accurately simulate right ventricular failure by partially clamping the right driveline pressure to weaken the ventricle and adding volume to the right atrium to mimic the volume retention of heart failure. The goal of CPS during right ventricular failure is to reduce the right ventricular preload and increase the flow through the body. The lungs are bypassed in this assist condition, which means the pCAS is also responsible for oxygenating and removing

carbon dioxide from the blood. In the case of additional respiratory failure, the pCAS must provide an adequate amount of oxygenated blood throughout the body while restoring acceptable hemodynamics. Because of the right driveline pressure being insufficiently regulated, the experiment with the pCAS in 100 bpm pulsatile mode was excluded from evaluation. The pCAS in 140 bpm pulsatile mode was sufficient to evaluate the pump in pulsatile mode for CPS with right ventricular failure.

The pCAS providing CPS during right ventricular failure faced the same problems as the pCAS providing CPS during normal heart conditions. The maximum flow rates provided by the pCAS for CPS with RVF were 0.69 L/min at 2000 RPM in continuous mode and 0.50 L/min at 4.10 V_{pk} in 140 bpm pulsatile mode. These values fall short of the 100 ml/min/kg requirement for total CPS for a 10 kg patient. Again, this was due to the high aortic pressure caused by the lack of regulated systemic vasculature resistance and excessive negative inlet pressures caused by the small inflow cannula and large return cannula. The entrainment of air bubbles did occur in both the continuous and pulsatile experiments. The excessive peak negative inlet pressure of the pCAS in pulsatile mode caused the air to be introduced at lower flows than with the pCAS in continuous mode.

The pCAS was successfully reducing the preload on the right ventricle as its flow was increasing. At 0.69 L/min flow with the pCAS in continuous mode, the RAP had been reduced from 19 mmHg to 12 mmHg. This is not yet reached the RAP of 7 mmHg measured at normal heart conditions, but by enabling more flow (by decreasing the AoP and increasing the inlet pressure) the pCAS can be expected to continue its trend of RAP reduction until normal values are achieved.

Veno-venous ECMO was successfully performed on the mock circulation system during normal heart conditions. The primary goal of VV ECMO is to provide oxygenation and carbon dioxide removal in the blood because of respiratory failure. To do this successfully, the pCAS must be able to provide enough flow to adequately pump oxygenated blood throughout the body. Because the fluid is both drawn and returned to the right atrium, the pCAS will have little effect on the hemodynamics of the heart. A 14 Fr double lumen cannula was used for these experiments.

The pCAS in continuous mode was able to pump 0.97 L/min flow at 3900 RPM. This is an adequate amount of flow based on the 100 ml/min/kg requirement. Pulsatile assist is not generally used in VV ECMO because of the return cannula going to the right atrium, but the pCAS in pulsatile mode was evaluated to further characterize the pump. Because of controller limitations, the pCAS in pulsatile mode was not able to be increased above a peak voltage of 5V. At this peak voltage, the pCAS produced 0.50 L/min flow.

Because of the resistance of the double lumen cannula, the outlet pressure of the pCAS was very high. In continuous mode, the mean outlet pressure rose above 400 mmHg at a flow of 0.72 mmHg and 3000 RPM. Though this high outflow resistance helped keep the inlet pressure up, the negative inlet pressure would need to be monitored as it reached mean values of -29 mmHg at 3900 RPM.

In efforts to better understand the effects of connection tubing length on the pumping ability of the pCAS, an additional LVA experiment was performed with 20 cm connection tubing between the inflow and return cannulae and pCAS. In all the previous MCS and acute animal experiments 60 cm connection tubing was used.

As expected, the efficiency of the pump was increased by reducing the length of the tubing. With the 20 cm tubing, the pCAS was able to provide 0.99 L/min at 1400 RPM. With the 60 cm tubing, the pCAS needed 1600 RPM to provide the same flow of 0.99 L/min. This increase in efficiency is due to the loss of inflow and outflow resistance because of the reduction in tubing length. As indicated by the calculated Reynolds numbers, the fluid being pumped through the tubing experienced both laminar and transitional flow. As described by Poiseuille's equation, the laminar flow through the tubing with reduced length was greater at the same ΔP value. During transitional flow, an even more pronounced increase in flow was seen for the same ΔP values. These effects caused by the reduction in tubing enables the pCAS to be able to pump the same amount of flow at a lesser inlet/outlet ΔP , making more efficient use of the pump. Because of the increase in pumping efficiency, the connection tubing is desired to be kept at a minimum. Other requirements may necessitate the use of longer tubing, however, for which the pCAS using 60 cm tubing has also been proven successful in restoring acceptable hemodynamics. The reduced tubing is not essential for successful use of the pCAS, but if the situation permits the use of shorter tubing then it should be used.

VI. RECOMMENDATIONS

The pCAS evaluated in this research is an early developmental version of the device which has a 3 inch diameter pump. Ideally for neonates and infants, the pump can be reduced to a 2 inch diameter. Further developments are to be made for the pCAS in the following years of the program headed by Ension Inc. Evaluations on the pump in this developmental stage will help determine what next steps in the evolution of the pCAS are necessary. The support and development process is essential to examine what works well and what does not work well with the current system.

Many comparisons were drawn in this research regarding the ability of the pCAS to pump in continuous versus pulsatile modes. The versatility of providing either continuous or pulsatile assist with the pCAS was added because of debate among surgeons, clinicians, and researchers today about which mode provides the most affective VAD support for end-organ perfusion and preventing elevating vascular resistance.^{5,7,9,10,22} Clinical benefits of pulsatility have been reported for adults, but long-term implications are still debated. Among neonates and infants, the author has found no definitive studies that have been completed on this subject.

Those in favor of pulsatile assist cite the fact that it more accurately mimics the normal function of the heart to the organs and vasculature. The first concern in using nonpulsatile assist for ventricular unloading is that the normal ventricular mechanical properties will be altered. The lack of pulsatility would cause an increase in myocardial elastance (stiffer heart) that may lead to reduced myocardial perfusion.^{10,22,23} An additional concern is that continuous VAD flow will alter the vascular mechanical properties. The lack of normal pulsatility provided by a healthy heart would lead to an

increase in vascular resistance and elastance (stiffer vasculature) that may increase pulse wave propagation, increase the ventricular workload during ejection, and reduce myocardial perfusion during relaxation.^{10,22,23} These ventricular and vasculature effects may be progressive in cardiac support requiring a long duration, leading some to argue that pulsatile assist is more effective for situations where a long duration of VAD support is necessary.⁷ Some pediatric ventricular assist devices providing pulsatile flow that have yet to gain approval for clinical use in the United States are the Thoratec VAD System^{5,7} (Thoratec Corp., Pleasanton, CA), the Berlin Heart EXCOR Pediatric VAD^{2,7} (Berlin Heart AG, Berlin, Germany), the Penn State PVAD^{1,5} (Penn State University, University Park, PA), and the MEDOS VAD^{5,7} (MEDOS Medizintechnik AG, Stolberg, Germany).

Nonpulsatile assist produces flat continuous flow in which there is little or no pulse pressure, with any residual pulsations due to the contraction of the natural heart. Traditionally, centrifugal pumps (non-occlusive pumps) have fallen under this category. Those favoring continuous flow consider maintaining adequate mean pressures and flows more important than pulsatility.¹⁰ Pulsatile pumps if not properly controlled also produce excessive peak negative pressures which could prove dangerous. While some aspects of pulsatile flow may act to improve gas transfer, pulsatile flow in gas-exchange circuits is not currently as widely used as continuous flow. The lack of a pulsatility option also makes the pump controller simpler and reduces software needs of the pCAS.

The pCAS, as a centrifugal pump with no valves, is prone to negative inlet pressures because of the nature of the pump.¹⁷⁻¹⁸ As seen in this research, operating in pulsatile flow mode consistently causes much lower peak negative pressures. While dependent on the cannula size selected, length of connection tubing, and hemodynamic

parameters, the inlet pressure for the pCAS in pulsatile mode always reached more excessive negative values than the pCAS in continuous mode. This presents the danger of causing substantial blood traumatization and hemolysis or the introduction of air into the system.¹⁸

Gas exchange in blood during ECMO is generally done in the presence of nonpulsatile flow created by a roller or centrifugal pump.¹⁸ The ability to provide blood pumping and gas exchange in the same device is the novel idea of the pCAS and is the key to a successful device. As oxygenation and carbon dioxide removal have already been proven and well established with the use of nonpulsatile flow, this would be the logical choice for the pCAS. However, some aspects of pulsatile flow may actually act to improve gas transport.

The pCAS in continuous mode has advantages over pulsatile mode in its ability to maintain mean pressures and flows, higher inlet pressures (especially peak negative inlet pressures), more established gas exchange capabilities, and reduced complexity of the pump controller and software. Because of these reasons, it is recommended from this research that the next developmental stage of the pCAS remove the pulsatility option and focus only on continuous assist.

The experimental procedure is also evaluated for improvements. As discussed for the results of the cardiopulmonary support experiments, the pCAS was not able to provide the required 100 ml/min/kg flow. The reasons for this were because of the high aortic pressure in the mock circulation system and the excessive negative pCAS inlet pressure.

The mean aortic pressure for CPS during normal heart conditions reached as high as 112 mmHg with the pCAS providing only 0.61 L/min flow. For CPS with right ventricular failure, the mean AoP reached 101 mmHg at 0.69 L/min pCAS flow. In clinical use of VADs where the aortic pressure is this high, a vasodilatory drug is given to the patient. This drug causes the vasculature to relax and decrease in elastance, which decreases the systemic vascular resistance and brings down the aortic pressure. A recommended next step to the experimental procedure is to either manually adjust the systemic vascular resistance valve on the MCS to maintain a more consistent AoP or include an automatic servo-regulated systemic vascular resistance valve. This addition would most accurately simulate a clinical procedure and would benefit pCAS evaluation in all conditions.

The excessive negative inlet pressures during the CPS experiments were primarily caused by the size of the inlet and outlet cannulae. The small 8 Fr cannula used for the inflow brought a high resistance to fluid flow to the inlet of the pCAS. The large 20 Fr outflow cannula added to this effect by reducing the resistance on the return path of the fluid. Additional steps can be taken in clinical use of the pCAS to prevent dangerous levels of negative inlet pressure. The inlet pressure can be regulated by having a feedback loop from the measured pump inlet pressure to the controller.¹⁸ However, the maximum pump flow could be limited by this method.

Various cannulae sizes are necessary given the experimental circumstances. The size of the patient, type of assist, cannulation site on the body, and individual vasculature determine what cannula is necessary. It is recommended that further evaluation be performed on the pCAS performing the potential assist conditions with varying inflow

and return cannulae sizes. A systematic approach can be taken to determine optimal cannulae sizes, as well as what cannulae sizes increase risk to a patient.

Before advancing to the 2 inch model of the pCAS, some further efforts should be made to evaluate the pCAS in long durations of use and in providing gas exchange. Effects on blood characteristics can be evaluated by both in vitro and in vivo techniques. Chronic animal studies will be valuable for this analysis. Because of the novelty of a pump-oxygenator combination as proposed by the pCAS, it is recommended to evaluate the gas exchange of the pCAS before proceeding further in development of the pump itself. Depending on results, changes may need to be made to the membrane which is active both in gas exchange and pumping performance. Any changes in this membrane or the coating that covers it may affect the pumping ability of the pCAS. By narrowing the chances of changing internal components of the pCAS by more thoroughly investigating these issues, additional characterization of the pumping ability of the pCAS will be for a system closer to the desired final design.

This developmental version of the 3 inch pCAS has proved to be capable of providing adequate flow and restoring acceptable hemodynamics in the presence of right or left heart failure. The pumping ability of the pCAS at its current state has been evaluated thoroughly in this research and is acceptable. This research will guide further evolution of the pCAS design to create a revolutionary system to help save the lives of infants and small children.

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APPENDIX I. pCAS In Vitro Test Protocol

Title: Ension 3" pCAS Performance Study in Pediatric Mock Circulation System

Experiment number:

Test Date:

Initiator:

Investigators:

George M. Pantalos, Ph.D., UofL

Jeff Colyer, B.S., UofL

Greg Johnson, Ph.D., Ension

Chris Lucci, M.S., Ension

Jeff Speakman, Ension

Test Facility:

Cardiovascular Innovation Institute

University of Louisville

Sponsor:

Ension, Inc.

240 William Pitt Way Suite 121

Pittsburgh, PA 15238

(412) 828-5209

Statement of Study and Purpose:

The purpose of this experiment is to evaluate the performance of the pediatric Cardiopulmonary Assist System (pCAS) in a pediatric mock circulation system. The experiment will simulate different heart conditions and monitor the performance of the pump in both continuous and pulsatile assist modes for each case. These simulations will be left ventricular assist (LVA) with left ventricular failure, cardiopulmonary support (CPS) with normal heart conditions, CPS with right ventricular failure, and Veno-Venous Extracorporeal Membrane Oxygenation (VV ECMO). Hemodynamic data will be recorded and evaluated to measure the pumping performance of the pCAS.

Test Equipment:

UofL Pediatric Mock Circulation

Utah Heart Driver

Transonic Systems Flow Meters x3

UofL Data Acquisition System with Ectron pressure pre-amps

Ension 3" pCAS pump and controller

Test Fluid:

Distilled Water

Test Measurements:

Aortic Pressure (AoP) – Millar 5 Fr pressure catheter

Left Atrial Pressure (LAP) – Millar 5 Fr pressure catheter
 Right Atrial Pressure (RAP) – Millar 5 Fr pressure catheter
 Pulmonary Artery Pressure (PAP) – Millar 5 Fr pressure catheter
 pCAS Inlet Pressure (IN) – Millar 5 Fr pressure catheter
 pCAS Outlet Pressure (OUT) – Millar 5 Fr pressure catheter
 Aortic Flow (AoF) – Transonics inline flow probe (12N)
 Pulmonary Artery Flow (PAF) – Transonics inline flow probe (12N)
 Coronary Artery Flow (CAF) – Transonics inline flow probe (6N)
 Carotid Artery Flow (CdAF) – Transonics inline flow probe (6N)
 VAD Flow (VASF) – Transonics clamp-on flow probe (7C)

Test Conditions:

Parameter	Normal	Left Heart Failure	Right Heart Failure
mean AoP	70-75 mmHg	50-55 mmHg	60-70 mmHg
aortic flow	800-1000 ml/min	600-700 ml/min	600-700 ml/min
left atrial pressure	10-12 mmHg	18-25 mmHg	8-10 mmHg
right atrial pressure	8-10 mmHg	10-12 mmHg	18-20 mmHg
Pulmonary art. Pres.	18-22 mmHg	22-27 mmHg	15-19 mmHg
Coronary Flow	45-55 ml/min	35-40 ml/min	30-35 ml/min
Carotid Flow	90-110 ml/min	70-80 ml/min	80-90 ml/min
Left Driveline Pres.	120-130 mmHg	70-75 ml/min	120-130 ml/min
Right Driveline Pres.	40-45 ml/min	40-45 ml/min	40-45 ml/min (clamped)

*systolic/diastolic ratio = 50% for all test conditions

Experimental Protocol:

I. Pre-calibrate all pressure catheters and flow probes. All pressure catheters are calibrated simultaneously in a sealed fluid-filled volume chamber against a known pressure standard (Meriam Instruments, Cleveland, OH). Timed volume calibration curves and/or electronic calibration signals are used for the flow probe calibration.

II. After transducer preparation, hemodynamic waveforms will be monitored for signal quality and signal conditioning and adjusted to maximize analog-to-digital (A/D) resolution.

III. *Simulation of left ventricular assist (LVA).* Connect the pCAS pump inlet to the left atrium via a 20 Fr pediatric uptake cannula and connect the pump outlet to a return cannula in the ascending aorta.

1. Tune mock ventricle and circulation to simulate normal ventricular state
 - a. Set ventricular rate to 120 bpm
 - b. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
2. Tune mock ventricle and circulation to simulate left heart failure.
 - a. Reduce the driveline pressure to the left ventricle to simulate a weak ventricle
 - b. Add volume to the venous pool to increase left atrial pressure.

- c. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
3. *Continuous LVA*. Ensure operation of pCAS is in continuous mode.
 - a. With pCAS 'OFF', unclamp tubing, allow mock system to achieve steady state, and record hemodynamic waveforms (30 sec file)
 - b. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - c. Incrementally increase the pCAS speed until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
 - d. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.
3. *Pulsatile LVA*. Change operation of pCAS to pulsatile mode.
 - a. Unclamp tubing and turn 'ON' pulsatile pCAS until zero flow is achieved. Allow mock system to achieve steady state and record voltage and hemodynamic waveforms (30 sec file)
 - b. Incrementally increase the pCAS peak voltage until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record voltage and hemodynamic waveforms (30 sec file)
 - c. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.

V. *Simulation Cardiopulmonary Support (CPS) with normal ventricular conditions.*

Connect the pCAS pump inlet to the right atrium via an 8 Fr Medtronic Biomedicus ECMO pediatric uptake cannula and the pump outlet to a return cannula in the ascending aorta.

1. Tune mock ventricle and circulation to simulate normal ventricular state
 - a. Set ventricular rate to 120 bpm
 - b. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
2. *Continuous CPS with normal ventricular conditions*. Ensure operation of pCAS is in continuous mode.
 - a. With pCAS 'OFF', unclamp tubing, allow mock system to achieve steady state, and record hemodynamic waveforms (30 sec file)
 - b. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - c. Incrementally increase the pCAS speed until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
 - d. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.

3. *Pulsatile CPS with normal ventricular conditions.* Change operation of pCAS to pulsatile mode.

- a. Unclamp tubing and turn 'ON' pulsatile pCAS until zero flow is achieved. Allow mock system to achieve steady state and record voltage and hemodynamic waveforms (30 sec file)
- b. Incrementally increase the pCAS peak voltage until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record voltage and hemodynamic waveforms (30 sec file)
- c. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.

V. *Simulation of Cardiopulmonary Support (CPS) with right ventricular failure.* Connect the pCAS pump inlet to the right atrium via an 8 Fr Medtronic Biomedicus ECMO pediatric uptake cannula and the pump outlet to a return cannula in the ascending aorta.

1. Tune mock ventricle and circulation to simulate normal ventricular state
 - a. Set ventricular rate to 120 bpm
 - b. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
2. Tune mock ventricle and circulation to simulate right heart failure.
 - a. Partially clamp the driveline pressure to the right ventricle to simulate a weak ventricle.
 - b. Add volume to the systemic pool to increase right atrial pressure.
 - c. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
3. *Continuous CPS with right ventricular failure.* Ensure operation of pCAS is in continuous mode.
 - a. With pCAS 'OFF', unclamp tubing, allow mock system to achieve steady state, and record hemodynamic waveforms (30 sec file)
 - b. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - c. Incrementally increase the pCAS speed until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
 - d. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.
4. *Pulsatile CPS with right ventricular failure.* Change operation of pCAS to pulsatile mode.
 - a. Unclamp tubing and turn 'ON' pulsatile pCAS until zero flow is achieved. Allow mock system to achieve steady state and record voltage and hemodynamic waveforms (30 sec file)
 - b. Incrementally increase the pCAS peak voltage until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record voltage and hemodynamic waveforms (30 sec file)

- c. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.

VII. *Simulation of Veno-Venous Extracorporeal Membrane Oxygenation (VV ECMO).*

Connect a double-lumen 14 Fr OriGen cannula to the right atrium. Connect the pCAS pump inlet to uptake of the cannula and the pump outlet to the return of the cannula.

1. Tune mock ventricle and circulation to simulate normal ventricular state
 - a. Set ventricular rate to 120 bpm
 - b. Allow mock system to achieve steady-state and record hemodynamic waveforms (30 sec file)
2. *Continuous VV ECMO.* Ensure operation of pCAS is in continuous mode.
 - a. With pCAS 'OFF', unclamp tubing, allow mock system to achieve steady state, and record hemodynamic waveforms (30 sec file)
 - b. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - c. Incrementally increase the pCAS speed until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
 - d. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.
3. *Pulsatile VV ECMO.* Change operation of pCAS to pulsatile mode.
 - a. Unclamp tubing and turn 'ON' pulsatile pCAS until zero flow is achieved. Allow mock system to achieve steady state and record voltage and hemodynamic waveforms (30 sec file)
 - b. Incrementally increase the pCAS peak voltage until normal ventricular state is recovered. At each increment allow mock system to achieve steady-state and record voltage and hemodynamic waveforms (30 sec file)
 - c. Reduce pump speed to cause zero flow. Verify that this pump setting is near previous zero flow setting to prove no significant external changes in mock system. Clamp tubing and turn pCAS 'OFF'.

VIII. Post-calibrate all pressure catheters and flow probes. All pressure catheters will be calibrated simultaneously in a sealed fluid-filled volume chamber against a known pressure standard (Meriam Instruments, Cleveland, OH). Timed volume calibration curves and/or electronic calibration signals will be used for the flow probe calibration.

APPENDIX II. pCAS In Vivo Test Protocol

Title: Acute 3" pCAS Performance Study in Piglets

U of L IACUC Protocol: #04009 (Expires 26 February 2007)

Experiment number: _____

Test Date: _____

Test Pump(s): _____

Initiator: George M. Pantalos, Ph.D.

Inflow Cannula: _____

Outflow Cannula: _____

Investigators:

George M. Pantalos, Ph.D., UofL

Michael Mitchell, M.D., U of L

Jeff Colyer, B.S., UofL

Greg Johnson, Ph.D., Ension

Chris Lucci, M.S., Ension

Jeff Speakman, Ension

Test Facility:

Cardiovascular Innovation Institute

University of Louisville

Sponsor:

Ension, Inc.

240 William Pitt Way Suite 121

Pittsburgh, PA 15238

(412) 828-5209

Statement of Study and Purpose:

The purpose of this experiment is to evaluate the performance of the pediatric Cardiopulmonary Assist System (pCAS) in a live heart. The experiment will simulate different heart conditions and monitor the performance of the pump in each case. These simulations will be left ventricular failure with continuous VAD support and left ventricular failure with pulsatile VAD support. Hemodynamic data will be recorded and evaluated to measure the effectiveness of the pCAS. Specifically for this test:

1. Document the pCAS pumping performance in continuous mode of operation for left ventricular assist.
2. Document the pCAS pumping performance in pulsatile mode of operation (@ 100 & 140 bpm) for left ventricular assist.
3. Document the level of hemolysis associated with pCAS operation as represented by plasma-free hemoglobin.
4. Document the viscosity of the blood at different stages of the experiment
5. Compare pumping performance results of May 12, June 21, and August 4, 2005

6. Determine pressure drops across the cannulae and the pCAS pump

Test Equipment:

Transonic Systems Flow Meters x3
UofL Data Acquisition System with Ectron pressure pre-amps
Ension 3" pCAS pump and controller

Test Measurements:

Left Atrial Pressure (LAP) – Millar 2.5 Fr pressure catheter
Left Ventricular Pressure (LVP) – Millar 5 Fr double tip pressure catheter
Aortic Pressure (AoP) – Millar 5 Fr double tip pressure catheter
Central Venous Pressure (CVP) – fluid-filled catheter (optional)
Pulmonary Artery Pressure (PAP) – Millar 2.5 Fr pressure catheter
pCAS Inlet Pressure (IN) – Millar 2.5 Fr pressure catheter
pCAS Outlet Pressure (OUT) – Millar 2.5 Fr pressure catheter
Aortic Flow (AoF) – Transonics perivascular flow probe (10A or 12A)
Pulmonary Artery Flow (PAF) – Transonics perivascular flow probe (10A or 12A)
Coronary Artery Flow (CAF) – Transonics perivascular flow probe (2.5A, optional)
Carotid Artery Flow (CdAF) – Transonics inline flow probe (2.5A)
VAD Flow (VASF) – Transonics clamp-on flow probe (7C)

Preinduction/Induction/Preparation:

A 10-13 kg piglet will be fasted 12+ hours, anesthetized IM (30 mg/kg ketamine, 0.2 mg/kg acepromazine and pentathol), shaved and intubated by RRC personnel. The piglet is brought up to acute OR on a covered gurney and transferred to the OR table dorsal recumbant on a heating pad. The piglet is connected to the isoflurane small animal ventilator using a pediatric ventilator hose, and anesthesia is initiated at 1.5-3% Iso, 80-100 mm Hg PO₂, PCO₂ ~35 mm Hg and maintained as needed. A lubricated grounding pad is placed under the piglet's back and a rectal thermometer is inserted to monitor temperature. Overhead warming lights are lit as needed to provide heat. The pulse oximeter clip is placed on the piglet's lip or foot for oxygen sats and heart rate monitoring. 3 ECG Leads are connected to the appropriate limbs, data going to the UofL DAQ. The piglet's legs are secured to the table using rope tiedowns. Surgical hemostasis is provided using electrocautery and ligation of arteries.

Surgical Experimental Protocol:

I. All pressure catheters will be calibrated and verified before the experiment begins.

II. Surgery proceeds as follows:

1. Right Radial Artery - 24 gauge catheter (Peripheral Artery Pressure, for IABP experiments only)
2. Right Common Carotid Artery - PE Tubing (ABG's and arterial pressure), draw blood for initial blood gas, ACT, and plasma free Hb (green cap, Lithium Heparin), and viscosity (purple cap, EDTA)
3. Right Internal Jugular Vein - PE Tubing (CVP and ACT's)
4. Left Common Carotid Artery - 2.5 mm Flow Probe (Arterial Flow)

5. Right Femoral Artery - Extra length PE Tubing (ref. blood sample w/ pump, optional per microspheres)
6. Right Femoral Vein - Triple Lumen Catheter (for fluid and drug administration (LR or normal saline, prednisone and lidocaine)

III. After the neck and leg catheterizations have been completed and secured the animal is repositioned in right lateral recumbency so a left lateral thoracotomy is performed with the removal of the chest wall, approx. 2nd-5th ribs if necessary. Isolate hemiozygous vein for catheterization to coronary sinus. Open pericardium and retract with sutures. Isolate ascending aorta and PA.

1. Ascending Aorta- Flow probe (Transonics perivascular flow probe 10A or 12A)
3 or 5 Fr double tip Millar (AOP/LVP) or inserter retrograde via left ventricular apex.
2. Pulmonary Artery- Flow probe (Transonics perivascular flow probe 10A or 12A)
PE tubing (blood gases)
2.5 Fr single Tip Millar (PAP)
3 Fr double tip Millar (PAP/RVP) (Optional)
3. Left Atrium- Purse string for retraction and cannula prep.
PE Tubing (microsphere injection, optional)
2.5 Fr single tip Millar (LAP)
4. LAD Coronary Artery- Flow probe (Transonics perivascular flow probe 2.5A)
5. Isolate descending aorta and prepare purse string suture for LVAD return cannula.
6. Intra Myocardial Pressure (Left Ventricle)- Single tip 2 - 2.5 Fr Millar (IMP), optional.
7. Baseline ACT before heparinization.
8. Coronary Sinus- Wire Reinforced Cannula with Side Port.
9. Cannulate for pCAS.
 - a. Ascending Aorta – VAD return cannula, Research Medical 14 or 16 Fr
 - b. Left atrium – VAD uptake cannula, Research Medical 20 Fr
10. Heparinize the animal- 300 units/kg. Re-dose 1/3 amount q/45 minutes.
11. Prepare the pCAS pumping circuit by (a) incorporating connectors with pressure taps for pCAS inlet and outlet pressure measurement, (b) purge circuit with CO₂ at 1 l/min for 3 minutes, (c) prime and de-air circuit with Normosol-R, (d) replace the Normosol with whole blood and de-air (check pH and K⁺)

IV. After the instrumentation of the animal has been completed and the VAD cannulae inserted, give blood or fluids if necessary to increase CVP to 6-8 mm Hg.

