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TITLE: Development of a Paracorporeal Pump-Integrated Artificial Lung for Transport of Warfighters with Acute Respiratory Distress Syndrome (ARDS)

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CONTRACTING ORGANIZATION: University of Kentucky

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14. ABSTRACT
Our goal is to develop a pump-integrated artificial lung (pPIAL) device for the safe warfighter transfer from combat theaters to regional medical centers. This one-piece compact pPIAL allows attachment to the patient body (paracorporeal) to enable easy deployment in the battlefield setting. In this first year of the DoD grant, we utilized computational fluid dynamics (CFD) simulation to refine the original design, not only for least potential of blood damage and thrombogenicity, but also for best performance of pumping and oxygenation. Based on the refined design, we established the technique/methodology to fabricate a high quality, complete working pPIAL system prototype, including the artificial lung, integrated pneumatic pump, and pneumatic pump console. Using this fabrication methodology, we made an initial pPIAL system prototype. Our first year solid achievements smooth the continuation of next two years proposed research, including in vitro bench testing and long-term animal evaluation. Due to the simpler, paracorporeal circuit, the pPIAL system will be easily deployed in the battlefield. The considerably shorter blood tubing connection will make the transport of ARDS warfighters much safer. The combined rapid deployment of respiratory support and safe transport for more comprehensive treatment will likely decrease ARDS mortality in these soldiers.

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NONE LISTED

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1. INTRODUCTION:

Acute respiratory distress syndrome (ARDS) significantly contributes to combat casualty and has a high mortality rate. Extracorporeal lung support is needed for ARDS warfighter transport from combat theaters to regional medical centers. A venovenous extracorporeal membrane oxygenation (vv ECMO) system was previously used, but it was bulky/complicated with a blood pump, an artificial lung (AL), and their individual control systems, requiring remote positioning with very long connection tubing. **Our objective** is to develop a paracorporeal pump-integrated artificial lung (pPIAL) device to replace separate AL and bulky pump. This one-piece compact pPIAL allows direct attachment to the patient's body, eliminating the long tubing connection. In **Specific Aim 1**, pPIAL and pneumatic console working prototypes will be developed and fabricated. The pPIAL consists of a compact AL and an integrated pump. The pneumatic console drives the pump and supplies the sweep gas. This design will be fine-tuned with computational fluid dynamics. In **Specific Aim 2**, the *in vitro* gas exchange efficiency and pump performance of the pPIAL will be evaluated. In **Specific Aim 3**, the *in vivo* performance of the pPIAL in sheep will be evaluated. The pPIAL circuit will consist of the pPIAL prototype, the AvalonElite double lumen cannula, and a short blood tubing connection. This circuit will be tested in sheep for 6 hrs (N=10) and for 2 weeks (N=10). The new, simple pPIAL can be easily deployed on the battlefield, and the much shorter blood tubing connection makes ARDS warfighters transport much safer.

2. KEYWORDS:

acute respiratory distress syndrome (ARDS), paracorporeal pump-integrated artificial lung (pPIAL), extracorporeal membrane oxygenation (ECMO), sheep

3. ACCOMPLISHMENTS:

Specific Aim 1: To Develop and Fabricate a pPIAL Working Prototype with Pneumatic Console	**Time**	**Status**
Major Task 1: Initial redesign and fabrication preparation of pPIAL and pneumatic console	Month	
Milestone(s) Achieved:		
Finish first version of design blue print.	6th	Complete
Finish initial CFD simulation.	6th	Complete
Determine the detailed fabrication process and purchase main materials, parts, and supplies for fabrication.	6th	Complete
Major Task 2: Fabrication of first working prototype of pPIAL and pneumatic console for initial bench test to identify any major flaws		
Milestone(s) Achieved:		
Fabricate first working pPIAL prototype	12th	85% Complete
Finish CFD simulations	12th	Complete
Fabricate first working pneumatic console prototype	12th	Complete
Major Task 3: Fabrication of working prototype of pPIAL and pneumatic console for full bench test and short-term *in vivo* sheep test		
Milestone(s) Achieved:		
Fabricate working pPIAL prototypes	24th	
Finalize CFD simulation	24th	
Fabricate working pneumatic console prototypes	24th	
Major Task 4: Fabrication of mature of pPIAL and pneumatic console prototypes for long term animal test		
Milestone(s) Achieved:		
Finish mature pPIAL and pneumatic console prototypes for long term animal study	36th	
Specific Aim 2: To Evaluate pPIAL *in vitro* Gas Exchange Efficiency and Pump Performance	**Time**	**Status**
Major Task 1: Initial bench test with 37% glycerin	Month	
Milestone(s) Achieved:		
Finish design of benchtop mock loop	3rd	Complete
Finish assembly of benchtop mock loop	6th	Complete
Finish initial bench test	12th	50% Complete
Major Task 2: Finish full short-term benchtop test with bovine blood		
Milestone(s) Achieved:		
Finish bench test for pPIAL pump/gas exchange performance and bio- compatibility test. Identify potential problems for prototype modification.	20th	
Major Task 3: Finish one month pPIAL durability benchtop test with 37% glycerin		
Milestone(s) Achieved:		
Finish long-term pPIAL durability benchtop test with 37% glycerin	24th	