1. Take base line recordings - hemodynamic, ACT, Blood gas from Aorta, PA, Coronary Sinus, inject microspheres, optional. Draw blood for baseline plasma free Hb (green cap) and viscosity (purple cap)
2. Perform baseline ACT - target ACT >300 secs and give Breviblock bolus(5 mg/kg), start IV infusion (.05 mg/kg) Breviblock.

3. Induce Left Ventricular Failure using sequential coronary artery pledgeted ligation (cardiac output drops by 25-35%, LAP elevated to 13-15 mm Hg.) Wait 10 minutes between ligations.
4. Prime pCAS first with saline, then blood.
5. Record pre-cannulation baseline.
6. Take blood sample and inject into 'Green Top' container for subsequent measurement of plasma-free hemoglobin (PFHb).
7. Connect pCAS.

V. pCAS Measurements

1. Record post-cannulation baseline
2. Perform continuous left ventricular assist (cLVA).
 - a. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - b. Incrementally increase the pCAS speed by 100 RPM until normal ventricular state is recovered. At each increment allow system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
 - c. Take blood sample for PFHb determination.
3. Perform pulsatile left ventricular assist (pLVA).
 - a. Turn 'ON' continuous pCAS until zero flow is achieved and record RPM and hemodynamic waveforms (30 sec file)
 - b. Incrementally increase the pCAS peak voltage by 0.05 Volts until normal ventricular state is recovered. At each increment allow system to achieve steady-state and record RPM and hemodynamic waveforms (30 sec file)
4. Repeat experiment if animal condition allows.
5. With pCAS 'OFF', unclamp tubing, allow system to achieve steady state, and record hemodynamic waveforms (30 sec file)

V. Final procedures.

1. Sacrifice animal w/ a 20-40 mEq bolus of KCL as needed for euthanasia
2. Collect tissue samples for microsphere flow assay (optional), post-cal pressure sensors and flow probes
3. Dispose of animal carcass (double bagged) in RRC, return gurney to hallway of RRC
4. Clean OR and equipment, prepare tissue samples for microsphere assay

Time of Experiment Termination: _____

Reason for Experiment Termination:

Experiment Notes:

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV HR (bpm)	LV SV (ml)	LV CO (L/min)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)
005	PCAS_03_005_060212_2045.w_00	-	Normal	-	-	-	120	6.6	0.80	71.3	50.6	104.1	53.5	7655	45.9	-32.0	13.0	0.76	6.28	5.53	-0.75
005	PCAS_03_005_060212_2049.w_00	-	LVF	-	-	-	120	5.5	0.66	54.3	27.7	68.3	40.6	8961	62.8	-2.5	22.7	0.63	2.45	2.15	-0.29
005	PCAS_03_005_060212_2051.w_00	-	LVF	CF	0	-	120	7.6	0.91	40.0	50.9	66.5	15.6	3985	61.3	2.9	29.8	0.82	4.45	3.93	-0.52
005	PCAS_03_005_060212_2105.w_00	LVA	LVF	CF	811	-	120	5.9	0.70	53.3	31.0	70.0	39.0	6972	63.9	-2.7	21.4	0.62	2.52	2.29	-0.23
005	PCAS_03_005_060212_2106.w_01	LVA	LVF	CF	900	-	120	4.5	0.54	54.9	25.9	69.5	43.6	9091	61.0	-3.8	18.8	0.50	2.18	1.95	-0.23
005	PCAS_03_005_060212_2107.w_01	LVA	LVF	CF	1000	-	120	2.5	0.30	56.0	17.0	65.8	48.8	16046	54.5	-2.3	17.1	0.29	1.47	1.33	-0.14
005	PCAS_03_005_060212_2108.w_01	LVA	LVF	CF	1100	-	120	1.6	0.19	59.0	10.6	64.5	53.9	25453	53.6	-4.3	14.8	0.19	0.96	0.89	-0.07
005	PCAS_03_005_060212_2110.w_01	LVA	LVF	CF	1200	-	120	1.0	0.12	63.2	9.9	69.5	59.6	42409	55.0	-4.3	12.8	0.12	0.64	0.52	-0.12
005	PCAS_03_005_060212_2111.w_01	LVA	LVF	CF	1300	-	120	0.5	0.06	67.9	8.8	74.4	65.5	80604	55.5	-8.7	10.1	0.07	0.4	0.2	-0.1
005	PCAS_03_005_060212_2112.w_01	LVA	LVF	CF	1400	-	120	0.0	0.00	71.7	6.8	76.7	69.9	488490	49.3	-9.7	5.4	-0.04	0.2	0.0	-0.2
005	PCAS_03_005_060212_2113.w_01	LVA	LVF	CF	1500	-	120	0.0	0.00	80.4	5.9	84.9	78.9	390450	46.9	-9.9	3.9	-0.03	0.2	0.0	-0.2
005	PCAS_03_005_060212_2114.w_01	LVA	LVF	CF	1600	-	120	0.1	0.01	90.6	5.6	94.9	89.3	224120	43.3	-10.5	2.7	-0.03	0.2	0.0	-0.2
005	PCAS_03_005_060212_2121.w_01	LVA	LVF	PF	100	3.03/0.1	120	6.0	0.72	52.6	31.1	69.1	36.1	6829	64.7	-1.5	21.1	0.63	2.5	2.3	-0.2
005	PCAS_03_005_060212_2123.w_01	LVA	LVF	PF	100	3.10/0.1	120	5.1	0.61	54.0	26.2	68.1	41.9	8031	62.8	-2.6	19.3	0.55	2.3	2.1	-0.2
005	PCAS_03_005_060212_2124.w_02	LVA	LVF	PF	100	3.20/0.1	120	2.9	0.35	54.7	17.8	64.2	48.4	13308	57.4	-1.9	17.2	0.34	1.6	1.5	-0.1
005	PCAS_03_005_060212_2125.w_02	LVA	LVF	PF	100	3.30/0.1	120	1.8	0.21	56.9	14.8	64.6	49.9	22459	55.0	-2.1	15.1	0.21	1.2	1.1	-0.1
005	PCAS_03_005_060212_2126.w_02	LVA	LVF	PF	100	3.40/0.1	120	1.2	0.15	59.4	14.8	67.6	52.8	34479	52.6	-5.6	12.4	0.15	0.8	0.7	-0.1
005	PCAS_03_005_060212_2127.w_02	LVA	LVF	PF	100	3.50/0.1	120	1.0	0.11	61.4	15.9	70.4	54.5	50264	51.9	-6.0	10.8	0.11	0.7	0.5	-0.2
005	PCAS_03_005_060212_2128.w_02	LVA	LVF	PF	100	3.60/0.1	120	0.7	0.08	66.7	16.0	76.2	60.2	204000	49.1	-4.9	9.3	0.08	0.6	0.4	-0.2
005	PCAS_03_005_060212_2129.w_02	LVA	LVF	PF	100	3.70/0.1	120	0.4	0.04	71.6	16.4	81.2	64.7	25310	48.3	-8.1	8.2	0.04	0.5	0.2	-0.2
005	PCAS_03_005_060212_2130.w_02	LVA	LVF	PF	100	3.80/0.1	120	0.2	0.03	77.4	16.0	86.8	70.8	-161890	43.9	-9.5	7.2	0.00	0.4	0.2	-0.2
005	PCAS_03_005_060212_2132.w_02	LVA	LVF	PF	100	3.90/0.1	120	0.2	0.02	83.3	15.6	92.6	77.1	-46240	40.5	-2.6	6.6	-0.01	0.3	0.1	-0.2
005	PCAS_03_005_060212_2133.w_02	LVA	LVF	PF	100	4.00/0.1	120	0.2	0.03	89.3	14.9	98.4	83.5	3671	37.4	-4.0	5.8	-0.01	0.3	0.1	-0.2
005	PCAS_03_005_060212_2142.w_03	LVA	LVF	PF	140	2.99/0.1	120	5.6	0.68	52.1	32.9	70.0	37.1	7116	64.1	-2.3	21.1	0.60	2.7	2.3	-0.3
005	PCAS_03_005_060212_2144.w_03	LVA	LVF	PF	140	3.10/0.1	120	4.5	0.54	55.5	23.9	68.9	44.9	10342	60.3	-3.3	17.9	0.45	1.9	1.8	-0.2
005	PCAS_03_005_060212_2145.w_03	LVA	LVF	PF	140	3.20/0.1	120	2.1	0.26	56.6	14.6	64.7	50.1	18946	55.0	-2.4	16.0	0.24	1.3	1.2	-0.1
005	PCAS_03_005_060212_2146.w_03	LVA	LVF	PF	140	3.30/0.1	120	1.3	0.15	59.7	10.3	65.3	55.0	31811	54.0	-4.3	13.5	0.16	0.8	0.7	-0.1
005	PCAS_03_005_060212_2147.w_03	LVA	LVF	PF	140	3.40/0.1	120	0.7	0.08	63.0	10.5	69.1	58.7	75472	52.8	-5.2	10.4	0.08	0.5	0.4	-0.1
005	PCAS_03_005_060212_2148.w_03	LVA	LVF	PF	140	3.50/0.1	120	0.3	0.04	67.6	10.1	73.6	63.4	189500	50.3	-10.1	8.0	0.04	0.3	0.2	-0.1
005	PCAS_03_005_060212_2149.w_03	LVA	LVF	PF	140	3.60/0.1	120	0.1	0.01	73.6	9.2	79.0	69.8	53488	47.0	-11.3	6.2	-0.03	0.2	0.1	-0.2
005	PCAS_03_005_060212_2151.w_03	LVA	LVF	PF	140	3.70/0.1	120	0.0	0.01	81.0	9.3	86.5	77.2	63427	43.7	-13.0	4.6	-0.04	0.2	0.0	-0.2
005	PCAS_03_005_060212_2151.w_03	LVA	LVF	PF	140	3.80/0.1	120	0.0	0.00	88.5	8.7	93.7	85.0	1521400	40.4	-14.4	3.5	-0.05	0.2	0.0	-0.2
005	PCAS_03_005_060212_2152.w_03	LVA	LVF	PF	140	3.90/0.1	120	0.1	0.01	96.6	8.5	101.9	93.4	-176130	36.3	-16.0	2.1	-0.04	0.2	0.0	-0.2
005	PCAS_03_005_060212_2155.w_03	-	LVF	-	-	-	120	5.2	0.63	53.2	27.4	67.1	39.7	7313	66.8	-1.7	21.0	0.59	2.3	2.1	-0.3

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	CAF mean (mL/min)	CAF peak sys (mL/min)	CAF mean sys (mL/min)	CAF peak dias (mL/min)	CAF mean dias (mL/min)	CAF ratio	CdAF mean (mL/min)	CdAF pulse (mL/min)	CdAF peak positive (mL/min)	CdAF peak negative (mL/min)
005	PCAS_03_005_060212_2045_w_001	-	Normal	-	-	-	52.3	60.9	48.0	73.0	56.7	1.2	100.2	67.7	137.8	70.1
005	PCAS_03_005_060212_2049_w_002	-	LVF	-	-	-	39.6	43.1	36.3	61.8	43.0	1.2	81.0	19.5	90.8	71.3
005	PCAS_03_005_060212_2051_w_003	LVA	LVA	CF	0	-	25.5	42.3	24.3	54.1	26.8	1.1	58.6	49.0	79.4	30.4
005	PCAS_03_005_060212_2105_w_009	LVA	LVA	CF	811	-	38.8	40.3	36.0	46.1	41.6	1.2	79.4	20.2	89.6	68.4
005	PCAS_03_005_060212_2106_w_010	LVA	LVA	CF	900	-	39.8	42.2	36.0	58.6	43.7	1.2	81.3	4.0	83.4	79.5
005	PCAS_03_005_060212_2107_w_011	LVA	LVA	CF	1000	-	41.7	44.1	38.6	58.7	44.8	1.2	82.8	3.9	84.9	81.0
005	PCAS_03_005_060212_2108_w_012	LVA	LVA	CF	1100	-	45.4	46.7	41.8	62.2	49.1	1.2	86.4	1.9	87.5	85.6
005	PCAS_03_005_060212_2110_w_013	LVA	LVA	CF	1200	-	48.5	49.5	45.2	63.9	51.7	1.1	91.0	0.6	91.3	90.7
005	PCAS_03_005_060212_2111_w_014	LVA	LVA	CF	1300	-	51.4	66.5	52.9	57.5	50.0	0.9	95.7	0.5	95.9	95.5
005	PCAS_03_005_060212_2112_w_015	LVA	LVA	CF	1400	-	54.6	69.4	56.1	64.9	53.2	1.0	99.0	0.4	99.2	98.8
005	PCAS_03_005_060212_2113_w_016	LVA	LVA	CF	1500	-	60.8	72.8	62.0	69.0	59.7	1.0	108.6	0.5	108.9	108.4
005	PCAS_03_005_060212_2114_w_017	LVA	LVA	CF	1600	-	67.2	80.5	68.0	77.1	66.6	1.0	117.8	0.4	118.0	117.6
005	PCAS_03_005_060212_2121_w_018	LVA	LVA	PF	100	3.03/0.1	40.0	44.0	36.2	59.4	43.9	1.2	80.1	20.4	90.2	69.8
005	PCAS_03_005_060212_2123_w_019	LVA	LVA	PF	100	3.20/0.1	41.8	45.1	38.5	59.2	45.0	1.2	80.9	8.9	85.2	76.3
005	PCAS_03_005_060212_2124_w_020	LVA	LVA	PF	100	3.30/0.1	44.0	48.8	40.8	61.0	47.3	1.2	83.7	11.6	89.2	77.7
005	PCAS_03_005_060212_2125_w_021	LVA	LVA	PF	100	3.40/0.1	45.8	49.3	42.4	61.7	49.2	1.2	86.1	14.4	92.8	78.4
005	PCAS_03_005_060212_2126_w_022	LVA	LVA	PF	100	3.50/0.1	47.4	51.1	44.0	62.7	50.7	1.2	89.3	14.9	96.1	81.2
005	PCAS_03_005_060212_2127_w_023	LVA	LVA	PF	100	3.60/0.1	51.8	56.8	48.6	65.3	54.6	1.1	94.3	11.2	99.7	88.4
005	PCAS_03_005_060212_2128_w_024	LVA	LVA	PF	100	3.70/0.1	55.4	59.1	52.3	70.4	58.4	1.1	99.7	18.6	108.7	90.1
005	PCAS_03_005_060212_2129_w_025	LVA	LVA	PF	100	3.80/0.1	57.1	61.7	54.3	70.3	59.8	1.1	108.3	17.2	116.9	99.6
005	PCAS_03_005_060212_2130_w_026	LVA	LVA	PF	100	3.90/0.1	60.7	74.5	62.3	70.7	59.1	1.0	114.5	18.6	124.3	105.7
005	PCAS_03_005_060212_2132_w_027	LVA	LVA	PF	100	4.00/0.1	64.0	75.5	64.3	73.9	63.6	1.0	116.4	15.1	124.3	109.2
005	PCAS_03_005_060212_2133_w_028	LVA	LVA	PF	140	2.99/0.1	35.3	39.3	31.8	53.1	38.8	1.2	77.8	20.5	88.0	67.6
005	PCAS_03_005_060212_2142_w_029	LVA	LVA	PF	140	3.10/0.1	38.5	41.5	35.2	55.0	41.7	1.2	82.4	6.2	85.6	79.4
005	PCAS_03_005_060212_2144_w_030	LVA	LVA	PF	140	3.20/0.1	40.3	42.2	37.5	54.9	43.1	1.2	82.2	0.9	82.7	81.8
005	PCAS_03_005_060212_2145_w_031	LVA	LVA	PF	140	3.30/0.1	42.4	46.8	39.9	57.0	44.9	1.1	85.8	0.7	86.1	85.5
005	PCAS_03_005_060212_2146_w_032	LVA	LVA	PF	140	3.40/0.1	45.7	47.7	43.6	52.6	47.9	1.1	90.2	0.7	90.5	89.8
005	PCAS_03_005_060212_2147_w_033	LVA	LVA	PF	140	3.50/0.1	48.9	50.2	46.2	57.4	51.6	1.1	95.0	0.7	95.3	94.6
005	PCAS_03_005_060212_2148_w_034	LVA	LVA	PF	140	3.60/0.1	52.8	54.5	51.1	57.0	54.5	1.1	101.6	0.9	102.0	101.1
005	PCAS_03_005_060212_2149_w_035	LVA	LVA	PF	140	3.70/0.1	57.3	58.2	56.5	59.2	58.1	1.0	109.6	1.2	110.2	108.9
005	PCAS_03_005_060212_2151_w_036	LVA	LVA	PF	140	3.80/0.1	61.6	62.2	61.0	63.1	62.2	1.0	117.5	2.1	118.6	116.4
005	PCAS_03_005_060212_2151_w_037	LVA	LVA	PF	140	3.90/0.1	66.9	68.7	65.4	71.7	68.5	1.0	124.9	8.6	129.0	120.5
005	PCAS_03_005_060212_2152_w_038	LVA	LVA	PF	140	3.90/0.1	36.3	37.6	34.0	41.7	38.6	1.1	78.5	26.7	91.3	84.6
005	PCAS_03_005_060212_2155_w_039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)	Inlet mean (mmHg)	Outlet mean (mmHg)	Inlet peak positive (mmHg)	Inlet peak negative (mmHg)	Outlet peak positive (mmHg)	Outlet peak negative (mmHg)	pCAS ΔP (mmHg)
005	PCAS_03_005_060212_2045_w_001	-	Normal	-	-	-	0.00	0.00	0.00	0.00	-0.9	-3	-1	-1	-3	-4	
005	PCAS_03_005_060212_2049_w_002	-	LVF	-	-	-	0.00	0.00	0.00	0.00	-0.9	-3	-1	-1	-3	-3	-2
005	PCAS_03_005_060212_2051_w_003	LVA	LVF	CF	0	-	-0.47	0.28	-0.32	-0.60	31.1	30	76	7	74	5	-1
005	PCAS_03_005_060212_2105_w_009	LVA	LVF	CF	811	-	0.01	0.39	0.19	-0.20	20.3	51	65	-8	93	19	30
005	PCAS_03_005_060212_2106_w_010	LVA	LVF	CF	900	-	0.18	0.37	0.36	-0.01	16.9	54	60	-6	96	28	37
005	PCAS_03_005_060212_2107_w_011	LVA	LVF	CF	1000	-	0.41	0.37	0.58	0.21	13.3	60	52	-5	95	38	46
005	PCAS_03_005_060212_2108_w_012	LVA	LVF	CF	1100	-	0.54	0.37	0.72	0.35	9.6	66	46	-7	101	46	57
005	PCAS_03_005_060212_2110_w_013	LVA	LVF	CF	1200	-	0.64	0.36	0.84	0.48	6.2	74	45	-9	110	57	68
005	PCAS_03_005_060212_2111_w_014	LVA	LVF	CF	1300	-	0.74	0.36	0.96	0.60	2.1	82	43	-14	121	66	80
005	PCAS_03_005_060212_2112_w_015	LVA	LVF	CF	1400	-	0.83	0.32	1.04	0.72	-4.0	90	36	-22	127	69	94
005	PCAS_03_005_060212_2113_w_016	LVA	LVF	CF	1500	-	0.91	0.32	1.11	0.79	-6.7	102	33	-24	140	82	109
005	PCAS_03_005_060212_2114_w_017	LVA	LVF	CF	1600	-	0.99	0.32	1.19	0.87	-9.4	116	30	-28	156	97	126
005	PCAS_03_005_060212_2121_w_018	LVA	LVF	PF	100	3.03/0.1	0.00	0.78	0.34	-0.44	20.4	50	77	-29	122	7	30
005	PCAS_03_005_060212_2123_w_019	LVA	LVF	PF	100	3.10/0.1	0.13	0.90	0.53	-0.39	17.6	54	78	-31	132	10	36
005	PCAS_03_005_060212_2124_w_020	LVA	LVF	PF	100	3.20/0.1	0.34	1.07	0.83	-0.24	13.6	59	72	-35	135	15	46
005	PCAS_03_005_060212_2125_w_021	LVA	LVF	PF	100	3.30/0.1	0.48	1.24	1.04	-0.19	10.0	66	89	-44	154	17	56
005	PCAS_03_005_060212_2126_w_022	LVA	LVF	PF	100	3.40/0.1	0.58	1.40	1.25	-0.16	5.9	72	89	-55	163	19	67
005	PCAS_03_005_060212_2127_w_023	LVA	LVF	PF	100	3.50/0.1	0.62	1.58	1.39	-0.20	3.6	77	69	-65	175	18	73
005	PCAS_03_005_060212_2128_w_024	LVA	LVF	PF	100	3.60/0.1	0.70	1.74	1.56	-0.18	0.3	87	69	-75	195	23	87
005	PCAS_03_005_060212_2129_w_025	LVA	LVF	PF	100	3.70/0.1	0.80	1.97	1.80	-0.17	-2.5	98	68	-89	216	28	100
005	PCAS_03_005_060212_2130_w_026	LVA	LVF	PF	100	3.80/0.1	0.87	2.18	1.98	-0.20	-5.4	109	68	-100	239	33	114
005	PCAS_03_005_060212_2132_w_027	LVA	LVF	PF	100	3.90/0.1	0.91	2.40	2.18	-0.22	-7.3	119	65	-109	267	40	126
005	PCAS_03_005_060212_2133_w_028	LVA	LVF	PF	100	4.00/0.1	0.97	2.61	2.35	-0.27	-10.0	131	65	-127	285	44	141
005	PCAS_03_005_060212_2142_w_029	LVA	LVF	PF	140	2.99/0.1	-0.01	0.52	0.25	-0.27	20.5	50	74	-19	112	11	29
005	PCAS_03_005_060212_2144_w_030	LVA	LVF	PF	140	3.10/0.1	0.23	0.59	0.52	-0.07	16.0	56	72	-22	125	19	40
005	PCAS_03_005_060212_2145_w_031	LVA	LVF	PF	140	3.20/0.1	0.44	0.69	0.78	0.09	12.1	62	64	-27	131	25	50
005	PCAS_03_005_060212_2146_w_032	LVA	LVF	PF	140	3.30/0.1	0.57	0.81	0.96	0.14	8.1	69	64	-35	148	26	61
005	PCAS_03_005_060212_2147_w_033	LVA	LVF	PF	140	3.40/0.1	0.67	0.93	1.12	0.19	3.4	77	64	-47	160	31	74
005	PCAS_03_005_060212_2148_w_034	LVA	LVF	PF	140	3.50/0.1	0.76	1.05	1.27	0.22	-0.5	86	61	-62	180	33	86
005	PCAS_03_005_060212_2149_w_035	LVA	LVF	PF	140	3.60/0.1	0.84	1.16	1.41	0.25	-3.4	95	57	-67	196	37	99
005	PCAS_03_005_060212_2151_w_036	LVA	LVF	PF	140	3.70/0.1	0.90	1.33	1.55	0.23	-6.5	107	56	-79	217	44	113
005	PCAS_03_005_060212_2151_w_037	LVA	LVF	PF	140	3.80/0.1	0.96	1.48	1.69	0.21	-8.7	118	56	-87	238	50	127
005	PCAS_03_005_060212_2152_w_038	LVA	LVF	PF	140	3.90/0.1	1.03	1.64	1.84	0.20	-12.0	132	55	-103	256	57	144
005	PCAS_03_005_060212_2155_w_039	-	LVF	-	-	-	0.00	0.00	0.00	0.00	21.7	19	23	20	21	18	-2

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	TPR clinical (dyne-sec/cm5)	LV SV (ml)	LV HR (bpm)	LV CO (L/min)	LVP bd (mmHg)	LVP ed (mmHg)	LVP pksys (mmHg)	+dLVP/dt (mmHg/s)	-dLVP/dt (mmHg/s)	LV Ed (mmHg/ml)	LV EW (mmHg-ml)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)
019	Pig3_019_cVAD_050512_1047_w_001	-	-	-	4574	11.9	99	1.2	9.3	21.2	86.6	1052	-1521	1.00	816	68.2	29.1	81.0	51.9
019	Pig3_019_cVAD_050512_1131_w_002	-	-	-	4890	11.1	101	1.1	10.2	22.0	93.5	996	-1442	1.06	765	68.1	38.5	88.4	49.9
019	Pig3_019_cVAD_050512_1202_w_003	CF	1190	-	5762	10.0	106	1.1	8.5	18.5	100.0	1093	-1632	1.00	792	76.3	35.5	95.2	59.6
019	Pig3_019_cVAD_050512_1205_w_004	CF	1300	-	8473	7.1	108	0.8	6.7	11.5	91.8	851	-1480	0.67	548	73.2	27.7	88.1	66.4
019	Pig3_019_cVAD_050512_1207_w_005	CF	1400	-	10700	6.6	107	0.7	8.8	15.2	98.4	816	-1421	0.97	536	79.3	27.7	94.3	80.6
019	Pig3_019_cVAD_050512_1210_w_006	CF	1500	-	15747	5.5	107	0.6	8.3	13.8	101.1	812	-1461	1.00	467	82.6	26.2	97.1	70.9
019	Pig3_019_cVAD_050512_1211_w_007	CF	1600	-	24596	4.6	108	0.5	7.8	12.4	101.5	791	-1451	1.01	399	84.1	23.9	97.7	73.8
019	Pig3_019_cVAD_050512_1235_w_008	-	-	-	6215	4.8	149	0.7	4.7	6.7	70.0	939	-1279	0.41	285	54.5	23.4	67.6	44.1
019	Pig3_019_cVAD_050512_1235_w_009	CF	1072	-	9056	4.0	133	0.5	5.2	7.7	69.8	729	-1117	0.63	234	55.0	21.1	67.4	41.8
019	Pig3_019_cVAD_050512_1235_w_010	PF	100	1.30/0.1	8632	4.2	129	0.5	5.2	8.2	66.5	677	-1029	0.72	228	51.1	22.2	64.0	41.8
019	Pig3_019_cVAD_050512_1237_w_011	PF	140	1.30/0.1	9380	4.3	126	0.5	5.6	9.3	72.8	713	-1162	0.89	258	56.2	24.0	70.3	48.2
019	Pig3_019_cVAD_050512_1240_w_012	PF	140	1.40/0.1	16345	3.0	120	0.4	5.3	8.2	78.2	672	-1159	1.08	198	64.0	20.9	75.8	54.9
019	Pig3_019_cVAD_050512_1245_w_013	PF	140	1.45/0.1	20648	2.6	116	0.3	5.3	8.2	82.3	659	-1189	1.31	181	66.9	20.0	79.9	60.0
019	Pig3_019_cVAD_050512_1244_w_014	PF	140	1.50/0.1	25860	1.9	116	0.2	5.4	7.8	78.4	599	-1035	1.80	129	67.5	18.0	77.0	59.1
019	Pig3_019_cVAD_050512_1249_w_015	PF	100	1.33/0.1	7181	7.1	112	0.8	6.2	13.1	89.2	883	-1602	0.97	516	67.1	33.2	86.0	52.8
019	Pig3_019_cVAD_050512_1256_w_016	-	-	-	5302	10.4	107	1.1	17.2	17.2	97.8	1262	-2008	0.98	799	73.4	39.2	93.8	54.5
019	Pig3_019_cVAD_050512_1258_w_017	CF	1149	-	5360	9.9	109	1.1	7.3	17.3	96.0	1135	-1855	1.01	750	71.0	38.7	91.9	53.3
019	Pig3_019_cVAD_050512_1300_w_018	CF	1200	-	8238	8.7	109	0.9	7.0	16.1	94.7	1047	-1827	1.05	859	71.3	35.6	90.9	55.4
019	Pig3_019_cVAD_050512_1301_w_019	CF	1300	-	7570	7.4	111	0.8	6.4	13.7	93.0	965	-1819	0.99	562	71.3	32.2	89.6	57.4
019	Pig3_019_cVAD_050512_1302_w_020	CF	1400	-	9987	5.8	113	0.7	6.1	11.8	91.6	872	-1768	0.98	448	71.9	28.7	88.6	59.8
019	Pig3_019_cVAD_050512_1304_w_021	CF	1500	-	14189	4.7	114	0.5	6.5	10.4	91.1	803	-1727	0.99	365	73.1	25.7	88.3	62.5
019	Pig3_019_cVAD_050512_1306_w_022	CF	1600	-	21909	3.3	115	0.4	5.2	8.1	88.2	709	-1637	0.88	259	73.4	20.6	85.9	65.3
019	Pig3_019_cVAD_050512_1308_w_023	CF	1700	-	42168	2.6	119	0.3	5.1	7.3	90.9	719	-1621	0.91	216	78.0	17.5	88.6	71.1
019	Pig3_019_cVAD_050512_1311_w_024	PF	100	1.33/0.1	5748	8.7	114	1.0	6.6	14.2	90.1	1045	-1723	0.88	626	66.5	35.9	86.6	50.8
019	Pig3_019_cVAD_050512_1313_w_025	PF	100	1.33/0.1	8251	8.0	114	0.9	6.6	13.9	89.4	973	-1683	0.92	577	67.0	34.0	86.0	52.1
019	Pig3_019_cVAD_050512_1315_w_026	PF	100	1.40/0.1	8892	6.3	117	0.7	5.8	11.4	90.2	907	-1727	0.91	472	70.7	30.0	87.2	57.2
019	Pig3_019_cVAD_050512_1317_w_027	PF	100	1.45/0.1	12646	4.9	118	0.6	5.5	9.6	87.2	806	-1638	0.86	363	69.9	27.0	84.5	57.5
019	Pig3_019_cVAD_050512_1319_w_028	PF	100	1.50/0.1	16582	4.3	118	0.5	5.4	9.0	88.3	779	-1644	0.87	324	72.4	25.8	85.9	60.1
019	Pig3_019_cVAD_050512_1320_w_029	PF	100	1.55/0.1	37684	2.9	120	0.3	4.8	7.3	83.5	677	-1477	0.96	207	69.8	24.6	82.7	58.1
019	Pig3_019_cVAD_050512_1322_w_030	PF	100	1.60/0.1	-61870	2.1	123	0.3	4.9	6.8	85.3	675	-1414	1.23	158	73.6	23.9	86.5	62.9
019	Pig3_019_cVAD_050512_1323_w_031	PF	100	1.60/0.1	274320	1.6	125	0.2	5.0	6.7	81.6	635	-1267	4.80	113	71.2	23.2	84.0	60.8
019	Pig3_019_cVAD_050512_1326_w_032	PF	140	1.30/0.1	8253	7.7	119	0.9	6.3	13.4	90.0	990	-1730	0.92	560	67.6	34.3	86.9	52.6
019	Pig3_019_cVAD_050512_1327_w_033	PF	140	1.30/0.1	8858	7.0	120	0.8	6.1	12.6	88.1	928	-1666	0.92	505	67.2	32.0	85.2	53.2
019	Pig3_019_cVAD_050512_1329_w_034	PF	140	1.35/0.1	107570	5.1	125	0.6	4.8	8.9	86.8	909	-1737	0.79	386	69.6	26.3	84.3	58.0
019	Pig3_019_cVAD_050512_1330_w_035	PF	140	1.40/0.1	17488	3.7	133	0.5	4.7	7.4	85.3	850	-1665	0.75	281	70.4	21.8	83.0	61.1
019	Pig3_019_cVAD_050512_1332_w_036	PF	140	1.45/0.1	22295	3.7	139	0.5	4.9	7.7	89.7	921	-1809	0.76	293	77.2	19.3	87.4	68.1
019	Pig3_019_cVAD_050512_1333_w_037	PF	140	1.50/0.1	57237	2.9	137	0.4	5.0	7.7	91.0	869	-1703	0.94	236	76.6	21.0	88.8	67.8
019	Pig3_019_cVAD_050512_1335_w_038	PF	140	1.55/0.1	77904	1.9	138	0.3	4.0	5.6	90.9	833	-1675	0.95	156	78.4	22.9	89.7	66.9
019	Pig3_019_cVAD_050512_1337_w_039	PF	140	1.60/0.1	-37039	0.9	138	0.1	4.9	6.3	90.8	772	-1398	3.57	74	78.1	20.3	89.7	69.4
019	Pig3_019_cVAD_050512_1338_w_040	-	-	-	5635	7.6	135	1.0	6.5	13.3	90.7	1086	-1783	0.90	552	69.1	33.7	87.5	53.7

Piglet3 Number	Filken, Maria	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	RV HR (bpm)	RV SV (ml)	RV CO (L/min)	PaP mean (mmHg)	PaP pulse (mmHg)	PaP sys (mmHg)	PaP dia (mmHg)	PAF mean (L/min)	PAF pulse (L/min)	PAF peak positive (L/min)	PAF peak negative (L/min)	PVR clinical (dyne-sec/cm5)
019	Pg3_019_cVAD_050512_1047_w_001	-	-	-	101	10.7	1.1	29.4	13.7	35.5	21.8	1.18	3.71	3.34	-0.37	2009
019	Pg3_019_cVAD_050512_1131_w_002	-	-	-	101	14.7	1.5	31.6	14.6	38.6	24.0	1.51	5.73	4.85	-0.88	1695
019	Pg3_019_cVAD_050512_1202_w_003	CF	1190	-	108	14.3	1.5	36.3	18.8	46.0	27.1	1.54	6.11	4.94	-1.17	1898
019	Pg3_019_cVAD_050512_1205_w_004	CF	1300	-	109	12.6	1.4	41.5	20.7	52.7	32.0	1.38	5.87	4.80	-1.07	2429
019	Pg3_019_cVAD_050512_1207_w_005	CF	1400	-	107	14.2	1.5	36.5	17.7	45.7	28.0	1.52	6.37	5.29	-1.08	1926
019	Pg3_019_cVAD_050512_1209_w_006	CF	1500	-	107	15.1	1.6	34.2	17.1	43.2	26.0	1.61	6.74	5.65	-1.09	1703
019	Pg3_019_cVAD_050512_1211_w_007	CF	1600	-	108	15.3	1.7	34.4	17.6	43.7	26.1	1.65	6.89	5.78	-1.11	1682
019	Pg3_019_cVAD_050512_1229_w_008	-	-	-	149	4.3	0.6	46.6	14.0	54.5	40.5	0.64	3.33	2.53	-0.60	5975
019	Pg3_019_cVAD_050512_1222_w_009	CF	1072	-	133	4.5	0.6	44.4	13.4	51.9	38.5	0.61	3.31	2.54	-0.77	5915
019	Pg3_019_cVAD_050512_1235_w_010	PF	100	1.30 / 0.1	129	5.1	0.7	43.2	13.2	50.6	37.4	0.68	3.45	2.68	-0.78	5167
019	Pg3_019_cVAD_050512_1237_w_011	PF	140	1.30 / 0.1	126	5.9	0.7	42.3	13.6	49.9	36.3	0.76	3.82	2.87	-0.75	4473
019	Pg3_019_cVAD_050512_1240_w_012	PF	140	1.40 / 0.1	120	7.1	0.8	40.6	14.1	48.3	34.3	0.84	4.04	3.27	-0.78	3902
019	Pg3_019_cVAD_050512_1242_w_013	PF	140	1.45 / 0.1	116	7.7	0.9	38.9	14.4	46.8	32.4	0.88	4.26	3.48	-0.79	3561
019	Pg3_019_cVAD_050512_1244_w_014	PF	140	1.50 / 0.1	117	7.6	0.9	38.1	14.0	45.8	31.9	0.88	4.31	3.51	-0.80	3520
019	Pg3_019_cVAD_050512_1245_w_015	PF	100	1.33 / 0.1	112	8.2	0.9	35.3	13.2	42.3	29.1	0.88	4.34	3.43	-0.91	3216
019	Pg3_019_cVAD_050512_1255_w_016	-	-	-	107	11.8	1.3	30.6	13.6	37.0	23.4	1.22	4.81	3.92	-0.90	2005
019	Pg3_019_cVAD_050512_1258_w_017	CF	1149	-	109	11.9	1.3	30.6	13.3	37.0	23.7	1.24	4.92	4.02	-0.90	1981
019	Pg3_019_cVAD_050512_1300_w_018	CF	1200	-	109	11.9	1.3	30.6	13.3	37.0	23.7	1.24	4.92	4.02	-0.90	1981
019	Pg3_019_cVAD_050512_1301_w_019	CF	1300	-	111	12.4	1.4	30.7	13.8	37.4	23.6	1.36	5.62	4.62	-1.00	1815
019	Pg3_019_cVAD_050512_1302_w_020	CF	1400	-	113	12.8	1.4	31.1	14.2	38.0	23.7	1.41	6.04	5.05	-0.99	1784
019	Pg3_019_cVAD_050512_1304_w_021	CF	1500	-	114	12.7	1.4	31.6	14.7	38.8	24.1	1.41	6.25	5.23	-1.02	1807
019	Pg3_019_cVAD_050512_1306_w_022	CF	1600	-	115	12.1	1.4	32.0	15.2	39.4	24.3	1.39	6.15	5.11	-1.04	1852
019	Pg3_019_cVAD_050512_1308_w_023	CF	1700	-	119	12.3	1.5	33.1	15.4	40.8	25.4	1.47	6.30	5.26	-1.05	1814
019	Pg3_019_cVAD_050512_1311_w_024	PF	100	1.33 / 0.1	114	10.6	1.2	34.2	14.5	41.5	27.0	1.24	5.40	4.39	-1.02	2222
019	Pg3_019_cVAD_050512_1313_w_025	PF	100	1.33 / 0.1	115	10.1	1.2	35.0	14.5	42.4	28.0	1.18	5.34	4.32	-1.02	2391
019	Pg3_019_cVAD_050512_1315_w_026	PF	100	1.40 / 0.1	117	9.8	1.1	36.5	14.9	44.3	29.4	1.17	5.54	4.51	-1.03	2513
019	Pg3_019_cVAD_050512_1317_w_027	PF	100	1.45 / 0.1	118	9.8	1.2	36.7	15.7	44.9	29.2	1.19	5.82	4.74	-1.08	2487
019	Pg3_019_cVAD_050512_1319_w_028	PF	100	1.50 / 0.1	118	10.4	1.2	36.2	15.6	44.5	28.8	1.25	6.04	4.96	-1.08	2329
019	Pg3_019_cVAD_050512_1320_w_029	PF	100	1.55 / 0.1	120	10.2	1.2	36.3	15.7	44.6	28.9	1.24	6.04	4.90	-1.14	2351
019	Pg3_019_cVAD_050512_1322_w_030	PF	100	1.60 / 0.1	123	10.1	1.2	36.6	16.2	45.3	29.0	1.25	5.99	4.91	-1.08	2360
019	Pg3_019_cVAD_050512_1323_w_031	PF	100	1.60 / 0.1	125	9.6	1.2	37.1	16.0	45.6	29.6	1.21	5.83	4.74	-1.08	2465
019	Pg3_019_cVAD_050512_1326_w_032	PF	140	1.30 / 0.1	119	9.1	1.1	37.5	15.3	45.6	30.3	1.11	5.24	4.20	-1.04	2712
019	Pg3_019_cVAD_050512_1327_w_033	PF	140	1.30 / 0.1	120	8.2	1.0	38.9	15.1	47.0	31.9	0.98	5.10	4.00	-1.10	3190
019	Pg3_019_cVAD_050512_1329_w_034	PF	140	1.35 / 0.1	126	7.6	1.0	40.7	15.5	49.1	33.5	0.95	5.39	4.21	-1.18	3453
019	Pg3_019_cVAD_050512_1330_w_035	PF	140	1.40 / 0.1	133	7.6	1.0	41.3	15.6	49.7	34.1	1.00	5.57	4.36	-1.21	3342
019	Pg3_019_cVAD_050512_1332_w_036	PF	140	1.45 / 0.1	139	8.1	1.1	40.9	15.9	49.4	33.5	1.10	5.83	4.58	-1.25	2989
019	Pg3_019_cVAD_050512_1333_w_037	PF	140	1.50 / 0.1	138	8.5	1.2	39.9	15.8	48.3	32.5	1.16	5.86	4.64	-1.21	2778
019	Pg3_019_cVAD_050512_1335_w_038	PF	140	1.55 / 0.1	138	9.1	1.3	39.3	16.4	48.0	31.6	1.23	6.09	4.87	-1.22	2566
019	Pg3_019_cVAD_050512_1337_w_039	PF	140	1.60 / 0.1	138	9.3	1.3	38.9	16.2	47.5	31.3	1.27	6.02	4.84	-1.18	2463
019	Pg3_019_cVAD_050512_1338_w_040	-	-	-	135	8.8	1.2	38.6	14.5	46.3	31.8	1.21	5.34	4.26	-1.09	2576

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV SV (ml)	LV HR (bpm)	LV CO (L/min)	LVP bd (mmHg)	LVP ed (mmHg)	LVP pksys (mmHg)	+dLVP/dt (mmHg/s)	-dLVP/dt (mmHg/s)	LV Ed (mmHg/ml)	LV EW (mmHg-ml)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)
022	Pig3_022_eVAD_050804_1025_w_002	-	-	-	15.2	80	1.2	7.3	14.1	87.7	671	-1567	0.45	961	61.1	34.7	79.5	44.8	3811
022	Pig3_022_eVAD_050804_1145_w_003	-	-	-	13.5	102	1.4	8.1	18.4	101.7	1014	-1831	0.76	1063	68.5	42.9	92.0	49.1	4090
022	Pig3_022_eVAD_050804_1150_w_004	-	-	-	11.4	101	1.2	11.2	23.9	126.7	1146	-2066	1.10	1110	83.2	43.6	117.0	73.4	6393
022	Pig3_022_eVAD_050804_1155_w_005	-	-	-	12.1	93	1.1	10.0	20.7	101.1	756	-1747	0.89	921	69.8	39.5	91.1	51.6	4991
022	Pig3_022_eVAD_050804_1200_w_006	-	-	-	11.7	91	1.1	9.8	20.0	94.9	678	-1603	0.87	825	64.0	38.0	84.8	46.8	4934
022	Pig3_022_eVAD_050804_1233_w_007	-	-	-	7.3	115	0.8	17.2	32.1	91.6	470	-1092	2.03	446	66.1	25.9	79.8	53.9	7019
022	Pig3_022_eVAD_050804_1239_w_008	CF	922	-	5.8	109	0.6	12.4	24.9	68.1	333	-742	2.18	261	44.2	20.1	56.5	36.5	6099
022	Pig3_022_eVAD_050804_1241_w_009	CF	920	-	3.5	105	0.4	12.3	21.5	58.6	270	-573	2.60	134	37.9	14.1	47.3	33.2	9141
022	Pig3_022_eVAD_050804_1244_w_010	CF	1000	-	0.2	106	0.0	10.6	15.2	32.0	215	-242	31.51	1	28.5	0.8	29.2	28.4	735390
022	Pig3_022_eVAD_050804_1258_w_011	-	-	-	7.6	121	0.9	7.9	20.5	95.1	1047	-1651	1.66	561	66.9	34.1	85.5	51.4	5638
022	Pig3_022_eVAD_050804_1301_w_012	CF	1035	-	7.6	114	0.9	8.2	14.1	82.9	804	-1307	0.78	494	56.0	30.3	73.1	42.9	5194
022	Pig3_022_eVAD_050804_1303_w_013	CF	1100	-	5.2	114	0.6	8.9	10.3	69.6	675	-1038	0.85	257	48.7	18.8	60.5	41.6	6186
022	Pig3_022_eVAD_050804_1305_w_014	CF	1200	-	5.4	113	0.6	6.9	10.1	73.0	704	-1105	0.60	267	51.9	18.6	63.7	45.1	5427
022	Pig3_022_eVAD_050804_1305_w_015	CF	1300	-	5.8	114	0.7	7.2	10.8	81.6	770	-1260	0.61	318	59.5	19.5	72.1	52.5	5598
022	Pig3_022_eVAD_050804_1306_w_016	CF	1400	-	5.3	115	0.6	7.5	11.0	85.1	790	-1293	0.67	291	63.7	17.4	75.4	58.0	6223
022	Pig3_022_eVAD_050804_1310_w_017	CF	1500	-	6.0	116	0.7	7.4	10.6	90.9	1066	-1568	0.54	399	73.1	22.0	87.1	65.1	5945
022	Pig3_022_eVAD_050804_1312_w_018	CF	1600	-	6.2	116	0.7	7.4	10.4	99.3	1067	-1590	0.51	396	76.0	20.0	89.4	69.3	5779
022	Pig3_022_eVAD_050804_1313_w_019	CF	-	-	0.3	124	0.0	1.0	1.9	9.2	139	-115	3.68	2	43.4	2.0	45.2	43.2	7300
022	Pig3_022_eVAD_050804_1327_w_020	-	-	-	10.6	116	1.2	10.2	14.3	103.0	1116	-1723	1.16	871	71.8	37.0	91.5	54.5	4598
022	Pig3_022_eVAD_050804_1326_w_021	CF	1120	-	9.5	112	1.1	10.2	19.4	93.7	848	-1417	0.97	674	64.1	32.9	82.3	49.4	4932
022	Pig3_022_eVAD_050804_1327_w_022	CF	1120	-	8.1	111	0.9	9.3	18.1	85.7	821	-1260	1.08	535	58.0	28.9	74.5	45.6	5345
022	Pig3_022_eVAD_050804_1329_w_023	CF	1200	-	7.6	112	0.9	9.3	16.5	84.2	715	-1217	0.95	480	57.6	25.9	73.2	47.3	5154
022	Pig3_022_eVAD_050804_1331_w_024	CF	1300	-	7.5	112	0.8	9.5	16.9	90.9	796	-1334	1.00	490	63.6	27.0	79.8	52.8	5151
022	Pig3_022_eVAD_050804_1332_w_025	CF	1400	-	7.2	113	0.8	9.3	16.0	91.7	824	-1350	0.93	481	64.6	26.3	80.7	54.3	4895
022	Pig3_022_eVAD_050804_1334_w_026	CF	1500	-	8.0	112	0.9	8.9	14.4	84.0	676	-1147	0.80	409	61.0	18.4	73.3	54.9	4903
022	Pig3_022_eVAD_050804_1335_w_027	CF	1600	-	1.1	115	0.1	9.2	14.4	89.5	755	-1250	0.95	259	85.7	19.2	78.7	59.5	4703
022	Pig3_022_eVAD_050804_1350_w_028	-	-	-	9.6	115	1.1	11.4	20.4	121.9	1103	-1814	0.92	555	86.4	43.6	110.2	66.6	6251
022	Pig3_022_eVAD_050804_1359_w_029	PF	100	1.27 / 0.9	8.0	113	0.9	10.2	17.5	91.6	818	-1310	0.92	555	82.0	32.9	80.4	47.5	5927
022	Pig3_022_eVAD_050804_1401_w_030	PF	100	1.30 / 0.9	6.1	114	0.7	10.1	17.2	97.7	826	-1378	1.16	468	89.4	29.7	86.7	57.0	8853
022	Pig3_022_eVAD_050804_1404_w_031	PF	100	1.35 / 0.9	3.5	114	0.4	9.2	14.3	89.4	748	-1203	1.50	252	66.7	20.7	78.8	58.1	19949
022	Pig3_022_eVAD_050804_1405_w_032	PF	100	1.40 / 0.9	2.4	118	0.3	8.9	13.4	88.9	793	-1190	2.21	173	67.4	20.5	78.8	58.3	13142
022	Pig3_022_eVAD_050804_1407_w_033	PF	100	1.45 / 0.9	1.0	115	0.1	9.0	13.1	88.8	741	-1082	5.10	76	71.3	18.4	82.0	63.6	-194750
022	Pig3_022_eVAD_050804_1409_w_034	PF	100	1.50 / 0.9	0.3	116	0.0	8.6	12.5	86.7	721	-959	34.33	22	74.3	18.0	85.3	67.3	-26910
022	Pig3_022_eVAD_050804_1422_w_035	-	-	-	8.5	114	1.0	10.8	19.7	115.3	980	-1714	1.05	758	82.6	38.9	104.0	65.1	6946
022	Pig3_022_eVAD_050804_1425_w_036	PF	140	1.27 / 0.9	9.5	112	1.1	11.0	20.7	122.5	1143	-1832	1.02	896	86.7	44.1	111.0	66.8	6464
022	Pig3_022_eVAD_050804_1427_w_037	PF	140	1.30 / 0.9	8.2	112	0.9	10.0	18.1	117.0	1028	-1776	0.99	757	83.1	39.8	105.6	65.8	7506
022	Pig3_022_eVAD_050804_1429_w_038	PF	140	1.35 / 0.9	6.5	113	0.7	9.9	17.5	122.8	1074	-1805	1.18	838	90.3	36.7	111.4	74.7	9747
022	Pig3_022_eVAD_050804_1430_w_039	PF	140	1.40 / 0.9	5.9	114	0.7	9.6	15.9	123.1	1124	-1805	1.10	586	92.0	34.6	111.9	77.3	10930
022	Pig3_022_eVAD_050804_1432_w_040	PF	140	1.45 / 0.9	3.6	113	0.4	8.8	13.8	115.0	958	-1626	1.41	350	89.1	25.8	104.1	78.3	16466
022	Pig3_022_eVAD_050804_1433_w_041	PF	140	1.50 / 0.9	3.5	116	0.4	9.0	13.8	120.2	1061	-1668	1.40	348	94.9	25.3	109.3	84.0	16407
022	Pig3_022_eVAD_050804_1435_w_042	PF	140	1.55 / 0.9	2.2	118	0.3	7.8	11.5	105.2	914	-1369	1.85	159	87.8	17.4	97.2	79.8	19738
022	Pig3_022_eVAD_050804_1437_w_043	-	-	-	9.6	115	1.1	11.4	20.4	121.9	1103	-1814	0.95	890	86.4	43.6	110.2	66.6	6251