Specific Aim 3: To Evaluate the in vivo Performance of pPIAL in Sheep	**Time**	**Status**
Major Task 1: IACUC/ACURO protocol approval	Month	
Milestone(s) Achieved		
IACUC Approval	8th	Complete
ACURO Approval	9th	Complete
Major Task 2: Perform short-term in vivo sheep study	Month	
Milestone(s) Achieved		
Finish short term in vivo sheep study	30th	
Major Task 3: Perform long-term in vivo sheep study	Month	
Milestone(s) Achieved		
Finish long-term in vivo sheep study	36th	

What was accomplished under these goals?

Specific Aim 1: To Develop and Fabricate a pPIAL Working Prototype with Pneumatic Console

Major Task (Activity) 1: Initial redesign and fabrication preparation of pPIAL and pneumatic console
Specific Objectives and Significant Results:

A. Finished initial and second versions of design blue print (Fig 1):

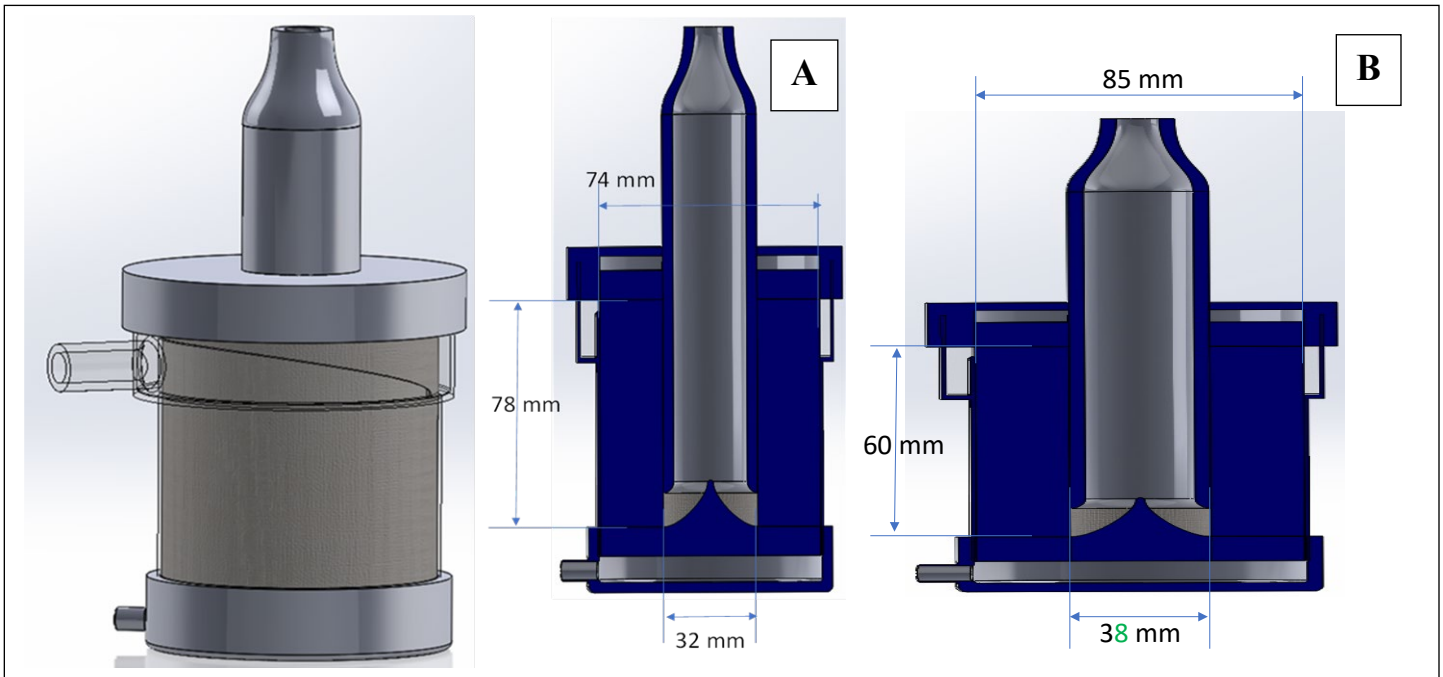

Fig 1 : The pPIAL Design Blue Print. **A:** Initial version; **B:** Second version