Page Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)	CdAF mean (L/min)	CdAF pulse (L/min)	CdAF peak positive (L/min)	CdAF peak negative (L/min)	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)
022	Pig3_022_cVAD_050804_1025.w_002	-	-	-	9.3	7.0	5.8	1.28	5.83	4.70	-1.13	83.7	153.7	177.6	23.9	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1145.w_003	-	-	-	12.4	4.0	7.9	1.34	5.14	4.66	-0.49	121.8	215.9	251.0	35.1	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1150.w_004	-	-	-	17.8	4.9	12.4	1.17	4.56	3.90	-0.66	140.3	153.3	231.2	77.9	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1159.w_005	-	-	-	15.3	3.9	10.1	1.12	4.48	3.93	-0.55	102.9	191.0	221.2	30.1	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1200.w_006	-	-	-	14.1	4.6	9.5	1.04	4.32	3.80	-0.52	93.2	198.9	181.6	19.7	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1233.w_007	-	-	-	20.4	18.4	16.4	0.76	3.60	2.83	-0.78	118.1	133.7	197.5	63.8	0.00	0.00	0.00	0.00
022	Pig3_022_cVAD_050804_1239.w_008	CF	922	-	13.2	12.8	9.4	0.58	3.02	2.23	-0.78	74.1	149.5	150.3	0.8	0.07	0.15	0.16	0.00
022	Pig3_022_cVAD_050804_1241.w_009	CF	920	-	12.1	11.0	8.2	0.33	2.44	1.68	-0.75	61.2	121.5	122.1	0.5	0.23	0.12	0.29	0.17
022	Pig3_022_cVAD_050804_1244.w_010	CF	1000	-	6.4	4.6	3.3	0.03	0.40	0.22	-0.18	44.9	11.3	51.1	39.8	0.47	0.05	0.50	0.45
022	Pig3_022_cVAD_050804_1258.w_011	-	-	-	12.5	10.5	7.8	0.95	3.73	3.09	-0.64	132.4	154.7	225.9	71.1	0.00	0.02	0.01	-0.01
022	Pig3_022_cVAD_050804_1301.w_012	CF	1035	-	13.0	2.9	8.1	0.86	3.25	2.72	-0.53	104.9	163.8	197.1	33.3	-0.03	0.26	0.12	-0.13
022	Pig3_022_cVAD_050804_1303.w_013	CF	1100	-	9.4	1.8	4.8	0.63	2.36	1.79	-0.57	91.9	117.3	154.6	37.4	0.29	0.17	0.38	0.22
022	Pig3_022_cVAD_050804_1305.w_014	CF	1200	-	8.6	1.8	4.4	0.77	2.41	1.80	-0.61	98.0	111.6	158.0	46.2	0.45	0.16	0.53	0.37
022	Pig3_022_cVAD_050804_1306.w_015	CF	1300	-	9.3	1.9	4.6	0.85	2.60	1.95	-0.65	111.9	114.2	172.9	58.7	0.54	0.17	0.63	0.46
022	Pig3_022_cVAD_050804_1308.w_016	CF	1400	-	9.4	2.0	4.5	0.82	2.23	1.81	-0.43	117.6	108.3	173.5	65.3	0.68	0.14	0.75	0.61
022	Pig3_022_cVAD_050804_1310.w_017	CF	1500	-	8.9	1.6	4.0	1.00	2.86	2.36	-0.50	134.3	122.2	200.5	78.3	0.74	0.18	0.83	0.65
022	Pig3_022_cVAD_050804_1312.w_018	CF	1600	-	8.2	1.9	3.7	1.05	2.52	2.09	-0.43	137.0	112.9	197.4	84.5	0.90	0.15	0.98	0.82
022	Pig3_022_cVAD_050804_1313.w_019	CF	-	-	-2.7	-3.7	-5.6	0.48	1.09	1.05	-0.03	63.0	34.3	76.1	41.8	0.62	0.60	0.85	0.25
022	Pig3_022_cVAD_050804_1322.w_020	-	-	-	13.1	3.3	9.3	1.25	4.65	3.95	-0.70	121.6	172.7	221.6	49.0	0.00	0.20	0.10	-0.11
022	Pig3_022_cVAD_050804_1326.w_021	CF	1120	-	11.9	3.4	8.8	1.04	3.86	3.21	-0.65	113.9	174.2	211.3	37.1	0.07	0.23	0.20	-0.04
022	Pig3_022_cVAD_050804_1327.w_022	CF	1120	-	10.4	9.4	7.2	0.88	3.59	2.88	-0.70	105.7	173.1	199.7	26.6	0.19	0.22	0.31	0.10
022	Pig3_022_cVAD_050804_1329.w_023	CF	1200	-	9.1	8.2	6.9	0.89	3.38	2.54	-0.84	112.3	153.8	195.8	42.0	0.40	0.18	0.50	0.31
022	Pig3_022_cVAD_050804_1331.w_024	CF	1300	-	9.5	8.7	6.9	0.99	3.89	2.81	-1.08	127.8	148.4	212.1	63.7	0.54	0.19	0.63	0.45
022	Pig3_022_cVAD_050804_1332.w_025	CF	1400	-	8.9	7.9	6.3	1.06	3.89	2.84	-1.05	132.1	140.8	212.0	71.3	0.71	0.17	0.79	0.62
022	Pig3_022_cVAD_050804_1334.w_026	CF	1500	-	7.4	6.5	5.1	1.00	2.31	2.17	-0.14	125.4	120.6	194.4	73.8	0.94	0.13	0.99	0.87
022	Pig3_022_cVAD_050804_1335.w_027	CF	1600	-	7.5	6.6	5.3	1.12	2.00	2.02	0.02	136.7	116.8	204.0	87.1	1.06	0.13	1.13	0.99
022	Pig3_022_cVAD_050804_1350.w_028	-	-	-	12.6	4.4	9.3	1.11	4.41	3.54	-0.87	100.1	147.0	190.8	43.7	0.00	0.24	0.12	-0.12
022	Pig3_022_cVAD_050804_1359.w_029	PF	100	1.21/0.9	11.4	3.4	8.8	0.84	3.93	3.04	-0.89	87.1	191.2	192.5	1.3	0.03	0.98	0.50	-0.49
022	Pig3_022_cVAD_050804_1401.w_030	PF	100	1.30/0.9	10.8	5.3	8.2	0.63	3.74	2.73	-1.01	96.6	170.4	188.7	18.3	0.33	1.40	1.01	-0.38
022	Pig3_022_cVAD_050804_1404.w_031	PF	100	1.35/0.9	8.6	4.0	6.5	0.28	3.38	2.17	-1.20	92.4	148.4	165.6	17.1	0.63	1.59	1.43	-0.16
022	Pig3_022_cVAD_050804_1405.w_032	PF	100	1.40/0.9	7.9	3.5	5.6	0.12	3.00	1.76	-1.25	94.9	132.7	158.3	25.7	0.84	1.78	1.74	-0.04
022	Pig3_022_cVAD_050804_1407.w_033	PF	100	1.45/0.9	6.9	3.6	4.9	-0.09	2.61	1.16	-1.45	100.2	124.0	157.4	33.4	1.00	2.04	2.04	0.00
022	Pig3_022_cVAD_050804_1409.w_034	PF	100	1.50/0.9	6.1	2.7	3.9	-0.28	2.02	0.66	-1.36	100.9	121.9	158.1	36.2	1.14	2.25	2.30	0.04
022	Pig3_022_cVAD_050804_1422.w_035	-	-	-	11.6	4.2	8.9	0.95	4.17	3.31	-0.86	82.9	144.2	170.3	26.1	0.00	0.18	0.09	-0.09
022	Pig3_022_cVAD_050804_1425.w_036	PF	140	1.27/0.9	12.2	7.1	9.0	1.08	4.36	3.46	-0.90	89.4	156.6	180.1	23.5	-0.06	0.94	0.38	-0.56
022	Pig3_022_cVAD_050804_1427.w_037	PF	140	1.30/0.9	10.1	7.5	7.1	0.89	4.22	3.21	-1.00	91.9	152.2	181.9	28.7	0.16	1.03	0.64	-0.39
022	Pig3_022_cVAD_050804_1429.w_038	PF	140	1.35/0.9	9.5	7.5	6.5	0.75	3.84	2.88	-0.97	99.3	138.5	180.7	42.3	0.41	1.21	1.00	-0.21
022	Pig3_022_cVAD_050804_1430.w_039	PF	140	1.40/0.9	8.3	6.2	5.6	0.69	3.73	2.76	-0.97	102.9	134.7	178.3	43.6	0.58	1.41	1.26	-0.15
022	Pig3_022_cVAD_050804_1432.w_040	PF	140	1.45/0.9	6.2	4.1	4.0	0.46	3.18	2.31	-0.87	101.1	124.7	167.9	43.3	0.88	1.57	1.65	0.08
022	Pig3_022_cVAD_050804_1433.w_041	PF	140	1.50/0.9	6.3	4.5	3.8	0.49	3.11	2.28	-0.83	111.4	120.6	173.5	52.9	1.05	1.76	1.93	0.17
022	Pig3_022_cVAD_050804_1435.w_042	PF	140	1.55/0.9	4.0	1.7	1.9	0.40	2.38	1.62	-0.76	110.4	100.8	155.1	54.3	1.31	1.93	2.28	0.35
022	Pig3_022_cVAD_050804_1437.w_043	-	-	-	12.6	4.4	9.3	1.11	4.41	3.54	-0.87	100.1	147.0	190.8	43.7	0.00	0.24	0.12	-0.12

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	RV HR (bpm)	RV SV (ml)	RV CO (L/min)	PaP mean (mmHg)	PaP pulse (mmHg)	PaP sys (mmHg)	PaP dia (mmHg)	PAF mean (L/min)	PAF pulse (L/min)	PAF peak positive (L/min)	PAF peak negative (L/min)	PVR clinical (dyne-sec/cm5)
022	Pg3_022_eVAD_050804_1025.w_002	-	-	-	80	15.1	1.2	18.6	10.5	24.4	13.8	1.28	5.83	4.70	-1.13	1158
022	Pg3_022_eVAD_050804_1145.w_003	-	-	-	103	15.8	1.6	21.1	11.6	26.8	15.2	1.60	6.41	5.29	-1.12	1052
022	Pg3_022_eVAD_050804_1150.w_004	-	-	-	101	10.5	1.1	26.2	15.7	34.5	18.7	1.01	4.88	3.68	-0.99	2083
022	Pg3_022_eVAD_050804_1150.w_005	-	-	-	93	NA	NA	22.1	13.6	29.0	15.5	NA	NA	NA	NA	NA
022	Pg3_022_eVAD_050804_1200.w_006	-	-	-	92	11.9	1.1	21.7	13.1	28.5	15.4	1.11	4.17	3.47	-0.70	1562
022	Pg3_022_eVAD_050804_1233.w_007	-	-	-	115	4.8	0.6	28.0	12.0	34.0	21.9	0.50	2.58	1.67	-0.91	4535
022	Pg3_022_eVAD_050804_1239.w_008	CF	922	-	109	4.5	0.5	24.2	11.1	30.2	19.1	0.34	3.19	2.00	-1.19	5856
022	Pg3_022_eVAD_050804_1241.w_009	CF	920	-	105	4.2	0.4	22.0	9.5	27.1	17.6	0.27	3.03	1.75	-1.27	6563
022	Pg3_022_eVAD_050804_1241.w_010	CF	1000	-	107	3.1	0.3	19.6	8.1	24.0	15.9	0.20	2.89	1.64	-1.26	8395
022	Pg3_022_eVAD_050804_1258.w_011	-	-	-	121	7.1	0.9	40.4	19.7	51.0	31.3	0.83	5.22	3.80	-1.42	3887
022	Pg3_022_eVAD_050804_1301.w_012	CF	1035	-	114	7.3	0.8	38.4	17.4	48.0	30.6	0.86	4.73	3.50	-1.23	3556
022	Pg3_022_eVAD_050804_1303.w_013	CF	1100	-	114	5.6	0.6	39.0	15.2	47.7	32.4	0.88	3.90	2.83	-0.97	4659
022	Pg3_022_eVAD_050804_1305.w_014	CF	1200	-	114	6.4	0.7	39.0	16.9	48.4	31.5	0.72	4.45	3.30	-1.15	4352
022	Pg3_022_eVAD_050804_1305.w_015	CF	1300	-	114	7.2	0.8	38.8	17.8	48.7	30.8	0.86	4.70	3.59	-1.11	3634
022	Pg3_022_eVAD_050804_1308.w_016	CF	1400	-	114	7.5	0.9	38.4	18.1	48.5	30.3	0.92	4.73	3.67	-1.06	3358
022	Pg3_022_eVAD_050804_1310.w_017	CF	1500	-	116	9.1	1.1	39.2	20.8	50.3	29.5	1.16	5.64	4.49	-1.15	2708
022	Pg3_022_eVAD_050804_1312.w_018	CF	1600	-	116	9.9	1.1	38.3	21.2	49.6	28.4	1.25	5.97	4.77	-1.20	2458
022	Pg3_022_eVAD_050804_1313.w_019	CF	-	-	124	3.2	0.4	22.2	7.5	26.4	18.9	0.45	2.20	1.96	-0.24	4050
022	Pg3_022_eVAD_050804_1322.w_020	-	-	-	116	10.6	1.2	28.9	16.5	37.2	20.7	1.24	5.26	4.25	-1.00	1873
022	Pg3_022_eVAD_050804_1326.w_021	CF	1120	-	112	7.8	0.9	26.1	14.6	33.3	18.6	0.81	4.57	3.33	-1.24	2618
022	Pg3_022_eVAD_050804_1327.w_022	CF	1120	-	111	9.7	1.1	27.4	14.9	34.7	19.8	1.09	5.51	4.38	-1.13	2013
022	Pg3_022_eVAD_050804_1329.w_023	CF	1200	-	112	10.2	1.1	27.3	15.6	34.9	19.3	1.21	5.42	4.37	-1.05	1809
022	Pg3_022_eVAD_050804_1331.w_024	CF	1300	-	112	9.9	1.1	27.5	16.1	35.5	19.3	1.16	5.65	4.40	-1.24	1901
022	Pg3_022_eVAD_050804_1332.w_025	CF	1400	-	113	10.5	1.2	27.5	16.6	35.6	19.0	1.22	5.88	4.71	-1.17	1806
022	Pg3_022_eVAD_050804_1332.w_026	CF	1500	-	112	10.1	1.1	26.0	15.4	33.5	18.1	1.13	5.68	4.49	-1.19	1853
022	Pg3_022_eVAD_050804_1335.w_027	CF	1600	-	115	11.2	1.3	26.7	16.3	34.7	18.4	1.35	5.96	4.94	-1.02	1598
022	Pg3_022_eVAD_050804_1350.w_028	-	-	-	118	NA	NA	28.2	17.3	36.8	19.5	NA	NA	NA	NA	NA
022	Pg3_022_eVAD_050804_1359.w_029	PF	100	1.21/0.9	113	6.2	0.7	30.2	16.7	38.8	22.0	0.86	4.11	2.85	-1.27	3704
022	Pg3_022_eVAD_050804_1401.w_030	PF	100	1.30/0.9	114	8.1	0.9	30.7	17.2	39.5	22.3	0.98	4.53	3.59	-0.94	2554
022	Pg3_022_eVAD_050804_1404.w_031	PF	100	1.35/0.9	113	8.3	0.9	31.1	17.3	40.0	22.7	1.01	4.27	3.42	-0.85	2491
022	Pg3_022_eVAD_050804_1405.w_032	PF	100	1.40/0.9	118	8.3	1.0	32.3	17.9	41.4	23.5	1.07	4.57	3.70	-0.86	2434
022	Pg3_022_eVAD_050804_1407.w_033	PF	100	1.45/0.9	115	8.3	1.0	31.8	18.0	40.9	22.9	1.02	4.53	3.50	-1.03	2501
022	Pg3_022_eVAD_050804_1409.w_034	PF	100	1.50/0.9	116	7.9	0.9	31.9	18.0	41.2	23.3	0.98	4.58	3.70	-0.88	2646
022	Pg3_022_eVAD_050804_1422.w_035	-	-	-	114	10.2	1.2	32.0	18.1	41.6	23.4	1.30	4.86	3.83	-1.03	1979
022	Pg3_022_eVAD_050804_1425.w_036	PF	140	1.27/0.9	112	10.6	1.2	33.6	19.3	43.8	24.5	1.31	5.21	4.06	-1.16	2063
022	Pg3_022_eVAD_050804_1427.w_037	PF	140	1.30/0.9	112	11.0	1.2	33.0	19.7	43.3	23.6	1.35	5.54	4.39	-1.15	1967
022	Pg3_022_eVAD_050804_1429.w_038	PF	140	1.35/0.9	113	11.2	1.3	34.2	20.9	45.1	24.2	1.41	5.82	4.62	-1.21	1948
022	Pg3_022_eVAD_050804_1430.w_039	PF	140	1.40/0.9	114	11.6	1.3	34.8	21.1	45.7	24.6	1.42	6.16	4.83	-1.33	1968
022	Pg3_022_eVAD_050804_1432.w_040	PF	140	1.45/0.9	113	10.8	1.2	33.9	21.0	44.8	23.8	1.35	5.94	4.75	-1.19	2012
022	Pg3_022_eVAD_050804_1433.w_041	PF	140	1.50/0.9	116	8.1	0.9	34.6	21.3	45.9	24.6	0.93	5.43	4.03	-1.40	3014
022	Pg3_022_eVAD_050804_1435.w_042	PF	140	1.55/0.9	118	10.3	1.2	34.2	21.9	45.7	23.8	1.14	6.68	5.08	-1.61	2412
022	Pg3_022_eVAD_050804_1437.w_043	-	-	-	115	8.5	1.0	36.1	20.9	47.3	26.5	0.92	5.05	3.60	-1.46	3170

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV SV (ml)	LV HR (bpm)	LV CO (L/min)	LVP bd (mmHg)	LVP ed (mmHg)	LVP pksys (mmHg)	+dLVP/dt (mmHg/s)	-dLVP/dt (mmHg/s)	LV Ed (mmHg/ml)	LV EW (mmHg-ml)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)
025	Pig3_025_cVAD_051013_1052_w_002	-	-	-	16.5	109	1.8	9.5	22.3	88.4	1274	-1883	0.78	1128	87.1	32.9	83.1	50.2
025	Pig3_025_cVAD_051013_1142_w_003	-	-	-	11.6	113	1.3	11.3	24.5	84.2	1435	-1378	1.15	730	56.3	37.6	77.5	39.9
025	Pig3_025_cVAD_051013_1212_w_004	CF	1200	-	10.4	163	1.6	8.0	18.6	120.9	3282	-3003	1.02	1036	90.0	48.6	114.1	65.5
025	Pig3_025_cVAD_051013_1214_w_005	CF	1300	-	8.8	137	1.2	7.3	16.0	103.5	2463	-2305	0.99	751	73.2	44.6	96.8	52.2
025	Pig3_025_cVAD_051013_1216_w_006	CF	1400	-	7.1	131	0.9	7.0	14.5	95.0	2389	-1859	1.07	565	64.4	42.8	88.7	45.9
025	Pig3_025_cVAD_051013_1217_w_007	CF	1500	-	4.8	123	0.6	6.9	13.9	87.4	1756	-1533	1.50	347	60.5	35.4	81.2	45.8
025	Pig3_025_cVAD_051013_1222_w_008	CF	640	-	14.7	118	1.7	9.0	22.1	92.8	2028	-1561	0.89	1059	57.0	50.6	84.8	34.2
025	Pig3_025_cVAD_051013_1224_w_009	CF	700	-	14.2	115	1.6	9.0	21.8	92.3	2019	-1577	0.90	1024	57.8	48.8	84.3	35.5
025	Pig3_025_cVAD_051013_1226_w_010	CF	800	-	13.3	114	1.5	8.9	21.9	95.2	2160	-1680	0.98	1007	62.1	47.8	87.4	39.6
025	Pig3_025_cVAD_051013_1227_w_011	CF	900	-	12.1	114	1.4	8.8	21.4	97.3	2250	-1776	1.04	949	65.9	46.0	89.6	43.6
025	Pig3_025_cVAD_051013_1229_w_012	CF	1000	-	10.8	114	1.2	8.6	20.3	98.5	2321	-1801	1.09	866	68.3	44.4	91.1	46.7
025	Pig3_025_cVAD_051013_1230_w_013	CF	1100	-	9.4	114	1.1	8.4	19.5	99.3	2280	-1858	1.18	765	70.9	42.1	92.3	50.2
025	Pig3_025_cVAD_051013_1231_w_014	CF	1200	-	7.9	115	0.9	8.1	18.7	99.3	2216	-1830	1.34	643	72.0	40.2	92.5	52.4
025	Pig3_025_cVAD_051013_1233_w_015	CF	1300	-	6.7	115	0.8	7.7	17.6	101.0	2264	-1873	1.47	564	74.5	39.8	94.6	55.8
025	Pig3_025_cVAD_051013_1235_w_016	CF	1400	-	5.5	116	0.8	7.4	16.7	102.6	2281	-1933	1.71	472	77.0	37.4	96.5	59.1
025	Pig3_025_cVAD_051013_1237_w_017	CF	1500	-	4.2	117	0.5	7.1	16.2	104.6	2285	-1966	2.20	366	79.9	35.7	98.6	62.9
025	Pig3_025_cVAD_051013_1239_w_018	CF	1600	-	3.1	117	0.4	7.1	16.0	106.3	2222	-1997	2.89	281	82.8	33.6	100.4	66.9
025	Pig3_025_cVAD_051013_1241_w_019	CF	1700	-	1.8	116	0.2	6.6	14.8	103.6	2079	-1881	4.83	157	81.4	30.4	97.9	67.6
025	Pig3_025_cVAD_051013_1243_w_020	CF	1800	-	1.0	117	0.1	5.8	14.3	103.1	1877	-1864	9.07	93	83.3	25.8	97.5	71.7
025	Pig3_025_cVAD_051013_1245_w_021	CF	1900	-	1.1	117	0.1	5.7	12.7	100.1	1752	-1669	6.83	92	81.7	22.9	94.6	71.7
025	Pig3_025_cVAD_051013_1247_w_022	CF	2000	-	0.4	117	0.0	6.1	12.2	93.2	1490	-1444	18.77	29	75.8	19.4	87.0	67.6
025	Pig3_025_cVAD_051013_1249_w_023	CF	670	-	14.4	117	1.7	8.7	22.6	93.1	1879	-1759	0.96	1054	59.3	49.1	85.0	35.9
025	Pig3_025_cVAD_051013_1301_w_024	PF	100	2.94/0.1	13.1	118	1.5	10.4	23.7	82.5	1340	-1371	1.02	805	53.1	42.1	75.2	33.0
025	Pig3_025_cVAD_051013_1304_w_025	PF	100	3.10/0.1	12.5	118	1.5	10.6	24.8	90.9	1545	-1673	1.09	881	60.4	45.3	83.7	38.4
025	Pig3_025_cVAD_051013_1306_w_026	PF	100	3.20/0.1	12.1	120	1.4	10.6	25.9	106.0	2039	-1894	1.17	933	66.9	46.8	90.7	43.9
025	Pig3_025_cVAD_051013_1309_w_027	PF	100	3.30/0.1	11.5	121	1.4	10.1	25.8	110.9	2207	-2174	1.28	982	74.1	49.5	98.9	49.5
025	Pig3_025_cVAD_051013_1311_w_028	PF	100	3.45/0.1	10.0	121	1.2	9.7	24.3	112.7	2228	-2469	1.54	875	81.7	48.5	105.8	57.3
025	Pig3_025_cVAD_051013_1313_w_029	PF	100	3.60/0.1	9.1	121	1.1	9.3	22.3	113.9	2200	-2516	1.55	810	84.4	45.7	107.3	61.5
025	Pig3_025_cVAD_051013_1315_w_030	PF	100	3.75/0.1	7.3	120	0.9	9.1	21.4	114.1	2127	-2473	1.94	657	85.8	42.7	107.6	64.8
025	Pig3_025_cVAD_051013_1317_w_031	PF	100	3.90/0.1	6.6	121	0.8	8.6	20.5	116.4	2180	-2555	2.35	616	88.4	42.6	110.0	67.5
025	Pig3_025_cVAD_051013_1319_w_032	PF	100	4.05/0.1	5.0	121	0.6	8.2	18.6	115.9	2100	-2492	3.70	466	89.2	40.3	109.7	69.4
025	Pig3_025_cVAD_051013_1324_w_034	PF	100	4.20/0.1	4.4	121	0.5	7.9	17.7	115.6	2071	-2432	3.67	417	91.0	36.5	109.4	72.9
025	Pig3_025_cVAD_051013_1325_w_035	PF	100	4.35/0.1	2.9	122	0.3	7.5	16.3	113.3	1946	-2226	8.35	263	89.1	36.4	106.8	70.4
025	Pig3_025_cVAD_051013_1326_w_036	PF	100	4.50/0.1	2.3	123	0.3	7.5	15.3	110.5	1789	-2054	16.46	209	89.5	33.0	105.6	72.5
025	Pig3_025_cVAD_051013_1328_w_037	PF	100	4.65/0.1	0.5	126	0.1	5.9	13.0	104.1	1582	-1551	28.81	31	84.9	39.6	103.7	64.0
025	Pig3_025_cVAD_051013_1332_w_038	PF	100	4.80/0.1	0.5	130	0.1	6.1	11.5	92.2	1401	-1531	13.27	14	76.1	31.3	93.1	61.8
025	Pig3_025_cVAD_051013_1334_w_039	PF	140	3.21/0.1	13.8	124	1.7	8.9	24.0	127.1	2860	-3237	1.13	1354	92.4	58.3	120.7	62.3
025	Pig3_025_cVAD_051013_1336_w_040	PF	140	3.35/0.1	11.6	123	1.4	8.9	23.2	132.9	2959	-3294	1.25	1218	99.6	55.2	126.7	71.5
025	Pig3_025_cVAD_051013_1338_w_041	PF	140	3.50/0.1	9.5	123	1.2	8.4	20.7	136.0	3064	-3416	1.32	1041	104.4	52.2	130.1	77.9
025	Pig3_025_cVAD_051013_1339_w_042	PF	140	3.65/0.1	7.9	124	1.0	7.7	18.3	136.5	3045	-3455	1.39	869	106.7	48.4	130.7	82.2
025	Pig3_025_cVAD_051013_1341_w_043	PF	140	3.80/0.1	6.9	124	0.9	7.1	16.2	135.1	2974	-3369	1.51	862	107.4	44.6	129.4	84.9
025	Pig3_025_cVAD_051013_1343_w_044	PF	140	3.95/0.1	6.2	124	0.8	6.7	14.3	131.9	2841	-3240	1.94	391	106.6	39.3	126.3	87.1
025	Pig3_025_cVAD_051013_1344_w_045	PF	140	4.10/0.1	5.6	125	0.7	6.2	12.7	129.6	2672	-3036	1.84	358	106.9	34.5	124.0	89.4
025	Pig3_025_cVAD_051013_1346_w_046	PF	140	4.25/0.1	2.5	126	0.3	5.8	11.4	127.1	2680	-2816	2.58	273	107.5	31.3	122.4	91.1
025	Pig3_025_cVAD_051013_1348_w_047	PF	140	4.40/0.1	0.8	129	0.1	5.3	9.9	118.2	2281	-2420	12.16	81	101.4	24.1	114.2	90.1
025	Pig3_025_cVAD_051013_1350_w_048	-	-	-	11.3	127	1.4	7.1	16.9	130.6	3126	-3580	0.87	1226	95.9	55.0	124.2	89.2
025	Pig3_025_cVAD_051013_1357_w_049	CF	1950	-	0.2	130	0.0	5.5	9.6	108.6	1737	-1782	34.53	6	98.9	11.5	104.6	93.2
025	Pig3_025_cVAD_051013_1403_w_049	CF	1860	-	0.0	130	0.0	6.1	10.6	114.0	1932	-1983	495.20	3	103.2	12.2	109.0	96.8
025	Pig3_025_cVAD_051013_1415_w_050	-	-	-	9.6	128	1.2	6.8	14.3	118.3	2853	-3215	0.78	957	85.7	50.7	112.2	61.5
025	Pig3_025_cVAD_051013_1419_w_051	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)	CdAF mean (L/min)	CdAF pulse (L/min)	CdAF peak positive (L/min)	CdAF peak negative (L/min)
025	Pig3_025_vAD_051013_1262_w_002	-	-	-	2915	16.2	15.7	9.8	1.84	7.82	6.60	-1.22	135.2	191.9	241.0	49.1
025	Pig3_025_vAD_051013_1142_w_003	-	-	-	3658	22.6	7.5	14.6	1.28	6.28	5.08	-1.21	119.1	243.7	273.9	30.2
025	Pig3_025_vAD_051013_1212_w_004	CF	1200	-	4583	18.1	7.8	11.3	1.58	7.82	6.90	-0.82	205.1	213.9	334.9	121.0
025	Pig3_025_vAD_051013_1214_w_005	CF	1300	-	5008	14.0	7.3	10.3	1.18	6.70	5.77	-0.93	172.2	206.3	302.0	95.7
025	Pig3_025_vAD_051013_1216_w_006	CF	1400	-	6657	14.5	8.5	10.1	0.81	6.48	5.23	-1.25	161.4	213.0	304.9	91.8
025	Pig3_025_vAD_051013_1217_w_007	CF	1500	-	13055	13.8	7.6	9.7	0.98	6.48	5.23	-1.11	159.3	164.8	266.6	103.8
025	Pig3_025_vAD_051013_1222_w_008	CF	840	-	2704	19.3	8.1	12.7	1.09	7.88	6.86	-1.02	124.4	325.4	341.4	16.0
025	Pig3_025_vAD_051013_1224_w_009	CF	700	-	2944	19.3	8.1	12.8	1.57	7.87	6.73	-1.14	124.5	318.9	336.8	17.9
025	Pig3_025_vAD_051013_1226_w_010	CF	800	-	3400	19.8	8.4	13.0	1.42	7.78	6.54	-1.24	134.3	302.3	332.8	30.6
025	Pig3_025_vAD_051013_1227_w_011	CF	900	-	4134	19.6	8.1	13.0	1.28	7.45	6.35	-1.10	140.9	278.1	319.5	41.4
025	Pig3_025_vAD_051013_1227_w_012	CF	1000	-	5102	18.8	7.9	12.5	1.07	7.12	6.09	-1.03	145.3	260.9	313.5	52.6
025	Pig3_025_vAD_051013_1228_w_013	CF	1100	-	6436	18.4	7.3	12.3	0.88	7.11	5.69	-1.42	151.0	233.6	298.4	85.8
025	Pig3_025_vAD_051013_1231_w_014	CF	1200	-	8478	17.8	7.0	12.0	0.68	6.77	5.28	-1.49	154.0	210.6	287.0	76.4
025	Pig3_025_vAD_051013_1233_w_015	CF	1300	-	11970	17.3	6.5	11.3	0.50	6.37	4.90	-1.47	160.4	188.5	278.7	102.2
025	Pig3_025_vAD_051013_1235_w_016	CF	1400	-	20920	16.7	6.3	10.9	0.30	5.94	4.47	-1.47	168.5	171.8	272.7	102.9
025	Pig3_025_vAD_051013_1237_w_017	CF	1500	-	74385	16.5	6.3	10.7	0.10	5.40	3.86	-1.54	172.0	153.4	268.6	115.2
025	Pig3_025_vAD_051013_1239_w_018	CF	1600	-	82320	16.6	6.4	10.6	-0.04	4.74	3.08	-1.62	177.5	133.8	281.3	127.5
025	Pig3_025_vAD_051013_1241_w_019	CF	1700	-	25049	15.7	6.1	10.1	-0.27	3.33	1.67	-1.66	174.7	118.2	251.5	133.3
025	Pig3_025_vAD_051013_1245_w_020	CF	1800	-	116851	15.3	6.1	9.7	-0.40	2.97	1.34	-1.64	177.9	101.1	246.1	144.9
025	Pig3_025_vAD_051013_1247_w_021	CF	1900	-	11294	14.3	6.1	9.4	-0.58	3.14	1.24	-1.91	181.5	91.1	244.9	153.8
025	Pig3_025_vAD_051013_1247_w_022	CF	2000	-	8445	13.3	6.5	9.1	-0.72	2.65	0.81	-1.84	178.3	77.4	231.1	153.7
025	Pig3_025_vAD_051013_1252_w_023	CF	670	-	2914	19.9	7.9	12.4	1.63	7.91	6.72	-1.19	117.8	238.7	261.7	23.0
025	Pig3_025_vAD_051013_1304_w_024	PF	100	2.94 / 0.1	2879	20.1	9.4	13.3	1.48	7.03	5.75	-1.29	92.5	114.3	154.1	39.7
025	Pig3_025_vAD_051013_1305_w_025	PF	100	3.00 / 0.1	3315	21.5	9.5	14.1	1.46	7.10	5.75	-1.35	86.0	89.4	133.4	44.0
025	Pig3_025_vAD_051013_1306_w_026	PF	100	3.10 / 0.1	3809	22.7	9.6	14.6	1.41	7.08	5.87	-1.22	81.9	77.0	121.0	44.0
025	Pig3_025_vAD_051013_1309_w_027	PF	100	3.20 / 0.1	4424	23.4	9.4	14.7	1.35	7.58	6.14	-1.43	85.8	76.3	124.3	48.0
025	Pig3_025_vAD_051013_1311_w_028	PF	100	3.30 / 0.1	4944	23.6	9.2	14.6	1.39	7.58	6.22	-1.36	92.8	82.1	133.7	51.6
025	Pig3_025_vAD_051013_1313_w_029	PF	100	3.45 / 0.1	6868	22.6	9.0	14.0	1.04	7.53	5.86	-1.67	94.4	77.5	132.3	54.9
025	Pig3_025_vAD_051013_1315_w_030	PF	100	3.60 / 0.1	8774	21.9	8.9	13.5	0.90	7.26	5.48	-1.78	88.3	66.2	119.8	53.6
025	Pig3_025_vAD_051013_1317_w_031	PF	100	3.75 / 0.1	15785	20.7	8.7	12.9	0.67	6.09	4.60	-1.50	90.2	63.0	119.7	56.8
025	Pig3_025_vAD_051013_1319_w_032	PF	100	3.90 / 0.1	15482	19.7	8.4	12.2	0.52	6.74	4.44	-2.30	94.8	66.6	125.5	58.9
025	Pig3_025_vAD_051013_1322_w_033	PF	100	4.05 / 0.1	10309	18.2	8.0	11.4	0.33	5.16	3.56	-1.60	99.8	70.0	130.9	60.9
025	Pig3_025_vAD_051013_1324_w_034	PF	100	4.20 / 0.1	40564	17.7	7.9	11.2	0.20	5.97	3.83	-2.14	110.6	74.1	141.6	67.5
025	Pig3_025_vAD_051013_1325_w_035	PF	100	4.35 / 0.1	94245	16.6	8.5	10.5	0.02	4.94	2.90	-2.04	120.6	88.4	157.1	88.6
025	Pig3_025_vAD_051013_1326_w_036	PF	100	4.50 / 0.1	7245	16.0	9.3	10.1	-0.12	4.35	2.37	-1.88	132.5	106.8	176.2	89.4
025	Pig3_025_vAD_051013_1329_w_037	PF	100	4.65 / 0.1	14243	15.3	7.3	9.0	-0.54	3.58	1.44	-2.14	138.6	142.9	198.7	56.8
025	Pig3_025_vAD_051013_1332_w_038	PF	100	4.80 / 0.1	8454	18.9	7.4	9.8	-0.57	7.49	2.79	-4.70	131.0	260.2	273.5	13.4
025	Pig3_025_vAD_051013_1336_w_039	PF	140	3.21 / 0.1	4826	20.9	10.8	13.9	1.56	12.77	8.76	-4.01	118.5	195.6	231.6	36.0
025	Pig3_025_vAD_051013_1338_w_040	PF	140	3.35 / 0.1	6998	20.7	8.6	13.5	1.34	9.73	7.55	-2.18	128.2	172.1	225.4	53.2
025	Pig3_025_vAD_051013_1339_w_041	PF	140	3.50 / 0.1	12253	18.6	10.3	12.2	1.07	9.51	7.32	-2.20	132.7	158.3	224.1	65.8
025	Pig3_025_vAD_051013_1339_w_041	PF	140	3.65 / 0.1	2481	16.7	9.6	11.0	0.79	8.53	6.60	-1.93	137.0	146.3	222.2	75.9
025	Pig3_025_vAD_051013_1343_w_043	PF	140	3.80 / 0.1	5049	15.0	6.2	9.5	0.59	11.68	7.07	-4.62	139.1	138.0	220.1	82.1
025	Pig3_025_vAD_051013_1344_w_044	PF	140	3.95 / 0.1	8312	13.6	3.2	7.2	0.38	10.89	6.02	-4.87	141.8	128.2	217.1	88.9
025	Pig3_025_vAD_051013_1346_w_045	PF	140	4.10 / 0.1	3387	12.8	2.8	6.5	0.19	8.22	4.43	-3.80	143.8	119.4	212.1	92.7
025	Pig3_025_vAD_051013_1348_w_046	PF	140	4.25 / 0.1	9205	12.0	2.5	5.9	0.06	4.45	2.82	-1.63	143.7	115.0	206.3	91.3
025	Pig3_025_vAD_051013_1360_w_047	PF	140	4.40 / 0.1	17539	11.4	2.5	5.4	-0.22	4.04	1.90	-2.14	139.9	105.1	194.3	89.2
025	Pig3_025_vAD_051013_1367_w_048	-	-	-	5820	14.8	3.6	8.3	1.33	8.54	7.20	-1.35	96.7	127.4	173.4	46.0
025	Pig3_025_vAD_051013_1403_w_049	CF	1950	-	29665	10.2	1.9	4.9	-0.36	2.53	0.96	-1.57	103.2	23.4	115.8	92.5
025	Pig3_025_vAD_051013_1415_w_050	CF	1860	-	16175	11.1	2.1	5.3	-0.52	1.87	0.25	-1.82	77.5	21.5	89.2	87.7
025	Pig3_025_vAD_051013_1419_w_051	-	-	-	6077	11.9	2.7	6.5	1.13	8.11	6.96	-1.14	57.7	68.5	99.4	30.9

Piglet3 Number	Filename	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)	pCAS Inlet Pres. mean (mmHg)	pCAS Inlet Pres. max (mmHg)	pCAS Inlet Pres. min (mmHg)	pCAS Outlet Pres. mean (mmHg)	pCAS Outlet Pres. max (mmHg)	pCAS Outlet Pres. min (mmHg)	pCAS ΔP (mmHg)
025	Pg3_025_eVAD_051013_1052_w_002	-	-	-	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0
025	Pg3_025_eVAD_051013_1142_w_003	-	-	-	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0
025	Pg3_025_eVAD_051013_1212_w_004	CF	1200	-	0.67	0.62	1.02	0.41	42	116	-19	105	179	46	63
025	Pg3_025_eVAD_051013_1214_w_005	CF	1300	-	0.93	0.47	1.20	0.74	24	85	-22	98	160	52	74
025	Pg3_025_eVAD_051013_1216_w_006	CF	1400	-	1.13	0.41	1.36	0.95	13	79	-27	97	162	58	85
025	Pg3_025_eVAD_051013_1217_w_007	CF	1500	-	1.31	0.40	1.53	1.13	3	56	-32	102	155	69	99
025	Pg3_025_eVAD_051013_1222_w_008	CF	640	-	-0.02	0.48	0.27	-0.21	38	99	-1	55	115	17	17
025	Pg3_025_eVAD_051013_1224_w_009	CF	700	-	0.07	0.49	0.36	-0.12	37	98	0	58	117	21	21
025	Pg3_025_eVAD_051013_1226_w_010	CF	800	-	0.19	0.52	0.51	-0.02	37	98	0	64	125	27	27
025	Pg3_025_eVAD_051013_1227_w_011	CF	900	-	0.32	0.55	0.65	0.10	36	97	-2	71	131	34	35
025	Pg3_025_eVAD_051013_1229_w_012	CF	1000	-	0.46	0.55	0.80	0.24	33	95	-3	77	138	40	44
025	Pg3_025_eVAD_051013_1230_w_013	CF	1100	-	0.59	0.55	0.92	0.38	30	90	-7	83	141	49	53
025	Pg3_025_eVAD_051013_1231_w_014	CF	1200	-	0.73	0.54	1.05	0.52	26	84	-8	89	146	54	63
025	Pg3_025_eVAD_051013_1233_w_015	CF	1300	-	0.87	0.54	1.19	0.65	22	81	-12	97	154	63	75
025	Pg3_025_eVAD_051013_1235_w_016	CF	1400	-	1.00	0.54	1.33	0.79	18	75	-18	105	162	72	87
025	Pg3_025_eVAD_051013_1237_w_017	CF	1500	-	1.14	0.55	1.46	0.91	14	69	-22	114	172	80	100
025	Pg3_025_eVAD_051013_1239_w_018	CF	1600	-	1.29	0.57	1.62	1.06	9	67	-28	124	177	88	115
025	Pg3_025_eVAD_051013_1241_w_019	CF	1700	-	1.44	0.55	1.76	1.21	1	57	-35	130	183	97	129
025	Pg3_025_eVAD_051013_1243_w_020	CF	1800	-	1.59	0.56	1.91	1.36	-5	49	-42	140	191	104	145
025	Pg3_025_eVAD_051013_1245_w_021	CF	1900	-	1.75	0.52	2.06	1.54	-15	37	-50	148	201	115	162
025	Pg3_025_eVAD_051013_1247_w_022	CF	2000	-	1.92	0.56	2.22	1.66	-27	23	-65	154	201	115	181
025	Pg3_025_eVAD_051013_1252_w_023	CF	670	-	-0.03	0.51	0.28	-0.23	39	95	1	58	115	19	20
025	Pg3_025_eVAD_051013_1304_w_024	PF	100	2.94/0.1	0.02	0.56	0.28	-0.28	36	86	-12	53	112	12	17
025	Pg3_025_eVAD_051013_1306_w_025	PF	100	3.00/0.1	0.00	0.66	0.30	-0.36	40	93	-17	60	129	13	20
025	Pg3_025_eVAD_051013_1308_w_026	PF	100	3.10/0.1	0.07	0.82	0.45	-0.37	41	100	-23	68	147	17	27
025	Pg3_025_eVAD_051013_1309_w_027	PF	100	3.20/0.1	0.16	1.00	0.61	-0.38	42	109	-31	77	169	17	34
025	Pg3_025_eVAD_051013_1311_w_028	PF	100	3.30/0.1	0.27	1.17	0.80	-0.37	42	114	-42	84	187	18	42
025	Pg3_025_eVAD_051013_1313_w_029	PF	100	3.45/0.1	0.47	1.43	1.14	-0.28	38	115	-59	93	208	18	56
025	Pg3_025_eVAD_051013_1315_w_030	PF	100	3.60/0.1	0.65	1.66	1.46	-0.20	33	116	-74	102	229	20	70
025	Pg3_025_eVAD_051013_1317_w_031	PF	100	3.75/0.1	0.82	1.89	1.77	-0.12	26	115	-87	111	251	21	85
025	Pg3_025_eVAD_051013_1319_w_032	PF	100	3.90/0.1	0.99	2.18	2.10	-0.08	21	115	-116	122	280	22	101
025	Pg3_025_eVAD_051013_1322_w_033	PF	100	4.05/0.1	1.16	2.41	2.41	0.00	14	114	-134	131	312	22	118
025	Pg3_025_eVAD_051013_1324_w_034	PF	100	4.20/0.1	1.33	2.69	2.77	0.08	4	113	-157	145	336	23	141
025	Pg3_025_eVAD_051013_1325_w_035	PF	100	4.35/0.1	1.49	2.98	3.09	0.11	-5	106	-183	152	367	25	157
025	Pg3_025_eVAD_051013_1328_w_036	PF	100	4.50/0.1	1.61	3.24	3.41	0.17	-20	101	-209	162	396	28	182
025	Pg3_025_eVAD_051013_1330_w_037	PF	100	4.65/0.1	1.88	3.68	3.82	0.14	-28	101	-324	165	399	-10	193
025	Pg3_025_eVAD_051013_1332_w_038	PF	100	4.80/0.1	1.85	5.25	5.03	-0.22	-55	101	-396	158	399	-78	213
025	Pg3_025_eVAD_051013_1336_w_039	PF	140	3.21/0.1	-0.05	0.95	0.47	-0.48	49	133	-36	92	192	17	43
025	Pg3_025_eVAD_051013_1338_w_040	PF	140	3.35/0.1	0.16	1.03	0.71	-0.31	47	138	-45	104	213	21	56
025	Pg3_025_eVAD_051013_1339_w_041	PF	140	3.50/0.1	0.41	1.23	1.04	-0.19	42	140	-67	115	241	28	72
025	Pg3_025_eVAD_051013_1341_w_042	PF	140	3.65/0.1	0.62	1.35	1.31	-0.04	36	136	-74	124	263	30	88
025	Pg3_025_eVAD_051013_1343_w_043	PF	140	3.80/0.1	0.80	1.52	1.59	0.07	29	133	-91	131	282	31	102
025	Pg3_025_eVAD_051013_1344_w_044	PF	140	3.95/0.1	1.02	1.66	1.88	0.23	19	129	-113	140	307	34	121
025	Pg3_025_eVAD_051013_1346_w_045	PF	140	4.10/0.1	1.22	1.87	2.20	0.33	8	122	-137	150	331	40	142
025	Pg3_025_eVAD_051013_1348_w_046	PF	140	4.25/0.1	1.36	2.13	2.51	0.38	-3	120	-161	159	352	39	162
025	Pg3_025_eVAD_051013_1350_w_047	PF	140	4.40/0.1	1.58	2.18	2.71	0.54	-24	115	-205	166	355	0	190
025	Pg3_025_eVAD_051013_1357_w_048	-	-	-	0.01	0.14	0.09	-0.05	44	166	-46	45	174	-52	1
025	Pg3_025_eVAD_051013_1403_w_049	CF	1950	-	1.58	0.81	2.00	1.19	-19	33	-77	156	205	105	175
025	Pg3_025_eVAD_051013_1415_w_050	CF	1860	-	1.42	0.72	1.83	1.12	-8	52	-49	152	207	110	160
025	Pg3_025_eVAD_051013_1419_w_051	-	-	-	0.01	0.12	0.08	-0.04	36	154	-40	37	162	-44	1

* Files 037 & 038 - Max Outlet pressure exceeded 400mmHg limit.

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV HR (bpm)	LV SV (ml)	LV CO (L/min)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)
003	PCAS_03_003_051108_1745.w_049	-	Normal	-	-	-	120	6.7	0.81	70.9	50.8	103.4	52.6	7451	43.4	-27.3	12.8	0.77	6.05	5.27	-0.78
003	PCAS_03_003_051108_1747.w_050	CPS	Normal	CF	0	-	120	7.0	0.85	43.7	68.0	87.3	19.3	4242	44.8	-26.2	13.3	0.84	7.27	6.55	-0.72
003	PCAS_03_003_051108_1752.w_051	CPS	Normal	CF	1140	-	120	6.4	0.77	71.4	50.1	103.3	53.2	7526	43.3	-27.0	12.7	0.77	6.11	5.35	-0.75
003	PCAS_03_003_051108_1754.w_052	CPS	Normal	CF	1200	-	120	6.5	0.79	75.9	45.5	105.7	60.2	7909	43.1	-27.0	12.6	0.77	5.72	5.14	-0.58
003	PCAS_03_003_051108_1755.w_053	CPS	Normal	CF	1300	-	120	6.4	0.77	82.1	38.1	107.3	69.2	9199	43.0	-15.9	12.5	0.73	5.28	4.74	-0.54
003	PCAS_03_003_051108_1757.w_054	CPS	Normal	CF	1400	-	120	6.5	0.78	88.8	34.5	111.7	77.2	9542	42.9	-27.4	12.3	0.75	4.86	4.43	-0.43
003	PCAS_03_003_051108_1758.w_055	CPS	Normal	CF	1500	-	120	6.0	0.72	94.5	30.2	114.4	84.2	11050	42.8	-26.8	12.2	0.70	4.50	4.04	-0.46
003	PCAS_03_003_051108_1759.w_056	CPS	Normal	CF	1600	-	120	5.6	0.67	100.5	25.4	117.4	92.0	11921	42.5	-17.7	12.1	0.69	4.28	3.68	-0.60
003	PCAS_03_003_051108_1801.w_057	CPS	Normal	CF	1700	-	120	5.1	0.62	105.2	22.1	120.5	98.4	15000	42.2	-22.8	12.1	0.58	4.0	3.3	-0.7
003	PCAS_03_003_051108_1802.w_058	CPS	Normal	CF	1800	-	120	4.7	0.57	109.1	18.5	121.0	100.6	17950	41.2	-4.8	12.2	0.50	3.8	3.1	-0.7
003	PCAS_03_003_051108_1803.w_059	CPS	Normal	CF	1900	-	120	4.3	0.51	109.1	18.5	121.9	103.5	20902	36.9	-11.3	12.3	0.43	3.4	2.8	-0.6
003	PCAS_03_003_051108_1805.w_060	CPS	Normal	CF	2000	-	120	4.0	0.48	112.3	16.4	123.7	107.3	22790	34.5	-15.5	12.2	0.40	3.0	2.5	-0.5
003	PCAS_03_003_051108_1818.w_061	-	Normal	-	-	-	120	6.6	0.79	70.2	50.4	102.7	52.2	7235	44.8	-27.4	13.3	0.78	6.1	5.4	-0.6
003	PCAS_03_003_051108_1827.w_062	CPS	Normal	PF	100	3.35 / 0.1	120	6.5	0.78	70.6	49.3	102.2	52.9	7386	45.4	-27.3	13.3	0.77	6.1	5.4	-0.6
003	PCAS_03_003_051108_1829.w_063	CPS	Normal	PF	100	3.50 / 0.1	120	6.3	0.76	76.9	43.8	106.1	62.3	8060	45.3	-27.8	13.2	0.77	5.7	5.1	-0.6
003	PCAS_03_003_051108_1830.w_064	CPS	Normal	PF	100	3.65 / 0.1	120	6.4	0.77	82.7	38.8	108.6	69.8	8538	45.1	-28.1	13.1	0.78	5.3	4.8	-0.5
003	PCAS_03_003_051108_1832.w_065	CPS	Normal	PF	100	3.80 / 0.1	120	6.4	0.76	87.8	33.9	110.3	76.4	9483	44.8	-28.2	13.0	0.75	4.9	4.5	-0.4
003	PCAS_03_003_051108_1833.w_066	CPS	Normal	PF	100	3.95 / 0.1	120	6.2	0.75	92.7	31.1	113.0	81.9	9813	44.5	-28.0	12.9	0.76	4.5	4.1	-0.4
003	PCAS_03_003_051108_1834.w_067	CPS	Normal	PF	100	4.10 / 0.1	120	5.7	0.69	97.1	27.6	115.3	87.6	11259	43.7	-24.8	12.7	0.70	4.4	3.9	-0.5
003	PCAS_03_003_051108_1836.w_068	CPS	Normal	PF	100	4.25 / 0.1	120	5.7	0.68	100.4	24.8	117.1	92.3	12608	43.0	-17.8	12.5	0.67	4.1	3.7	-0.4
003	PCAS_03_003_051108_1837.w_069	CPS	Normal	PF	100	4.40 / 0.1	120	5.3	0.64	103.5	23.0	119.2	96.2	13475	42.3	-9.6	12.5	0.64	3.9	3.4	-0.5
003	PCAS_03_003_051108_1847.w_070	CPS	Normal	PF	140	3.30 / 0.1	120	6.3	0.76	71.5	48.3	102.9	54.5	7815	43.9	-27.8	12.6	0.74	6.0	5.3	-0.7
003	PCAS_03_003_051108_1850.w_071	CPS	Normal	PF	140	3.45 / 0.1	120	6.1	0.73	79.6	41.3	107.8	66.5	8856	43.8	-28.1	12.4	0.75	5.6	4.9	-0.7
003	PCAS_03_003_051108_1852.w_072	CPS	Normal	PF	140	3.50 / 0.1	120	5.9	0.72	82.0	39.2	108.8	69.6	9434	43.6	-28.2	12.3	0.71	5.5	4.8	-0.7
003	PCAS_03_003_051108_1855.w_073	CPS	Normal	PF	140	3.65 / 0.1	120	5.9	0.71	89.3	33.1	111.3	78.2	10247	43.6	-28.6	12.2	0.71	4.9	4.3	-0.6
003	PCAS_03_003_051108_1853.w_074	CPS	Normal	PF	140	3.80 / 0.1	120	5.5	0.66	95.4	28.6	114.2	85.6	11503	43.3	-28.0	12.2	0.68	4.5	4.0	-0.5
003	PCAS_03_003_051108_1854.w_075	CPS	Normal	PF	140	3.95 / 0.1	120	5.3	0.64	101.1	24.2	117.6	93.3	12456	42.9	-26.7	12.1	0.66	4.2	3.6	-0.6
003	PCAS_03_003_051108_1855.w_076	CPS	Normal	PF	140	4.10 / 0.1	120	5.3	0.64	102.2	23.6	118.3	94.8	13471	42.6	-25.1	12.0	0.62	4.1	3.5	-0.6
003	PCAS_03_003_051108_1856.w_077	CPS	Normal	PF	140	4.25 / 0.1	120	4.9	0.59	106.4	20.6	120.8	100.2	16685	41.2	-15.5	12.0	0.55	3.8	3.2	-0.6

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	CAF mean (mL/min)	CAF peak sys (mL/min)	CAF mean sys (mL/min)	CAF peak dias (mL/min)	CAF mean dias (mL/min)	CAF ratio	CdAF mean (mL/min)	CdAF pulse (mL/min)	CdAF peak positive (mL/min)	CdAF peak negative (mL/min)
003	PCAS_03_003_051108_1745_w_049	-	Normal	-	-	-	53.0	62.1	50.2	70.9	55.9	1.1	102.5	103.2	172.8	69.5
003	PCAS_03_003_051108_1747_w_050	CPS	Normal	CF	0	-	31.9	50.4	32.5	54.1	31.4	1.0	66.4	122.0	143.3	21.3
003	PCAS_03_003_051108_1752_w_051	CPS	Normal	CF	1140	-	53.2	61.6	50.2	69.4	56.4	1.1	103.9	113.2	180.7	67.6
003	PCAS_03_003_051108_1754_w_052	CPS	Normal	CF	1200	-	56.5	63.2	54.0	68.2	59.0	1.1	108.4	114.0	186.9	71.9
003	PCAS_03_003_051108_1755_w_053	CPS	Normal	CF	1300	-	59.6	64.5	58.0	68.7	61.3	1.1	115.2	105.7	186.5	80.8
003	PCAS_03_003_051108_1757_w_054	CPS	Normal	CF	1400	-	63.7	68.4	62.5	70.8	64.8	1.0	121.2	107.2	190.2	82.9
003	PCAS_03_003_051108_1758_w_055	CPS	Normal	CF	1500	-	67.7	72.0	65.9	76.6	69.5	1.1	126.3	99.6	188.6	89.0
003	PCAS_03_003_051108_1759_w_056	CPS	Normal	CF	1600	-	70.8	75.8	70.0	77.6	71.6	1.0	131.1	87.0	185.0	98.0
003	PCAS_03_003_051108_1801_w_057	CPS	Normal	CF	1700	-	73.3	77.2	71.6	81.4	75.0	1.0	135.8	80.2	185.6	105.4
003	PCAS_03_003_051108_1802_w_058	CPS	Normal	CF	1800	-	75.3	80.3	73.5	85.9	77.1	1.1	136.2	74.2	181.9	107.7
003	PCAS_03_003_051108_1803_w_059	CPS	Normal	CF	1900	-	76.2	82.9	73.0	90.9	79.4	1.1	137.9	71.6	179.6	107.9
003	PCAS_03_003_051108_1805_w_060	CPS	Normal	CF	2000	-	76.9	112.1	78.0	115.5	77.9	1.0	127.5	73.6	168.0	94.4
003	PCAS_03_003_051108_1818_w_061	-	Normal	-	-	-	52.2	62.8	50.0	71.3	54.5	1.1	108.2	126.6	197.4	70.8
003	PCAS_03_003_051108_1827_w_062	CPS	Normal	PF	100	3.35 / 0.1	52.2	63.2	50.8	69.7	53.7	1.1	108.3	122.9	191.1	68.2
003	PCAS_03_003_051108_1829_w_063	CPS	Normal	PF	100	3.50 / 0.1	56.1	65.1	54.2	73.3	57.9	1.1	114.8	124.3	196.0	71.7
003	PCAS_03_003_051108_1830_w_064	CPS	Normal	PF	100	3.65 / 0.1	59.9	68.1	58.7	73.5	61.3	1.0	122.2	118.4	198.7	80.3
003	PCAS_03_003_051108_1832_w_065	CPS	Normal	PF	100	3.80 / 0.1	63.4	73.1	62.2	78.7	64.7	1.0	127.2	108.9	197.6	88.7
003	PCAS_03_003_051108_1833_w_066	CPS	Normal	PF	100	3.95 / 0.1	68.0	103.4	67.4	95.4	68.6	1.0	130.1	104.5	196.2	91.7
003	PCAS_03_003_051108_1834_w_067	CPS	Normal	PF	100	4.10 / 0.1	69.3	130.7	68.8	115.4	69.9	1.0	132.4	106.1	192.8	86.7
003	PCAS_03_003_051108_1836_w_068	CPS	Normal	PF	100	4.25 / 0.1	79.0	146.3	79.7	131.2	78.2	1.0	126.3	123.4	192.1	68.7
003	PCAS_03_003_051108_1837_w_069	CPS	Normal	PF	100	4.40 / 0.1	83.2	173.8	83.0	167.2	83.4	1.0	149.4	157.4	231.7	74.3
003	PCAS_03_003_051108_1847_w_070	CPS	Normal	PF	140	3.30 / 0.1	52.7	87.9	51.7	74.8	53.6	1.0	102.0	134.7	190.7	56.0
003	PCAS_03_003_051108_1849_w_071	CPS	Normal	PF	140	3.45 / 0.1	56.1	90.4	55.5	77.5	56.7	1.0	110.6	134.4	196.9	62.5
003	PCAS_03_003_051108_1850_w_072	CPS	Normal	PF	140	3.50 / 0.1	58.3	89.4	57.1	80.3	59.6	1.0	112.9	133.2	197.6	64.4
003	PCAS_03_003_051108_1851_w_073	CPS	Normal	PF	140	3.65 / 0.1	63.1	88.5	61.5	85.0	64.9	1.1	120.5	116.4	194.8	78.4
003	PCAS_03_003_051108_1853_w_074	CPS	Normal	PF	140	3.80 / 0.1	68.4	98.4	67.0	92.0	69.8	1.0	126.8	109.4	193.4	84.1
003	PCAS_03_003_051108_1854_w_075	CPS	Normal	PF	140	3.95 / 0.1	71.5	106.1	71.1	100.4	72.0	1.0	132.0	98.6	192.7	94.1
003	PCAS_03_003_051108_1855_w_076	CPS	Normal	PF	140	4.10 / 0.1	70.3	106.4	68.5	104.4	79.7	1.1	131.4	97.7	189.3	91.6
003	PCAS_03_003_051108_1856_w_077	CPS	Normal	PF	140	4.25 / 0.1	77.4	119.9	75.2	120.3	72.0	1.1	125.1	104.7	183.0	78.4

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)	Inlet mean (mmHg)	Outlet mean (mmHg)	Inlet peak positive (mmHg)	Inlet peak negative (mmHg)	Outlet peak positive (mmHg)	Outlet peak negative (mmHg)	pCAS ΔP (mmHg)
003	PCAS_03_003_051108_1745.w_049	-	Normal	-	-	-	0.00	0.01	0.00	-0.01	5.5	3	6	5	3	3	-3
003	PCAS_03_003_051108_1747.w_090	CPS	Normal	CF	0	-	0.35	0.37	0.49	0.12	36.9	35	70	-11	71	-9	-2
003	PCAS_03_003_051108_1752.w_051	CPS	Normal	CF	1140	-	0.00	0.30	0.22	-0.08	3.6	68	29	-40	97	26	64
003	PCAS_03_003_051108_1754.w_082	CPS	Normal	CF	1200	-	0.06	0.30	0.26	-0.02	1.0	73	22	-42	98	31	72
003	PCAS_03_003_051108_1755.w_053	CPS	Normal	CF	1300	-	0.14	0.29	0.37	0.07	-4.6	80	15	-46	102	43	84
003	PCAS_03_003_051108_1757.w_054	CPS	Normal	CF	1400	-	0.21	0.30	0.43	0.13	-11.2	88	11	-54	111	49	99
003	PCAS_03_003_051108_1758.w_055	CPS	Normal	CF	1500	-	0.28	0.30	0.49	0.19	-19.5	94	2	-65	118	54	114
003	PCAS_03_003_051108_1759.w_056	CPS	Normal	CF	1600	-	0.34	0.27	0.53	0.26	-29.3	102	-8	-72	124	62	131
003	PCAS_03_003_051108_1801.w_057	CPS	Normal	CF	1700	-	0.40	0.23	0.56	0.33	-40.2	108	-21	-78	130	71	148
003	PCAS_03_003_051108_1802.w_058	CPS	Normal	CF	1800	-	0.47	0.24	0.63	0.39	-54.0	111	-34	-91	134	75	165
003	PCAS_03_003_051108_1803.w_059	CPS	Normal	CF	1900	-	0.55	0.32	0.74	0.42	-71.2	116	-51	-107	141	82	187
003	PCAS_03_003_051108_1805.w_060	CPS	Normal	CF	2000	-	0.61	0.62	0.94	0.32	-86.3	121	-68	-116	145	88	207
003	PCAS_03_003_051108_1818.w_061	-	Normal	-	-	-	0.00	0.01	0.01	0.00	2.1	-1	2	2	-1	-1	-3
003	PCAS_03_003_051108_1827.w_062	CPS	Normal	PF	100	3.35/0.1	0.00	0.87	0.46	-0.41	4.7	67	68	-102	140	13	63
003	PCAS_03_003_051108_1829.w_063	CPS	Normal	PF	100	3.50/0.1	0.07	1.04	0.62	-0.42	-4.9	75	67	-128	160	18	80
003	PCAS_03_003_051108_1830.w_064	CPS	Normal	PF	100	3.65/0.1	0.14	1.23	0.81	-0.42	-17.3	83	67	-158	175	22	100
003	PCAS_03_003_051108_1832.w_065	CPS	Normal	PF	100	3.80/0.1	0.21	1.49	1.04	-0.45	-30.9	90	68	-188	195	26	121
003	PCAS_03_003_051108_1833.w_066	CPS	Normal	PF	100	3.95/0.1	0.26	1.82	1.33	-0.49	-43.2	96	69	-202	196	27	139
003	PCAS_03_003_051108_1834.w_067	CPS	Normal	PF	100	4.10/0.1	0.33	2.27	1.71	-0.56	-52.9	102	69	-202	196	30	155
003	PCAS_03_003_051108_1836.w_068	CPS	Normal	PF	100	4.25/0.1	0.38	2.89	2.24	-0.65	-58.6	105	70	-202	196	11	164
003	PCAS_03_003_051108_1837.w_069	CPS	Normal	PF	100	4.40/0.1	0.43	3.68	2.86	-0.82	-63.4	108	68	-202	196	-12	171
003	PCAS_03_003_051108_1847.w_070	CPS	Normal	PF	140	3.30/0.1	0.00	0.64	0.31	-0.33	5.2	68	57	-85	131	10	62
003	PCAS_03_003_051108_1849.w_071	CPS	Normal	PF	140	3.45/0.1	0.09	0.77	0.46	-0.31	-4.8	77	57	-103	149	18	81
003	PCAS_03_003_051108_1850.w_072	CPS	Normal	PF	140	3.50/0.1	0.12	0.82	0.53	-0.30	-8.9	80	57	-109	158	19	89
003	PCAS_03_003_051108_1851.w_073	CPS	Normal	PF	140	3.65/0.1	0.20	0.97	0.69	-0.28	-20.8	89	57	-135	182	23	109
003	PCAS_03_003_051108_1853.w_074	CPS	Normal	PF	140	3.80/0.1	0.28	1.14	0.88	-0.27	-34.9	97	59	-165	196	25	132
003	PCAS_03_003_051108_1854.w_075	CPS	Normal	PF	140	3.95/0.1	0.34	1.34	1.10	-0.24	-48.7	104	56	-199	196	31	153
003	PCAS_03_003_051108_1855.w_076	CPS	Normal	PF	140	4.10/0.1	0.36	1.68	1.33	-0.35	-58.3	105	59	-202	196	31	163
003	PCAS_03_003_051108_1856.w_077	CPS	Normal	PF	140	4.25/0.1	0.44	1.96	1.70	-0.26	-70.8	109	53	-202	196	35	180

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV HR (bpm)	LV SV (ml)	LV CO (L/min)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)
003	PCAS_03_003_051108_1911_w_078	-	Normal	-	-	-	120	6.3	0.76	73.1	46.8	104.1	57.3	7696	44.0	-26.3	12.9	0.77	5.9	5.3	-0.6
003	PCAS_03_003_051108_1920_w_079	-	RVF	-	-	-	120	5.7	0.68	66.6	48.6	97.7	49.1	8248	34.4	-28.0	8.1	0.66	6.0	5.1	-0.8
003	PCAS_03_003_051108_1922_w_080	CPS	RVF	CF	0	-	120	5.7	0.69	42.7	61.5	81.5	20.0	5118	34.1	-27.4	8.0	0.68	6.6	5.9	-0.7
003	PCAS_03_003_051108_1924_w_081	CPS	RVF	CF	960	-	120	5.3	0.64	63.2	48.1	94.1	46.0	8737	32.6	-27.9	7.6	0.59	6.1	5.1	-1.0
003	PCAS_03_003_051108_1926_w_082	CPS	RVF	CF	1000	-	120	5.1	0.61	64.5	45.7	94.1	48.4	9374	30.5	-28.4	7.0	0.56	5.9	4.9	-1.0
003	PCAS_03_003_051108_1927_w_083	CPS	RVF	CF	1100	-	120	4.8	0.58	69.0	42.3	96.5	54.2	10597	29.1	-25.6	6.5	0.53	5.7	4.6	-1.1
003	PCAS_03_003_051108_1928_w_084	CPS	RVF	CF	1200	-	120	4.5	0.54	72.9	36.9	96.1	59.2	12369	29.1	-3.1	6.0	0.49	5.2	4.3	-0.9
003	PCAS_03_003_051108_1930_w_085	CPS	RVF	CF	1300	-	120	3.9	0.47	72.9	32.4	93.7	61.3	13551	27.2	-0.7	5.8	0.44	4.5	3.8	-0.7
003	PCAS_03_003_051108_1931_w_086	CPS	RVF	CF	1400	-	120	3.5	0.41	74.0	29.2	92.9	63.7	15352	26.7	1.5	5.8	0.39	4.1	3.5	-0.6
003	PCAS_03_003_051108_1932_w_087	CPS	RVF	CF	1500	-	120	3.2	0.39	77.6	27.1	95.1	68.0	17422	25.4	1.9	5.4	0.36	3.9	3.2	-0.6
003	PCAS_03_003_051108_1934_w_088	CPS	RVF	CF	1600	-	120	3.0	0.37	81.9	25.1	96.3	73.2	19428	24.5	1.8	4.9	0.34	3.6	3.0	-0.6
003	PCAS_03_003_051108_1935_w_089	CPS	RVF	CF	1700	-	120	2.9	0.35	87.1	22.7	102.1	79.4	22145	23.7	1.9	4.8	0.32	3.4	2.8	-0.5
003	PCAS_03_003_051108_1936_w_090	CPS	RVF	CF	1800	-	120	2.7	0.33	92.2	20.3	105.5	85.1	25748	22.9	2.4	5.1	0.29	3.2	2.6	-0.5
003	PCAS_03_003_051108_1937_w_091	CPS	RVF	CF	1900	-	120	2.6	0.31	96.7	17.8	108.7	90.9	33059	21.6	2.5	4.9	0.24	3.0	2.4	-0.5
003	PCAS_03_003_051108_1938_w_092	CPS	RVF	CF	2000	-	120	2.4	0.28	101.1	16.2	112.1	95.9	38247	20.9	2.3	4.9	0.22	2.8	2.2	-0.5
003	PCAS_03_003_051108_1954_w_093	-	RVF	-	-	-	120	6.5	0.78	64.3	53.7	98.8	45.1	6696	39.4	-25.7	9.6	0.78	6.3	5.6	-0.7
003	PCAS_03_003_051108_1959_w_094	CPS	RVF	PF	100	3.05 / 0.1	120	5.4	0.85	52.6	53.6	88.1	34.5	6918	33.9	-23.2	10.1	0.62	6.3	5.4	-0.9
003	PCAS_03_003_051108_2000_w_095	CPS	RVF	PF	100	3.20 / 0.1	120	5.3	0.84	57.7	49.7	91.0	41.3	7622	33.7	-23.4	10.1	0.62	6.0	5.2	-0.8
003	PCAS_03_003_051108_2001_w_096	CPS	RVF	PF	100	3.35 / 0.1	120	5.2	0.82	62.4	46.0	93.4	47.4	8756	33.4	-23.5	10.1	0.58	5.9	5.0	-0.9
003	PCAS_03_003_051108_2002_w_097	CPS	RVF	PF	100	3.50 / 0.1	120	5.2	0.83	68.5	43.6	97.7	54.1	9384	35.0	-23.9	9.9	0.60	5.8	4.9	-0.9
003	PCAS_03_003_051108_2004_w_098	CPS	RVF	PF	100	3.65 / 0.1	120	5.2	0.83	73.9	41.3	101.5	60.2	9810	36.0	-23.7	9.7	0.63	5.5	4.7	-0.8
003	PCAS_03_003_051108_2005_w_099	CPS	RVF	PF	100	3.80 / 0.1	120	5.5	0.86	81.0	36.8	105.8	69.0	9506	39.3	-14.1	9.3	0.70	5.2	4.5	-0.7
003	PCAS_03_003_051108_2006_w_100	CPS	RVF	PF	100	3.95 / 0.1	120	5.5	0.86	84.2	33.5	106.8	73.4	10165	38.8	-2.8	9.2	0.68	4.9	4.3	-0.6
003	PCAS_03_003_051108_2009_w_101	CPS	RVF	PF	100	4.10 / 0.1	120	4.9	0.59	86.3	31.5	107.5	76.0	13118	36.9	-4.1	9.3	0.56	4.7	4.1	-0.7
003	PCAS_03_003_051108_2028_w_102	-	RVF	-	-	-	120	4.9	0.58	63.7	44.9	93.4	48.5	9599	28.5	-27.1	8.9	0.54	5.5	4.7	-0.8
003	PCAS_03_003_051108_2032_w_103	CPS	RVF	PF	140	3.12 / 0.1	120	4.7	0.56	62.5	44.3	91.6	47.3	9717	27.3	-27.7	8.5	0.53	5.5	4.7	-0.8
003	PCAS_03_003_051108_2034_w_104	CPS	RVF	PF	140	3.20 / 0.1	120	4.6	0.55	66.4	41.7	93.9	52.2	10725	26.9	-27.9	8.3	0.51	5.4	4.5	-0.9
003	PCAS_03_003_051108_2036_w_105	CPS	RVF	PF	140	3.35 / 0.1	120	3.9	0.46	76.5	31.6	96.8	65.3	14210	25.9	-0.4	6.9	0.44	4.3	3.7	-0.6
003	PCAS_03_003_051108_2041_w_106	CPS	RVF	PF	140	3.80 / 0.1	120	2.8	0.33	81.3	24.6	97.5	72.9	17173	23.2	1.5	3.7	0.30	3.5	2.9	-0.6
003	PCAS_03_003_051108_2041_w_107	CPS	RVF	PF	140	3.95 / 0.1	120	2.7	0.33	87.1	22.7	102.0	79.3	25793	22.5	1.8	3.9	0.28	3.3	2.8	-0.6
003	PCAS_03_003_051108_2042_w_108	CPS	RVF	PF	140	4.10 / 0.1	120	2.6	0.31	93.2	19.9	106.2	86.3	28911	21.7	2.1	4.3	0.27	3.1	2.6	-0.6

MCS Number	003	PCAS_03_003_051108_1911_w_078	Assist Condition	-	Heart Condition Simulated	Normal	Device Mode (CF or PF)	-	Device Setting (rpm or bpm)	-	Vpeak / Voffset	CAF mean (mL/min)	CAF peak sys (mL/min)	CAF mean sys (mL/min)	CAF peak dias (mL/min)	CAF mean dias (mL/min)	CAF ratio	CdAF mean (mL/min)	CdAF pulse (mL/min)	CdAF peak positive (mL/min)	CdAF peak negative (mL/min)
003	003	PCAS_03_003_051108_1920_w_079	-	-	RVF	CF	CF	0	-	-	-	50.6	85.7	49.4	71.5	51.9	1.1	104.3	126.5	194.2	67.7
003	003	PCAS_03_003_051108_1922_w_080	CPS	-	RVF	CF	CF	960	-	-	-	43.0	57.8	38.4	64.3	47.7	1.2	90.7	131.8	188.7	36.9
003	003	PCAS_03_003_051108_1924_w_081	CPS	-	RVF	CF	CF	1000	-	-	-	25.0	45.6	27.2	48.9	27.2	1.2	55.4	147.9	120.2	-27.8
003	003	PCAS_03_003_051108_1926_w_082	CPS	-	RVF	CF	CF	1100	-	-	-	41.1	55.4	36.9	62.9	45.4	1.2	87.0	126.4	159.4	33.0
003	003	PCAS_03_003_051108_1927_w_083	CPS	-	RVF	CF	CF	1200	-	-	-	42.8	56.7	38.7	63.9	46.9	1.2	89.2	122.7	159.1	36.4
003	003	PCAS_03_003_051108_1928_w_084	CPS	-	RVF	CF	CF	1300	-	-	-	46.1	58.6	41.8	66.2	50.5	1.2	95.7	121.2	167.5	46.2
003	003	PCAS_03_003_051108_1930_w_085	CPS	-	RVF	CF	CF	1400	-	-	-	48.3	60.5	44.3	66.9	52.4	1.2	101.0	108.3	163.4	55.1
003	003	PCAS_03_003_051108_1931_w_086	CPS	-	RVF	CF	CF	1500	-	-	-	48.9	62.1	46.9	67.0	52.9	1.2	103.6	98.5	159.4	60.9
003	003	PCAS_03_003_051108_1932_w_087	CPS	-	RVF	CF	CF	1600	-	-	-	50.4	62.1	46.9	67.0	54.0	1.2	105.8	91.9	158.0	66.1
003	003	PCAS_03_003_051108_1934_w_088	CPS	-	RVF	CF	CF	1700	-	-	-	52.8	63.3	49.2	68.9	56.5	1.2	109.6	88.8	159.5	70.7
003	003	PCAS_03_003_051108_1935_w_089	CPS	-	RVF	CF	CF	1800	-	-	-	55.6	65.1	52.0	71.8	59.2	1.1	115.4	86.7	163.5	76.8
003	003	PCAS_03_003_051108_1936_w_090	CPS	-	RVF	CF	CF	1900	-	-	-	59.4	68.3	55.1	75.5	63.7	1.2	119.8	83.4	166.1	82.8
003	003	PCAS_03_003_051108_1937_w_091	CPS	-	RVF	CF	CF	2000	-	-	-	59.8	71.8	55.8	79.2	63.7	1.2	124.8	78.9	167.5	88.6
003	003	PCAS_03_003_051108_1938_w_092	CPS	-	RVF	CF	CF	-	-	-	-	61.5	82.4	56.9	91.2	66.2	1.2	120.7	76.7	160.0	83.3
003	003	PCAS_03_003_051108_1939_w_093	CPS	-	RVF	CF	CF	-	-	-	-	67.9	91.5	64.1	99.6	71.7	1.1	127.2	77.2	166.4	89.2
003	003	PCAS_03_003_051108_1940_w_094	CPS	-	RVF	CF	CF	-	-	-	-	36.8	73.2	37.0	59.9	36.7	1.0	80.4	132.3	172.9	40.6
003	003	PCAS_03_003_051108_2000_w_095	CPS	-	RVF	PF	PF	100	3.05 / 0.1	3.20 / 0.1	33.2	29.2	66.3	31.3	54.7	27.1	0.9	65.1	132.1	155.3	23.3
003	003	PCAS_03_003_051108_2001_w_096	CPS	-	RVF	PF	PF	100	3.35 / 0.1	3.68 / 0.1	36.8	68.0	68.3	37.0	58.2	32.2	0.9	72.4	125.5	159.7	34.3
003	003	PCAS_03_003_051108_2002_w_097	CPS	-	RVF	PF	PF	100	3.50 / 0.1	41.0	72.1	68.3	68.3	37.0	61.3	36.7	1.0	78.8	122.6	163.3	40.6
003	003	PCAS_03_003_051108_2004_w_098	CPS	-	RVF	PF	PF	100	3.65 / 0.1	45.1	76.4	68.3	68.3	37.0	62.7	41.0	1.0	86.0	125.2	170.3	45.1
003	003	PCAS_03_003_051108_2006_w_099	CPS	-	RVF	PF	PF	100	3.80 / 0.1	52.4	113.3	53.5	53.5	52.5	85.4	51.3	1.0	100.2	121.8	177.3	55.4
003	003	PCAS_03_003_051108_2008_w_100	CPS	-	RVF	PF	PF	100	3.95 / 0.1	53.7	112.7	53.7	53.7	52.5	89.7	55.0	1.1	99.7	116.1	170.2	54.1
003	003	PCAS_03_003_051108_2009_w_101	CPS	-	RVF	PF	PF	100	4.10 / 0.1	57.4	120.3	57.4	57.4	52.5	97.8	57.6	1.0	97.4	117.0	164.9	48.0
003	003	PCAS_03_003_051108_2028_w_102	-	-	RVF	-	-	-	-	-	-	32.0	57.0	29.6	50.6	34.3	1.2	84.4	127.3	156.1	28.8
003	003	PCAS_03_003_051108_2032_w_103	CPS	-	RVF	PF	PF	140	3.12 / 0.1	31.6	53.4	29.4	53.4	29.4	49.7	33.8	1.2	83.7	122.0	150.4	28.4
003	003	PCAS_03_003_051108_2034_w_104	CPS	-	RVF	PF	PF	140	3.20 / 0.1	33.7	54.3	31.1	54.3	29.4	49.7	33.8	1.2	89.8	117.8	155.3	37.5
003	003	PCAS_03_003_051108_2036_w_105	CPS	-	RVF	PF	PF	140	3.35 / 0.1	40.8	57.7	38.6	57.7	38.6	55.5	42.9	1.1	104.9	94.6	156.9	62.3
003	003	PCAS_03_003_051108_2041_w_106	CPS	-	RVF	PF	PF	140	3.80 / 0.1	45.6	78.4	44.1	78.4	44.1	69.7	47.0	1.1	109.9	86.0	157.8	71.8
003	003	PCAS_03_003_051108_2041_w_107	CPS	-	RVF	PF	PF	140	3.95 / 0.1	47.4	78.2	45.5	78.2	45.5	74.6	49.4	1.1	112.6	84.7	156.3	71.6
003	003	PCAS_03_003_051108_2042_w_108	CPS	-	RVF	PF	PF	140	4.10 / 0.1	53.5	85.1	51.8	85.1	45.5	74.6	49.4	1.1	121.3	84.2	165.1	80.9

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)	Inlet mean (mmHg)	Outlet mean (mmHg)	Inlet peak positive (mmHg)	Inlet peak negative (mmHg)	Outlet peak positive (mmHg)	Outlet peak negative (mmHg)	pCAS ΔP (mmHg)
003	PCAS_03_003_051108_1911.w_078	-	Normal	-	-	-	0.00	0.00	0.00	0.00	70.5	67	72	69	88	65	-3
003	PCAS_03_003_051108_1920.w_079	-	RVF	-	-	-	0.00	0.00	0.00	0.00	44.6	41	45	44	42	41	-3
003	PCAS_03_003_051108_1922.w_080	CPS	RVF	CF	0	-	-0.27	0.40	-0.01	-0.40	38.1	35	77	-13	77	-12	-3
003	PCAS_03_003_051108_1924.w_081	CPS	RVF	CF	960	-	0.01	0.37	0.27	-0.10	16.2	59	54	-38	100	7	43
003	PCAS_03_003_051108_1926.w_082	CPS	RVF	CF	1000	-	0.06	0.35	0.31	-0.04	13.6	61	49	-38	98	8	47
003	PCAS_03_003_051108_1927.w_083	CPS	RVF	CF	1100	-	0.13	0.33	0.37	0.04	8.5	66	38	-41	98	17	58
003	PCAS_03_003_051108_1928.w_084	CPS	RVF	CF	1200	-	0.20	0.30	0.44	0.13	1.1	71	28	-45	100	27	70
003	PCAS_03_003_051108_1930.w_085	CPS	RVF	CF	1300	-	0.29	0.31	0.51	0.21	-10.2	73	18	-52	103	30	83
003	PCAS_03_003_051108_1931.w_086	CPS	RVF	CF	1400	-	0.35	0.30	0.57	0.27	-20.9	75	9	-61	108	37	96
003	PCAS_03_003_051108_1932.w_087	CPS	RVF	CF	1500	-	0.41	0.30	0.62	0.32	-31.1	81	-2	-68	111	45	112
003	PCAS_03_003_051108_1934.w_088	CPS	RVF	CF	1600	-	0.47	0.28	0.67	0.36	-41.7	86	-13	-76	117	52	128
003	PCAS_03_003_051108_1935.w_089	CPS	RVF	CF	1700	-	0.52	0.29	0.73	0.43	-52.8	93	-25	-88	122	58	146
003	PCAS_03_003_051108_1936.w_090	CPS	RVF	CF	1800	-	0.57	0.32	0.78	0.46	-64.5	100	-38	-93	128	68	164
003	PCAS_03_003_051108_1937.w_091	CPS	RVF	CF	1900	-	0.62	0.44	0.88	0.44	-77.4	106	-53	-107	136	74	184
003	PCAS_03_003_051108_1938.w_092	CPS	RVF	CF	2000	-	0.69	0.66	1.04	0.38	-93.1	113	-68	-119	141	85	206
003	PCAS_03_003_051108_1954.w_093	-	RVF	-	-	-	0.00	0.00	0.00	0.00	22.2	19	22	22	19	18	-4
003	PCAS_03_003_051108_1959.w_094	CPS	RVF	PF	100	3.05/0.1	0.00	0.59	0.32	-0.28	17.2	49	75	-68	108	-11	32
003	PCAS_03_003_051108_2000.w_095	CPS	RVF	PF	100	3.20/0.1	0.06	0.72	0.47	-0.25	8.9	55	73	-85	127	-7	46
003	PCAS_03_003_051108_2001.w_096	CPS	RVF	PF	100	3.35/0.1	0.15	0.86	0.62	-0.24	-1.4	61	72	-108	143	-3	63
003	PCAS_03_003_051108_2002.w_097	CPS	RVF	PF	100	3.50/0.1	0.21	1.03	0.79	-0.24	-11.7	69	75	-136	159	2	81
003	PCAS_03_003_051108_2004.w_098	CPS	RVF	PF	100	3.65/0.1	0.27	1.21	0.97	-0.24	-23.4	76	72	-172	180	8	99
003	PCAS_03_003_051108_2006.w_099	CPS	RVF	PF	100	3.80/0.1	0.31	1.45	1.18	-0.27	-34.6	85	73	-202	196	16	119
003	PCAS_03_003_051108_2008.w_100	CPS	RVF	PF	100	3.95/0.1	0.38	1.73	1.46	-0.28	-48.5	90	70	-202	196	18	139
003	PCAS_03_003_051108_2009.w_101	CPS	RVF	PF	100	4.10/0.1	0.45	2.08	1.82	-0.26	-58.7	94	70	-202	196	17	153
003	PCAS_03_003_051108_2026.w_102	-	RVF	-	-	-	0.00	0.01	0.01	0.00	16.2	13	16	16	13	13	-3
003	PCAS_03_003_051108_2032.w_103	CPS	RVF	PF	140	3.12/0.1	0.00	0.53	0.28	-0.25	15.9	59	71	-60	121	0	43
003	PCAS_03_003_051108_2034.w_104	CPS	RVF	PF	140	3.20/0.1	0.05	0.58	0.35	-0.23	11.6	63	70	-69	132	4	51
003	PCAS_03_003_051108_2036.w_105	CPS	RVF	PF	140	3.35/0.1	0.23	0.78	0.64	-0.14	-12.5	76	62	-107	163	18	89
003	PCAS_03_003_051108_2041.w_106	CPS	RVF	PF	140	3.80/0.1	0.39	1.11	1.07	-0.04	-45.4	85	50	-172	196	31	131
003	PCAS_03_003_051108_2041.w_107	CPS	RVF	PF	140	3.95/0.1	0.45	1.35	1.32	-0.03	-60.0	93	49	-202	196	25	153
003	PCAS_03_003_051108_2042.w_108	CPS	RVF	PF	140	4.10/0.1	0.50	1.63	1.61	-0.02	-72.7	100	47	-202	196	24	173

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	RV HR (bpm)	RV SV (ml)	RV CO (L/min)	PAP mean (mmHg)	PAP pulse (mmHg)	PAP sys (mmHg)	PAP dia (mmHg)	PAF mean (L/min)	PAF pulse (L/min)	PAF peak positive (L/min)	PAF peak negative (L/min)	PVR clinical (dyne-sec/cm5)	RAP mean (mmHg)	RAP sys (mmHg)	RAP dia (mmHg)
003	PCAS_03_003_051108_1911_w_078	-	Normal	-	-	-	120	5.5	0.66	15.2	36.2	37.4	1.2	0.65	4.13	3.60	-0.53	1899	7.4	36.0	-8.9
003	PCAS_03_003_051108_1920_w_079	-	RVF	-	-	-	120	5.2	0.62	14.1	21.2	23.9	2.7	0.56	2.06	1.62	-0.44	2026	19.0	27.6	5.1
003	PCAS_03_003_051108_1924_w_080	CPS	RVF	CF	0	-	120	5.1	0.60	14.2	22.6	22.4	-0.2	0.55	2.05	1.61	-0.44	2075	20.7	29.2	7.8
003	PCAS_03_003_051108_1927_w_081	CPS	RVF	CF	960	-	120	5.0	0.62	14.0	13.3	22.8	9.5	0.55	1.98	1.55	-0.43	2088	18.5	26.7	5.0
003	PCAS_03_003_051108_1926_w_082	CPS	RVF	CF	1000	-	120	5.0	0.60	14.0	11.6	21.6	10.1	0.54	1.87	1.46	-0.41	2090	17.9	26.0	4.7
003	PCAS_03_003_051108_1927_w_083	CPS	RVF	CF	1100	-	120	4.7	0.57	13.9	11.1	21.3	10.1	0.50	1.82	1.36	-0.45	2272	17.3	25.7	4.3
003	PCAS_03_003_051108_1928_w_084	CPS	RVF	CF	1200	-	120	4.4	0.53	13.8	11.1	21.0	9.9	0.48	1.71	1.33	-0.37	2331	16.7	25.3	4.0
003	PCAS_03_003_051108_1930_w_085	CPS	RVF	CF	1300	-	120	4.1	0.49	13.7	13.2	23.8	10.6	0.44	1.61	1.22	-0.39	2555	15.4	24.3	3.5
003	PCAS_03_003_051108_1931_w_086	CPS	RVF	CF	1400	-	120	3.7	0.45	13.6	17.4	25.9	8.5	0.37	1.56	1.14	-0.42	2983	14.3	23.5	3.1
003	PCAS_03_003_051108_1932_w_087	CPS	RVF	CF	1500	-	120	3.6	0.43	13.6	19.0	26.7	7.7	0.38	1.52	1.13	-0.39	2919	13.8	23.0	3.0
003	PCAS_03_003_051108_1934_w_088	CPS	RVF	CF	1600	-	120	3.3	0.40	13.6	20.2	27.4	7.2	0.34	1.48	1.06	-0.42	3270	13.4	22.7	2.9
003	PCAS_03_003_051108_1935_w_089	CPS	RVF	CF	1700	-	120	3.3	0.40	13.6	20.5	27.5	7.0	0.34	1.45	1.05	-0.40	3293	13.1	22.4	2.9
003	PCAS_03_003_051108_1936_w_090	CPS	RVF	CF	1800	-	120	3.2	0.38	13.6	20.5	27.5	6.9	0.33	1.40	1.02	-0.38	3429	12.9	22.1	2.8
003	PCAS_03_003_051108_1937_w_091	CPS	RVF	CF	1900	-	120	3.0	0.37	13.6	20.9	27.6	6.7	0.31	1.36	0.98	-0.38	3503	12.5	22.0	2.4
003	PCAS_03_003_051108_1938_w_092	CPS	RVF	CF	2000	-	120	2.9	0.34	13.6	21.3	27.7	6.4	0.29	1.38	0.98	-0.41	3885	12.1	21.8	1.9
003	PCAS_03_003_051108_1934_w_093	-	RVF	-	-	-	120	1.0	0.12	14.0	3.4	16.2	12.9	0.62	0.53	0.89	0.36	1822	19.9	22.4	17.8
003	PCAS_03_003_051108_1939_w_094	CPS	RVF	PF	100	3.05/0.1	120	1.4	0.16	13.8	4.4	17.3	12.9	0.54	0.56	0.82	0.26	2043	19.2	23.8	16.5
003	PCAS_03_003_051108_2000_w_095	CPS	RVF	PF	100	3.20/0.1	120	1.0	0.12	13.8	4.1	17.0	12.9	0.54	0.49	0.77	0.28	2082	19.0	23.8	16.5
003	PCAS_03_003_051108_2001_w_096	CPS	RVF	PF	100	3.35/0.1	120	1.3	0.15	13.8	3.9	16.9	13.0	0.51	0.57	0.80	0.22	2190	18.7	23.3	16.3
003	PCAS_03_003_051108_2002_w_097	CPS	RVF	PF	100	3.50/0.1	120	1.5	0.19	13.8	3.7	16.9	13.2	0.52	0.68	0.87	0.19	2158	18.9	23.9	16.4
003	PCAS_03_003_051108_2004_w_098	CPS	RVF	PF	100	3.65/0.1	120	1.3	0.16	13.8	3.6	16.8	13.2	0.52	0.65	0.87	0.22	2129	18.9	24.1	16.7
003	PCAS_03_003_051108_2006_w_099	CPS	RVF	PF	100	3.80/0.1	120	1.4	0.17	13.8	3.7	17.0	13.2	0.53	0.71	0.92	0.20	2130	19.0	24.9	16.9
003	PCAS_03_003_051108_2008_w_100	CPS	RVF	PF	100	3.95/0.1	120	0.8	0.11	13.8	5.0	16.9	11.9	0.52	0.81	0.94	0.14	2176	18.7	24.5	16.1
003	PCAS_03_003_051108_2009_w_101	CPS	RVF	PF	100	4.10/0.1	120	1.1	0.13	13.8	5.4	16.8	11.4	0.52	0.86	1.02	0.16	2166	18.4	24.4	15.6
003	PCAS_03_003_051108_2028_w_102	-	RVF	-	-	-	120	4.9	0.59	13.8	9.8	21.7	11.9	0.55	1.76	1.43	-0.33	2040	18.4	25.3	5.1
003	PCAS_03_003_051108_2032_w_103	CPS	RVF	PF	140	3.12/0.1	120	4.5	0.54	13.8	10.5	22.4	12.0	0.50	1.90	1.52	-0.38	2254	18.3	25.7	4.7
003	PCAS_03_003_051108_2034_w_104	CPS	RVF	PF	140	3.20/0.1	120	4.4	0.53	13.8	10.6	22.3	11.7	0.49	1.94	1.52	-0.46	2290	17.8	25.4	4.4
003	PCAS_03_003_051108_2036_w_105	CPS	RVF	PF	140	3.35/0.1	120	3.9	0.47	13.6	9.9	21.0	11.1	0.43	1.76	1.31	-0.44	2590	15.4	23.7	3.7
003	PCAS_03_003_051108_2041_w_106	CPS	RVF	PF	140	3.80/0.1	120	3.0	0.36	13.5	17.1	25.2	8.1	0.31	1.49	1.02	-0.47	3580	12.4	22.4	1.7
003	PCAS_03_003_051108_2041_w_107	CPS	RVF	PF	140	3.95/0.1	120	3.1	0.37	13.5	17.1	25.1	7.9	0.33	1.49	1.03	-0.46	3317	12.0	22.3	1.5
003	PCAS_03_003_051108_2042_w_108	CPS	RVF	PF	140	4.10/0.1	120	2.9	0.35	13.5	17.2	25.0	7.8	0.29	1.48	1.01	-0.48	3786	11.5	22.3	1.1

* Used PAF offset for analysis because PAF too low.

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV HR (bpm)	LV SV (ml)	LV CO (L/min)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)
003	PCAS_03_003_051110_1425.w.111	-	Normal	-	-	-	120	6.2	0.74	72.7	48.5	103.3	54.9	8015	42.9	-29.1	10.7	0.73	5.43	5.01	-0.42
003	PCAS_03_003_051110_1431.w.112	VVECMO	Normal	CF	600	-	120	6.0	0.72	73.2	48.6	104.1	55.5	7500	43.8	-29.5	11.0	0.79	5.82	5.03	-0.60
003	PCAS_03_003_051110_1432.w.113	VVECMO	Normal	CF	600	-	120	6.0	0.72	72.9	48.9	104.0	55.1	7537	43.6	-29.5	10.9	0.78	5.57	5.04	-0.53
003	PCAS_03_003_051110_1434.w.114	VVECMO	Normal	CF	800	-	120	6.1	0.73	73.0	48.7	103.9	55.3	7571	43.6	-29.5	10.9	0.78	5.58	5.03	-0.55
003	PCAS_03_003_051110_1435.w.115	VVECMO	Normal	CF	1000	-	120	6.1	0.73	73.1	48.7	104.1	55.4	7515	43.6	-29.5	10.9	0.78	5.72	5.04	-0.69
003	PCAS_03_003_051110_1436.w.116	VVECMO	Normal	CF	1200	-	120	5.9	0.71	72.8	48.9	103.8	54.9	7797	43.6	-29.5	10.9	0.75	5.76	5.01	-0.75
003	PCAS_03_003_051110_1438.w.117	VVECMO	Normal	CF	1400	-	120	6.5	0.77	72.8	48.8	103.8	55.0	7481	43.4	-29.5	10.8	0.79	5.54	4.99	-0.55
003	PCAS_03_003_051110_1439.w.118	VVECMO	Normal	CF	1600	-	120	6.0	0.72	72.7	48.9	103.8	54.8	7719	43.4	-29.5	10.8	0.76	5.62	5.03	-0.59
003	PCAS_03_003_051110_1440.w.119	VVECMO	Normal	CF	1800	-	120	6.0	0.73	72.7	49.0	103.8	54.8	7739	43.3	-29.4	10.8	0.76	5.7	5.0	-0.8
003	PCAS_03_003_051110_1451.w.123	VVECMO	Normal	CF	2000	-	120	5.9	0.71	72.7	49.0	103.9	54.9	7628	42.8	-29.3	10.7	0.77	5.6	5.0	-0.6
003	PCAS_03_003_051110_1452.w.124	VVECMO	Normal	CF	2200	-	120	6.0	0.73	72.9	49.0	104.1	55.0	7563	42.7	-29.2	10.7	0.78	5.5	5.0	-0.5
003	PCAS_03_003_051110_1453.w.125	VVECMO	Normal	CF	2400	-	120	5.9	0.71	72.7	48.9	103.8	54.9	7687	42.6	-29.2	10.6	0.76	5.6	5.0	-0.6
003	PCAS_03_003_051110_1454.w.126	VVECMO	Normal	CF	2700	-	120	5.9	0.70	72.7	49.0	103.9	54.8	8051	42.5	-29.2	10.6	0.73	5.6	5.0	-0.6
003	PCAS_03_003_051110_1455.w.127	VVECMO	Normal	CF	3000	-	120	6.2	0.74	72.7	48.9	103.8	54.9	7498	42.2	-29.1	10.5	0.78	5.5	5.0	-0.5
003	PCAS_03_003_051110_1456.w.128	VVECMO	Normal	CF	3300	-	120	5.9	0.71	72.8	49.0	104.0	55.0	7768	41.9	-29.1	10.5	0.76	5.5	5.0	-0.6
003	PCAS_03_003_051110_1458.w.128	VVECMO	Normal	CF	3900	-	120	6.5	0.78	73.4	48.3	104.3	55.9	7621	41.2	-29.0	10.2	0.78	5.6	5.0	-0.8
003	PCAS_03_003_051110_1507.w.130	VVECMO	Normal	PF	100	2.80/0.1	120	6.0	0.72	73.6	48.7	104.7	56.0	7779	42.5	-28.8	10.6	0.76	5.8	5.1	-0.7
003	PCAS_03_003_051110_1510.w.131	VVECMO	Normal	PF	100	3.00/0.1	120	6.1	0.73	73.5	48.9	104.8	55.9	7891	42.6	-28.9	10.6	0.75	5.7	5.0	-0.7
003	PCAS_03_003_051110_1511.w.132	VVECMO	Normal	PF	100	3.25/0.1	120	6.0	0.73	73.3	49.0	104.6	55.6	8006	42.5	-28.9	10.6	0.74	5.6	5.0	-0.6
003	PCAS_03_003_051110_1512.w.133	VVECMO	Normal	PF	100	3.50/0.1	120	5.9	0.71	73.0	49.1	104.4	55.3	7882	42.5	-28.9	10.6	0.75	5.6	5.0	-0.6
003	PCAS_03_003_051110_1513.w.134	VVECMO	Normal	PF	100	3.75/0.1	120	5.9	0.71	73.0	49.0	104.4	55.3	7878	42.4	-28.9	10.6	0.75	5.7	5.0	-0.7
003	PCAS_03_003_051110_1514.w.135	VVECMO	Normal	PF	100	4.00/0.1	120	6.0	0.72	72.9	49.1	104.4	55.2	8035	42.3	-28.9	10.5	0.73	5.7	5.1	-0.7
003	PCAS_03_003_051110_1515.w.136	VVECMO	Normal	PF	100	4.25/0.1	120	5.9	0.70	72.8	49.2	104.2	55.0	8009	42.2	-28.9	10.5	0.73	5.6	5.0	-0.6
003	PCAS_03_003_051110_1517.w.137	VVECMO	Normal	PF	100	4.50/0.1	120	5.8	0.70	72.7	49.1	104.0	54.9	8176	42.0	-28.9	10.4	0.72	5.7	5.0	-0.7
003	PCAS_03_003_051110_1520.w.138	VVECMO	Normal	PF	100	4.75/0.1	120	5.9	0.71	72.7	49.3	104.2	55.0	7839	41.7	-28.8	10.3	0.75	5.7	5.1	-0.6
003	PCAS_03_003_051110_1521.w.138	VVECMO	Normal	PF	100	5.00/0.1	120	6.0	0.72	72.9	49.2	104.4	55.2	7549	41.6	-28.8	10.3	0.78	5.7	5.1	-0.6
003	PCAS_03_003_051110_1524.w.140	VVECMO	Normal	PF	140	2.80/0.1	120	5.9	0.70	73.1	49.0	104.5	55.4	7974	42.0	-28.9	10.5	0.74	5.7	5.0	-0.7
003	PCAS_03_003_051110_1526.w.141	VVECMO	Normal	PF	140	3.00/0.1	120	5.8	0.70	72.9	49.3	104.4	55.1	7988	42.0	-28.9	10.4	0.74	5.7	5.0	-0.7
003	PCAS_03_003_051110_1528.w.142	VVECMO	Normal	PF	140	3.25/0.1	120	5.8	0.70	72.8	49.4	104.3	54.9	8073	42.1	-28.9	10.4	0.73	5.7	5.0	-0.6
003	PCAS_03_003_051110_1528.w.143	VVECMO	Normal	PF	140	3.50/0.1	120	5.8	0.70	72.7	49.2	104.2	54.9	8212	42.1	-28.9	10.4	0.71	5.7	5.0	-0.7
003	PCAS_03_003_051110_1529.w.144	VVECMO	Normal	PF	140	3.75/0.1	120	5.9	0.70	72.7	49.4	104.3	54.8	7973	42.1	-29.0	10.4	0.74	5.7	5.0	-0.7
003	PCAS_03_003_051110_1530.w.145	VVECMO	Normal	PF	140	4.00/0.1	120	5.8	0.70	72.6	49.3	104.1	54.7	8073	42.0	-28.9	10.3	0.73	5.7	5.1	-0.7
003	PCAS_03_003_051110_1532.w.146	VVECMO	Normal	PF	140	4.25/0.1	120	5.8	0.69	72.5	49.5	104.1	54.6	8148	41.8	-29.0	10.3	0.72	5.7	5.0	-0.7
003	PCAS_03_003_051110_1533.w.147	VVECMO	Normal	PF	140	4.50/0.1	120	5.8	0.70	72.6	49.5	104.3	54.8	8041	41.8	-29.0	10.3	0.73	5.6	5.0	-0.6
003	PCAS_03_003_051110_1534.w.148	VVECMO	Normal	PF	140	4.75/0.1	120	5.7	0.69	72.6	49.4	104.3	54.8	8369	41.8	-28.9	10.3	0.70	5.8	5.0	-0.7
003	PCAS_03_003_051110_1535.w.148	VVECMO	Normal	PF	140	5.00/0.1	120	6.0	0.72	72.8	49.2	104.3	55.1	7980	41.7	-28.9	10.2	0.74	5.7	5.0	-0.6

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	CAF mean (mL/min)	CAF peak sys (mL/min)	CAF mean sys (mL/min)	CAF peak dias (mL/min)	CAF mean dias (mL/min)	CAF ratio	CdAF mean (mL/min)	CdAF pulse (mL/min)	CdAF peak positive (mL/min)	CdAF peak negative (mL/min)
003	PCAS_03_003_051110_1425_w_111	-	Normal	-	-	-	51.0	52.8	48.1	57.6	53.9	1.1	95.3	71.7	129.8	58.1
003	PCAS_03_003_051110_1431_w_112	WECMO	Normal	CF	400	-	51.9	55.1	48.2	62.2	55.5	1.2	95.6	76.3	138.9	62.6
003	PCAS_03_003_051110_1432_w_113	WECMO	Normal	CF	600	-	51.9	54.9	48.3	62.0	55.4	1.2	95.4	74.3	136.4	62.1
003	PCAS_03_003_051110_1434_w_114	WECMO	Normal	CF	800	-	51.9	56.0	48.2	63.0	55.7	1.2	95.5	75.6	138.3	62.7
003	PCAS_03_003_051110_1435_w_115	WECMO	Normal	CF	1000	-	52.3	57.2	48.5	65.2	56.2	1.2	95.9	76.1	139.3	63.2
003	PCAS_03_003_051110_1436_w_116	WECMO	Normal	CF	1200	-	51.7	57.9	48.0	64.8	55.6	1.2	94.8	73.4	132.9	59.4
003	PCAS_03_003_051110_1438_w_117	WECMO	Normal	CF	1400	-	51.5	57.3	47.5	65.0	55.5	1.2	95.5	74.3	136.7	62.4
003	PCAS_03_003_051110_1439_w_118	WECMO	Normal	CF	1600	-	51.9	56.3	48.1	64.1	55.7	1.2	95.3	77.2	136.8	59.8
003	PCAS_03_003_051110_1440_w_119	WECMO	Normal	CF	1800	-	52.3	59.0	48.8	66.0	55.9	1.2	94.6	76.6	137.5	61.0
003	PCAS_03_003_051110_1451_w_123	WECMO	Normal	CF	2000	-	52.5	59.9	49.1	67.1	55.9	1.1	94.3	87.8	148.9	61.1
003	PCAS_03_003_051110_1452_w_124	WECMO	Normal	CF	2200	-	52.5	57.6	48.7	64.8	56.4	1.2	94.3	89.3	150.5	61.1
003	PCAS_03_003_051110_1453_w_125	WECMO	Normal	CF	2400	-	52.8	59.7	49.4	66.9	56.1	1.1	93.5	91.9	152.7	60.7
003	PCAS_03_003_051110_1454_w_126	WECMO	Normal	CF	2700	-	52.3	60.5	49.3	68.0	55.4	1.1	93.6	100.5	162.9	62.4
003	PCAS_03_003_051110_1455_w_127	WECMO	Normal	CF	3000	-	52.3	60.8	49.5	67.9	55.3	1.1	93.2	103.9	162.2	58.3
003	PCAS_03_003_051110_1456_w_128	WECMO	Normal	CF	3300	-	52.7	62.3	49.7	67.9	55.9	1.1	93.5	103.4	163.3	59.8
003	PCAS_03_003_051110_1458_w_129	WECMO	Normal	CF	3900	-	54.4	62.3	51.7	69.5	57.1	1.1	93.4	107.3	167.9	60.6
003	PCAS_03_003_051110_1507_w_130	WECMO	Normal	PF	100	2.80 / 0.1	55.4	60.9	51.9	68.0	58.9	1.1	93.8	114.5	174.3	59.8
003	PCAS_03_003_051110_1510_w_131	WECMO	Normal	PF	100	3.00 / 0.1	54.6	59.7	51.4	66.1	57.9	1.1	94.2	122.5	181.8	59.2
003	PCAS_03_003_051110_1511_w_132	WECMO	Normal	PF	100	3.25 / 0.1	54.1	60.2	50.9	67.0	57.4	1.1	94.3	121.6	181.3	59.7
003	PCAS_03_003_051110_1512_w_133	WECMO	Normal	PF	100	3.50 / 0.1	53.8	59.5	50.4	66.2	57.2	1.1	94.0	115.6	176.1	60.4
003	PCAS_03_003_051110_1513_w_134	WECMO	Normal	PF	100	3.75 / 0.1	53.8	58.1	50.3	65.1	57.4	1.1	93.6	115.1	174.6	59.5
003	PCAS_03_003_051110_1514_w_135	WECMO	Normal	PF	100	4.00 / 0.1	54.0	58.3	50.5	65.4	57.4	1.1	93.6	119.5	178.4	58.9
003	PCAS_03_003_051110_1515_w_136	WECMO	Normal	PF	100	4.25 / 0.1	53.6	59.0	50.3	65.5	57.0	1.1	93.9	119.4	178.6	59.3
003	PCAS_03_003_051110_1517_w_137	WECMO	Normal	PF	100	4.50 / 0.1	53.8	59.9	50.4	67.0	57.2	1.1	93.6	117.0	175.8	58.8
003	PCAS_03_003_051110_1520_w_138	WECMO	Normal	PF	100	4.75 / 0.1	53.9	59.7	50.7	65.8	57.1	1.1	93.5	120.2	179.3	59.1
003	PCAS_03_003_051110_1521_w_139	WECMO	Normal	PF	100	5.00 / 0.1	54.2	60.7	51.1	67.0	57.4	1.1	93.5	118.2	177.8	59.5
003	PCAS_03_003_051110_1524_w_140	WECMO	Normal	PF	140	2.80 / 0.1	54.6	60.6	51.2	67.7	58.1	1.1	93.9	117.6	177.7	60.1
003	PCAS_03_003_051110_1526_w_141	WECMO	Normal	PF	140	3.00 / 0.1	54.3	61.2	51.3	67.2	57.3	1.1	93.9	106.7	168.2	61.5
003	PCAS_03_003_051110_1527_w_142	WECMO	Normal	PF	140	3.25 / 0.1	54.2	60.8	51.0	67.4	57.5	1.1	93.9	110.6	171.3	60.8
003	PCAS_03_003_051110_1528_w_143	WECMO	Normal	PF	140	3.50 / 0.1	54.3	60.3	50.9	67.3	57.8	1.1	94.2	107.4	169.8	62.4
003	PCAS_03_003_051110_1529_w_144	WECMO	Normal	PF	140	3.75 / 0.1	53.9	61.0	50.8	67.2	57.1	1.1	94.3	104.3	166.2	62.0
003	PCAS_03_003_051110_1530_w_145	WECMO	Normal	PF	140	4.00 / 0.1	53.8	60.6	50.1	68.3	57.5	1.2	94.3	110.2	170.5	60.3
003	PCAS_03_003_051110_1532_w_146	WECMO	Normal	PF	140	4.25 / 0.1	53.7	60.0	50.2	66.9	57.2	1.1	93.9	115.4	175.0	59.6
003	PCAS_03_003_051110_1533_w_147	WECMO	Normal	PF	140	4.50 / 0.1	53.9	59.7	50.8	66.2	57.2	1.1	94.1	115.9	175.5	59.6
003	PCAS_03_003_051110_1534_w_148	WECMO	Normal	PF	140	4.75 / 0.1	54.0	59.9	50.8	66.3	57.2	1.1	93.6	115.1	174.7	59.5
003	PCAS_03_003_051110_1535_w_149	WECMO	Normal	PF	140	5.00 / 0.1	54.3	60.4	51.3	66.3	57.3	1.1	93.3	120.1	178.5	59.5

pCAS ΔP (mmHg)	-1	3	4	5	5	3	0.01	0.02	0.01	0.02	-	-	-	-	Normal	-	PCAS_03_003_051110_1425_w_111	003
Outlet peak negative (mmHg)	-9	-9	47	-13	30	11	0.04	0.10	0.06	0.06	-	-	-	-	Normal	WECMO	PCAS_03_003_051110_1431_w_112	003
Outlet peak positive (mmHg)	1	1	16	13	30	20	0.08	0.14	0.06	0.11	-	-	-	-	Normal	CF	PCAS_03_003_051110_1432_w_113	003
Inlet peak negative (mmHg)	16	16	62	-14	30	34	0.13	0.19	0.06	0.15	-	-	-	-	Normal	WECMO	PCAS_03_003_051110_1434_w_114	003
Inlet peak positive (mmHg)	33	33	79	-12	29	52	0.18	0.23	0.05	0.20	-	-	-	-	Normal	CF	PCAS_03_003_051110_1436_w_115	003
Outlet mean (mmHg)	49	49	103	-14	28	74	0.23	0.28	0.05	0.25	-	-	-	-	Normal	CF	PCAS_03_003_051110_1438_w_116	003
Inlet mean (mmHg)	56	56	132	-14	27	101	0.28	0.33	0.05	0.30	-	-	-	-	Normal	WECMO	PCAS_03_003_051110_1438_w_117	003
VADF peak negative (L/min)	81	81	162	-16	28	131	0.38	0.48	0.05	0.35	-	-	-	-	Normal	WECMO	PCAS_03_003_051110_1438_w_118	003
VADF peak positive (L/min)	100	100	199	-19	27	167	0.42	0.54	0.05	0.40	-	-	-	-	Normal	CF	PCAS_03_003_051110_1440_w_119	003
VADF pulse (L/min)	132	132	266	-27	28	205	0.48	0.59	0.06	0.46	-	-	-	-	Normal	CF	PCAS_03_003_051110_1451_w_123	003
VADF mean (L/min)	168	168	337	-31	23	250	0.53	0.68	0.07	0.51	-	-	-	-	Normal	CF	PCAS_03_003_051110_1452_w_124	003
Vpeak / Voffset	255	255	387	-41	25	298	0.60	0.77	0.08	0.56	-	-	-	-	Normal	CF	PCAS_03_003_051110_1454_w_126	003
Device Setting (rpm or bpm)	395	395	395	-58	31	395	0.67	0.87	0.13	0.72	-	-	-	-	Normal	CF	PCAS_03_003_051110_1456_w_127	003
Device Mode (CF or PF)	409	409	395	-72	19	395	0.74	0.88	0.13	0.81	-	-	-	-	Normal	CF	PCAS_03_003_051110_1456_w_128	003
Heart Condition Simulated	413	413	395	-72	31	395	0.89	1.07	0.18	0.97	-	-	-	-	Normal	CF	PCAS_03_003_051110_1507_w_130	003
Assist Condition	424	424	395	-72	31	395	0.03	0.16	0.09	0.09	-	-	-	-	Normal	PF	PCAS_03_003_051110_1510_w_131	003
Filename	9	9	92	-31	32	27	0.05	0.25	0.20	0.14	-	-	-	-	Normal	PF	PCAS_03_003_051110_1511_w_132	003
MCS Number	23	23	155	-43	42	50	0.08	0.36	0.29	0.20	-	-	-	-	Normal	PF	PCAS_03_003_051110_1512_w_133	003
	48	48	230	-56	53	75	0.09	0.46	0.37	0.24	-	-	-	-	Normal	PF	PCAS_03_003_051110_1512_w_133	003
	74	74	319	-71	59	100	0.09	0.56	0.47	0.28	-	-	-	-	Normal	PF	PCAS_03_003_051110_1513_w_134	003
	100	100	395	-86	71	132	0.11	0.66	0.55	0.32	-	-	-	-	Normal	PF	PCAS_03_003_051110_1514_w_135	003
	133	133	395	-104	80	159	0.12	0.77	0.85	0.37	-	-	-	-	Normal	PF	PCAS_03_003_051110_1515_w_136	003
	162	162	395	-119	90	180	0.14	0.88	0.73	0.42	-	-	-	-	Normal	PF	PCAS_03_003_051110_1517_w_137	003
	185	185	395	-141	100	195	0.15	0.97	0.82	0.46	-	-	-	-	Normal	PF	PCAS_03_003_051110_1520_w_138	003
	203	203	395	-160	104	210	0.16	1.08	0.92	0.50	-	-	-	-	Normal	PF	PCAS_03_003_051110_1521_w_139	003
	221	221	395	-20	30	140	0.15	0.85	0.77	0.43	-	-	-	-	Normal	PF	PCAS_03_003_051110_1522_w_140	003
	9	9	52	-3	4	30	0.15	0.24	0.15	0.16	-	-	-	-	Normal	PF	PCAS_03_003_051110_1523_w_141	003
	27	27	85	-28	31	57	0.12	0.34	0.22	0.22	-	-	-	-	Normal	PF	PCAS_03_003_051110_1527_w_142	003
	55	55	140	-42	40	78	0.12	0.43	0.31	0.26	-	-	-	-	Normal	PF	PCAS_03_003_051110_1528_w_143	003
	77	77	206	-57	49	109	0.15	0.53	0.38	0.31	-	-	-	-	Normal	PF	PCAS_03_003_051110_1528_w_143	003
	109	109	281	-76	65	149	0.17	0.63	0.46	0.36	-	-	-	-	Normal	PF	PCAS_03_003_051110_1530_w_145	003
	150	150	385	-91	73	190	0.20	0.74	0.53	0.42	-	-	-	-	Normal	PF	PCAS_03_003_051110_1532_w_147	003
	194	194	395	-111	88	211	0.22	0.85	0.63	0.48	-	-	-	-	Normal	PF	PCAS_03_003_051110_1533_w_147	003
	217	217	395	-132	114	218	0.21	0.95	0.74	0.49	-	-	-	-	Normal	PF	PCAS_03_003_051110_1534_w_148	003
	227	227	395	-162	133	232	0.21	1.05	0.84	0.53	-	-	-	-	Normal	PF	PCAS_03_003_051110_1535_w_149	003
	244	244	395	-184	147	232	0.22	1.05	0.84	0.53	-	-	-	-	Normal	PF	PCAS_03_003_051110_1535_w_149	003

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	LV HR (bpm)	LV SV (ml)	LV CO (L/min)	AoP mean (mmHg)	AoP pulse (mmHg)	AoP sys (mmHg)	AoP dia (mmHg)	TPR clinical (dyne-sec/cm5)	LAP sys (mmHg)	LAP dia (mmHg)	LAP mean (mmHg)	AoF mean (L/min)	AoF pulse (L/min)	AoF peak positive (L/min)	AoF peak negative (L/min)
003	PCAS_03_004_051214_1737_w_001	-	Normal	-	-	-	120	6.8	0.81	72.2	51.6	104.6	53.0	7970	45.4	-32.9	11.2	0.74	6.39	5.51	-0.88
003	PCAS_03_004_051214_1752_w_002	-	LVF	CF	0	-	120	5.9	0.71	53.8	28.1	67.0	38.8	6423	53.6	3.3	22.5	0.67	2.23	1.98	-0.24
003	PCAS_03_004_051214_1754_w_003	LVA	LVF	CF	818	-	120	8.0	0.96	41.3	43.5	63.0	19.6	3673	64.6	5.5	32.9	0.91	4.03	3.60	-0.42
003	PCAS_03_004_051214_1757_w_004	LVA	LVF	CF	818	-	120	6.1	0.73	54.0	31.4	70.6	39.2	6478	57.3	1.5	21.5	0.67	2.39	2.14	-0.25
003	PCAS_03_004_051214_1759_w_005	LVA	LVF	CF	900	-	120	6.8	0.80	55.1	25.1	68.8	43.7	8108	54.9	-0.1	19.0	0.55	1.88	1.76	-0.11
003	PCAS_03_004_051214_1800_w_006	LVA	LVF	CF	1000	-	120	5.6	0.67	56.9	17.2	65.6	48.5	11211	48.7	-0.6	16.3	0.41	1.28	1.27	-0.02
003	PCAS_03_004_051214_1802_w_007	LVA	LVF	CF	1100	-	120	1.9	0.23	59.3	13.6	66.8	53.3	22577	47.9	-2.1	13.3	0.22	1.04	0.90	-0.14
003	PCAS_03_004_051214_1803_w_008	LVA	LVF	CF	1200	-	120	1.0	0.12	61.9	10.7	68.6	57.9	42870	47.1	-4.9	10.0	0.12	0.59	0.49	-0.10
003	PCAS_03_004_051214_1805_w_009	LVA	LVF	CF	1300	-	120	0.3	0.04	65.7	7.9	71.1	63.2	54860	45.7	-8.1	7.4	0.05	0.3	0.2	-0.1
003	PCAS_03_004_051214_1806_w_010	LVA	LVF	CF	1400	-	120	0.1	0.01	71.8	6.1	76.3	70.2	-633970	40.6	-8.1	4.3	-0.03	0.2	0.1	-0.1
003	PCAS_03_004_051214_1808_w_011	-	LVF	-	-	-	120	6.0	0.72	53.8	27.9	66.9	38.9	6546	53.7	3.2	22.5	0.66	2.3	2.0	-0.3
003	PCAS_03_004_051214_1814_w_012	LVA	LVF	PF	100	3.00/0.1	120	5.9	0.71	52.8	31.8	68.3	36.5	6386	59.6	1.6	22.1	0.67	2.6	2.3	-0.4
003	PCAS_03_004_051214_1816_w_013	LVA	LVF	PF	100	3.10/0.1	120	4.6	0.55	53.0	25.7	66.1	40.4	8664	57.0	-0.4	19.1	0.51	2.2	1.9	-0.3
003	PCAS_03_004_051214_1818_w_014	LVA	LVF	PF	100	3.20/0.1	120	4.8	0.55	54.3	21.4	65.1	43.6	10441	54.5	-1.5	16.7	0.43	1.6	1.5	-0.1
003	PCAS_03_004_051214_1820_w_015	LVA	LVF	PF	100	3.30/0.1	120	2.4	0.28	56.4	21.1	67.0	45.9	16826	51.5	-1.4	14.1	0.31	1.4	1.2	-0.2
003	PCAS_03_004_051214_1821_w_016	LVA	LVF	PF	100	3.40/0.1	120	1.6	0.20	58.2	20.5	69.0	48.5	31186	49.6	-4.7	11.9	0.20	1.1	0.9	-0.2
003	PCAS_03_004_051214_1822_w_017	LVA	LVF	PF	100	3.50/0.1	120	1.0	0.12	61.8	20.5	73.1	52.6	61708	47.6	-6.0	10.8	0.12	0.8	0.6	-0.2
003	PCAS_03_004_051214_1824_w_018	LVA	LVF	PF	100	3.60/0.1	120	0.8	0.09	66.0	21.7	78.0	56.4	90585	45.7	-8.0	9.5	0.08	0.7	0.5	-0.2
003	PCAS_03_004_051214_1825_w_019	LVA	LVF	PF	100	3.70/0.1	120	0.5	0.06	70.3	21.5	82.5	61.0	88304	43.6	-9.1	8.8	0.03	0.5	0.3	-0.2
003	PCAS_03_004_051214_1826_w_020	LVA	LVF	PF	100	3.80/0.1	120	0.3	0.04	75.4	21.0	87.3	66.3	-101180	41.0	-9.8	7.8	-0.01	0.4	0.2	-0.2
003	PCAS_03_004_051214_1830_w_021	LVA	LVF	PF	140	2.98/0.1	120	5.9	0.71	54.1	30.9	70.3	39.4	6606	57.9	1.2	21.5	0.66	2.5	2.1	-0.3
003	PCAS_03_004_051214_1831_w_022	LVA	LVF	PF	140	3.10/0.1	120	5.0	0.61	54.5	22.4	68.4	43.9	9326	53.5	-0.9	18.0	0.48	1.8	1.6	-0.1
003	PCAS_03_004_051214_1833_w_023	LVA	LVF	PF	140	3.20/0.1	120	2.4	0.29	56.4	16.2	64.5	48.3	15023	50.8	-2.9	14.8	0.31	1.4	1.2	-0.2
003	PCAS_03_004_051214_1834_w_024	LVA	LVF	PF	140	3.30/0.1	120	1.5	0.18	58.7	13.6	65.4	51.9	28189	49.4	-5.1	11.7	0.17	0.9	0.8	-0.1
003	PCAS_03_004_051214_1835_w_025	LVA	LVF	PF	140	3.40/0.1	120	1.0	0.13	62.2	13.4	69.2	55.9	48103	47.1	-8.1	8.8	0.11	0.6	0.5	-0.1
003	PCAS_03_004_051214_1837_w_026	LVA	LVF	PF	140	3.50/0.1	120	0.5	0.06	66.3	13.0	73.0	60.0	118170	44.0	-9.8	7.1	0.06	0.3	0.2	-0.1
003	PCAS_03_004_051214_1838_w_027	LVA	LVF	PF	140	3.60/0.1	120	0.1	0.01	72.3	11.6	78.6	67.0	-28287	41.6	-11.0	6.3	-0.05	0.2	0.1	-0.1
003	PCAS_03_004_051214_1841_w_028	-	LVF	-	-	-	120	6.2	0.74	54.0	27.6	66.9	39.3	6811	52.9	3.2	22.0	0.64	2.2	1.9	-0.3
003	PCAS_03_004_051214_1849_w_029	-	Normal	-	-	-	120	6.9	0.83	72.8	49.9	104.2	54.2	7713	48.3	-33.3	11.7	0.77	6.8	5.8	-1.0

MCS Number	003	PCAS_03_004_051214_1737_w_001	Assist Condition	-	Heart Condition Simulated	Normal	Device Mode (CF or PF)	-	Device Setting (rpm or bpm)	-	Vpeak / Voffset	CAF mean (mL/min)	CAF peak sys (mL/min)	CAF mean sys (mL/min)	CAF peak dias (mL/min)	CAF mean dias (mL/min)	CAF ratio	CdAF mean (mL/min)	CdAF pulse (mL/min)	CdAF peak positive (mL/min)	CdAF peak negative (mL/min)
003	PCAS_03_004_051214_1752_w_002	-	-	LVF	-	-	-	-	36.6	77.3	42.3	54.3	92.8	50.4	79.1	79.1	1.1	93.6	99.4	157.4	58.0
003	PCAS_03_004_051214_1754_w_003	-	-	LVA	CF	0	CF	0	26.9	63.3	27.0	42.3	47.7	36.6	77.3	77.3	1.2	71.2	34.0	88.5	54.5
003	PCAS_03_004_051214_1757_w_004	LVA	LVA	LVA	CF	818	CF	818	36.1	75.1	42.6	42.6	46.6	36.1	75.1	75.1	1.0	51.6	50.0	75.1	25.1
003	PCAS_03_004_051214_1759_w_005	LVA	LVA	LVA	CF	900	CF	900	41.4	48.8	38.9	42.6	48.8	38.9	72.6	72.6	1.1	70.9	29.5	86.3	56.8
003	PCAS_03_004_051214_1800_w_006	LVA	LVA	LVA	CF	1000	CF	1000	43.5	51.0	41.1	43.5	51.0	41.1	71.4	71.4	1.1	71.9	25.4	85.1	59.8
003	PCAS_03_004_051214_1802_w_007	LVA	LVA	LVA	CF	1100	CF	1100	46.5	52.2	43.7	46.5	52.2	43.7	74.0	74.0	1.1	73.8	19.8	84.2	64.4
003	PCAS_03_004_051214_1803_w_008	LVA	LVA	LVA	CF	1200	CF	1200	46.2	68.1	46.8	46.2	68.1	46.8	68.1	68.1	1.0	80.4	12.5	87.8	68.4
003	PCAS_03_004_051214_1805_w_009	LVA	LVA	LVA	CF	1300	CF	1300	52.3	77.6	54.0	52.3	77.6	54.0	63.0	63.0	0.9	84.8	10.1	90.8	75.3
003	PCAS_03_004_051214_1806_w_010	LVA	LVA	LVA	CF	1400	CF	1400	59.2	83.3	61.5	59.2	83.3	61.5	66.2	66.2	0.9	87.8	10.9	93.8	82.9
003	PCAS_03_004_051214_1808_w_011	-	-	LVA	PF	-	PF	-	39.3	47.4	37.2	39.3	47.4	37.2	76.4	76.4	1.1	68.8	27.5	81.9	54.5
003	PCAS_03_004_051214_1814_w_012	LVA	LVA	LVA	PF	100	PF	100	39.0	53.2	37.7	39.0	53.2	37.7	73.5	73.5	1.1	68.1	31.0	82.8	51.9
003	PCAS_03_004_051214_1816_w_013	LVA	LVA	LVA	PF	100	PF	100	3.10/0.1	56.2	39.0	3.10/0.1	56.2	39.0	73.4	73.4	1.1	66.5	26.5	79.1	52.6
003	PCAS_03_004_051214_1818_w_014	LVA	LVA	LVA	PF	100	PF	100	3.20/0.1	55.7	38.2	3.20/0.1	55.7	38.2	67.0	67.0	1.1	69.0	24.8	80.0	55.2
003	PCAS_03_004_051214_1820_w_015	LVA	LVA	LVA	PF	100	PF	100	3.30/0.1	58.7	38.2	3.30/0.1	58.7	38.2	60.3	60.3	1.0	71.2	26.1	82.7	56.6
003	PCAS_03_004_051214_1821_w_016	LVA	LVA	LVA	PF	100	PF	100	3.40/0.1	54.4	44.4	3.40/0.1	54.4	44.4	75.9	75.9	1.2	73.6	25.6	84.5	58.9
003	PCAS_03_004_051214_1822_w_017	LVA	LVA	LVA	PF	100	PF	100	3.50/0.1	66.5	50.3	3.50/0.1	66.5	50.3	78.3	78.3	1.1	77.0	25.1	88.3	63.2
003	PCAS_03_004_051214_1824_w_018	LVA	LVA	LVA	PF	100	PF	100	3.60/0.1	58.2	49.6	3.60/0.1	58.2	49.6	78.6	78.6	1.1	82.5	22.8	92.3	69.5
003	PCAS_03_004_051214_1825_w_019	LVA	LVA	LVA	PF	100	PF	100	3.70/0.1	64.5	55.5	3.70/0.1	64.5	55.5	79.9	79.9	1.0	86.7	22.2	96.5	74.3
003	PCAS_03_004_051214_1826_w_020	LVA	LVA	LVA	PF	100	PF	100	3.80/0.1	57.0	63.5	3.80/0.1	57.0	63.5	80.3	80.3	1.1	91.4	20.8	100.7	79.9
003	PCAS_03_004_051214_1830_w_021	LVA	LVA	LVA	PF	140	PF	140	2.99/0.1	39.4	50.2	2.99/0.1	39.4	50.2	75.9	75.9	1.1	68.3	20.2	83.3	54.0
003	PCAS_03_004_051214_1831_w_022	LVA	LVA	LVA	PF	140	PF	140	3.10/0.1	39.8	55.5	3.10/0.1	39.8	55.5	39.1	39.1	1.0	68.8	23.0	80.2	57.2
003	PCAS_03_004_051214_1833_w_023	LVA	LVA	LVA	PF	140	PF	140	3.20/0.1	42.6	57.9	3.20/0.1	42.6	57.9	42.1	42.1	1.0	70.7	19.0	80.2	61.2
003	PCAS_03_004_051214_1834_w_024	LVA	LVA	LVA	PF	140	PF	140	3.30/0.1	44.3	49.4	3.30/0.1	44.3	49.4	41.5	41.5	1.1	73.5	15.1	81.8	66.7
003	PCAS_03_004_051214_1835_w_025	LVA	LVA	LVA	PF	140	PF	140	3.40/0.1	47.5	55.7	3.40/0.1	47.5	55.7	74.1	74.1	1.1	77.1	13.1	84.2	71.1
003	PCAS_03_004_051214_1837_w_026	LVA	LVA	LVA	PF	140	PF	140	3.50/0.1	50.2	58.7	3.50/0.1	50.2	58.7	76.3	76.3	1.1	81.1	12.7	87.7	75.0
003	PCAS_03_004_051214_1838_w_027	LVA	LVA	LVA	PF	140	PF	140	3.60/0.1	55.9	72.4	3.60/0.1	55.9	72.4	55.1	55.1	1.0	87.3	10.5	92.6	82.1
003	PCAS_03_004_051214_1841_w_028	-	-	LVA	PF	-	PF	-	38.3	46.9	36.5	38.3	46.9	36.5	75.7	75.7	1.1	67.2	25.5	80.0	54.4
003	PCAS_03_004_051214_1849_w_029	-	-	Normal	-	-	-	-	53.6	88.3	51.4	53.6	88.3	51.4	81.7	81.7	1.1	88.0	90.9	144.6	53.7

MCS Number	Filename	Assist Condition	Heart Condition Simulated	Device Mode (CF or PF)	Device Setting (rpm or bpm)	Vpeak / Voffset	VADF mean (L/min)	VADF pulse (L/min)	VADF peak positive (L/min)	VADF peak negative (L/min)	Inlet mean (mmHg)	Outlet mean (mmHg)	Inlet peak positive (mmHg)	Inlet peak negative (mmHg)	Outlet peak positive (mmHg)	Outlet peak negative (mmHg)	pCAS ΔP (mmHg)
003	PCAS_03_004_051214_1737_w_001	-	Normal	-	-	-	0.00	0.00	0.00	0.00	2	2	2	1	2	1	0
003	PCAS_03_004_051214_1735_w_002	-	LVF	-	-	-	0.00	0.00	0.00	0.00	1	1	1	1	1	1	0
003	PCAS_03_004_051214_1754_w_003	LVA	LVF	CF	0	-	-0.53	0.35	-0.34	-0.69	32	34	73	4	74	4	1
003	PCAS_03_004_051214_1757_w_004	LVA	LVF	CF	818	-	0.00	0.53	0.27	-0.26	20	54	50	-9	81	24	34
003	PCAS_03_004_051214_1755_w_005	LVA	LVF	CF	900	-	0.22	0.54	0.51	-0.03	16	57	48	-11	86	31	41
003	PCAS_03_004_051214_1800_w_006	LVA	LVF	CF	1000	-	0.45	0.52	0.74	0.21	13	63	40	-9	87	41	50
003	PCAS_03_004_051214_1802_w_007	LVA	LVF	CF	1100	-	0.60	0.49	0.89	0.40	9	69	38	-8	94	50	60
003	PCAS_03_004_051214_1803_w_008	LVA	LVF	CF	1200	-	0.75	0.45	1.01	0.56	4	76	35	-12	103	58	71
003	PCAS_03_004_051214_1805_w_009	LVA	LVF	CF	1300	-	0.90	0.46	1.15	0.69	0	84	33	-16	113	68	84
003	PCAS_03_004_051214_1806_w_010	LVA	LVF	CF	1400	-	0.99	0.39	1.21	0.83	-4	94	30	-17	123	76	98
003	PCAS_03_004_051214_1806_w_011	-	LVF	-	-	-	0.00	0.00	0.00	0.00	7	7	8	6	9	6	0
003	PCAS_03_004_051214_1814_w_012	LVA	LVF	PF	100	3.00/0.1	-0.02	1.17	0.52	-0.64	20	52	63	-21	107	13	32
003	PCAS_03_004_051214_1816_w_013	LVA	LVF	PF	100	3.10/0.1	0.20	1.44	0.87	-0.58	16	57	63	-31	127	17	41
003	PCAS_03_004_051214_1816_w_014	LVA	LVF	PF	100	3.20/0.1	0.36	1.68	1.16	-0.53	13	63	61	-40	136	19	50
003	PCAS_03_004_051214_1820_w_015	LVA	LVF	PF	100	3.30/0.1	0.50	1.94	1.43	-0.50	9	69	61	-48	152	22	60
003	PCAS_03_004_051214_1821_w_016	LVA	LVF	PF	100	3.40/0.1	0.61	2.17	1.70	-0.47	6	76	60	-54	163	23	71
003	PCAS_03_004_051214_1822_w_017	LVA	LVF	PF	100	3.50/0.1	0.73	2.34	1.92	-0.43	3	85	60	-58	193	26	82
003	PCAS_03_004_051214_1824_w_018	LVA	LVF	PF	100	3.60/0.1	0.81	2.57	2.15	-0.42	1	94	59	-71	206	30	94
003	PCAS_03_004_051214_1825_w_019	LVA	LVF	PF	100	3.70/0.1	0.90	2.81	2.38	-0.43	-2	105	58	-76	235	35	105
003	PCAS_03_004_051214_1828_w_020	LVA	LVF	PF	100	3.80/0.1	0.99	3.08	2.61	-0.46	-4	116	58	-79	264	39	120
003	PCAS_03_004_051214_1830_w_021	LVA	LVF	PF	140	2.99/0.1	0.00	0.81	0.40	-0.41	20	54	60	-22	103	16	34
003	PCAS_03_004_051214_1831_w_022	LVA	LVF	PF	140	3.10/0.1	0.31	0.98	0.79	-0.19	15	59	58	-26	114	21	44
003	PCAS_03_004_051214_1833_w_023	LVA	LVF	PF	140	3.20/0.1	0.49	1.15	1.04	-0.10	11	65	56	-30	125	25	54
003	PCAS_03_004_051214_1834_w_024	LVA	LVF	PF	140	3.30/0.1	0.64	1.31	1.28	-0.03	7	72	55	-37	139	27	65
003	PCAS_03_004_051214_1835_w_025	LVA	LVF	PF	140	3.40/0.1	0.75	1.48	1.48	0.00	3	80	56	-45	156	33	77
003	PCAS_03_004_051214_1837_w_026	LVA	LVF	PF	140	3.50/0.1	0.87	1.65	1.70	0.04	0	89	51	-51	176	37	90
003	PCAS_03_004_051214_1838_w_027	LVA	LVF	PF	140	3.60/0.1	0.97	1.86	1.88	0.08	-2	100	50	-59	192	45	103
003	PCAS_03_004_051214_1841_w_028	-	LVF	-	-	-	0.00	0.00	0.00	0.00	9	10	12	7	13	8	1
003	PCAS_03_004_051214_1844_w_029	-	Normal	-	-	-	0.00	0.00	0.00	0.00	1	2	1	1	2	1	1

FIGURE 55. Pig 019. pCAS performing continuous LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 56. Pig 019. pCAS performing 100bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 57. Fig 019. pCAS performing 140bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 58. Pig 022. pCAS performing continuous LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 59. Pig 022. pCAS performing 100bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 60. Pig 022. pCAS performing 140bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 18. Pig 025. pCAS performing continuous LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 21. Pig 025. pCAS performing 100bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist.

FIGURE 22. Pig 025. pCAS performing 140bpm pulsatile LVA at A) 0% B) 50% C) 100% of maximum assist

FIGURE 61. Pig 019. Continuous pCAS flow and LAP as a function of RPM.

FIGURE 62. Pig 019. Pulsatile pCAS flow and LAP as a function of peak voltage. A) 100 bpm. B) 140 bpm.

FIGURE 63. Pig 022. Continuous pCAS flow and LAP as a function of RPM.

FIGURE 64. Pig 022. Pulsatile pCAS flow and LAP as a function of peak voltage. A) 100 bpm. B) 140 bpm.

FIGURE 19. Pig 025. Continuous pCAS flow and LAP as a function of RPM.

FIGURE 26. Pig 025. Pulsatile pCAS flow and LAP as a function of peak voltage. A) 100 bpm. B) 140 bpm.

VITA

The author is a twenty four year old graduate student at the University of Louisville. He is from the Louisville, KY area and has attended the Speed Scientific School of Engineering since August, 2000. The long pursuit of a Master's degree in Electrical and Computer Engineering is nearing completion as a graduation date is set for May, 2006. The author got married to an amazing woman in May, 2005, which is almost exactly the same time the work on this research project began. This project has been a tremendous learning experience with a meaningful purpose. Hopefully the long hours put into evaluation of the pCAS will make a miraculous difference in the life of an infant or small child one day.