1. Design Rationale:
   1) An even blood flow AL will improve gas exchange performance and reduce thrombogenicity, which is required for long term use. Our design has a dramatically improved even blood flow pattern compared to Affinity oxygenator in our computational fluid dynamics (CFD) study.
   2) Diaphragm displacement pumps have been successfully used as ventricular assist devices for many years and have been proven to be simple, efficient and reliable. These pumps are not suitable for long term (months to years) implantation, but are perfect for months paracorporeal application, meeting requirement for a reliable, cost-efficient, ambulatory PAL.
   3) The pulsatile flow from the diaphragm displacement cylinder pump (DDCP) will further improve the flow pattern and gas exchange performance and decrease thrombogenicity.
   4) A compact portable pneumatic console is required to drive ambulatory pPIAL pumping. This console will also provide air to sweep AL for better ambulation.
   5) Polyurethane (PU) flexible diaphragm (tubing) has proven excellent durability, great strength, and outstanding biocompatibility in previous ventricular assist devices and total artificial heart.
   6) PU mechanical valve valve has been developed for total artificial heart by Co-I (ST) in Dr. Kolff's lab. This valve is simple, reliable, durable, and cost effective.

2. Summary:

In **Table 1**, the dimensions of the initial and second pPIAL prototype designs are compared. The second pPIAL design is shorter and wider than the initial design, which results in less blood flow resistance.

Table 1: Dimensions of Initial design and second design of pPIAL:

	Initial pPIAL Design	Second pPIAL Design
Fiber bundle height	78 mm	60 mm
Bundle outer diameter	74 mm	85 mm
Bundle inner diameter	32 mm	38 mm
Fiber bundle porosity	0.5	0.5 mm
Total surface area	1.44 M^2	1.43 M^2

B. Initial pPIAL Design CFD simulation:

1. CFD model setup:
   1) Computer aided model was created using Solidworks 2016.
   2) Flow domain was extracted using Ansys Designmodeler 19.2.
   3) Mesh was created using Ansys meshing 19.2.
   4) Flow fields were solved by Ansys Fluent 19.2.
      - Solving Navier-Stokes equations
        a. K-ω shear stress transport turbulence model
      - Boundary conditions
        a. Pulsatile flow inlet
           - 5 L/min mean flow rate
           - Square wave form (~70 bpm or wave cycle of 0.85 s)
           - PO2 = 47 mm Hg, SO2 = 65%
           - PCO2 =45 mm Hg
        b. Pressure outlet
           - 0 mm Hg static pressure
        c. Fiber bundle (modeled as homogeneous porous media)
           - Porosity 0.5 (total surface area 1.44 m2)
           - Flow path length 78 mm, OD 74 mm, ID 32 mm
        d. Simulation convergence
           - Flow rate difference between the inlet and outlet is less than 5%
           - The two same time points on the wave form have pressure difference less than 5%
        e. Mesh
           - 6.3 million elements
           - Inlet and outlet are extended to ensure fully developed flow
           - Mesh is refined adjacent to walls

2. CFD Result:
   1) Pressure distribution: at t = 3.85 s (**Fig 2**)
      a. Pressure loss happens mostly inside the fiber bundle
         - ΔP ~ 270 mm Hg
      b. Pressure loss after fiber bundle (excluding extended outlet)
      c. ΔP ~ 40 mm Hg

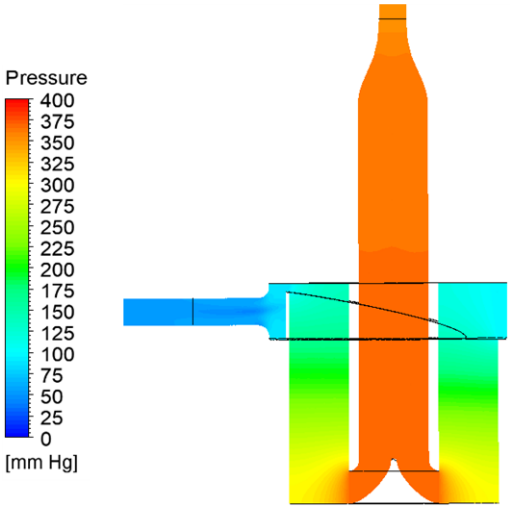

Fig 2: CFD Pressure Distribution

2) Velocity field: at t = 3.85 s

- Non-uniform flow and stagnation at the top of the fiber bundles
- Turbulent flow pattern at the exit (**Fig 3**)
- Velocity is mostly along the axial direction.
- When blood flow rate Q_ave = 5 L/min (assume HCT = 36%), the average oxygen transfer rate m_O2 = 380 ml/min.
- Fiber bundle is not fully utilized. Both top and bottom regions have non-uniform flow.

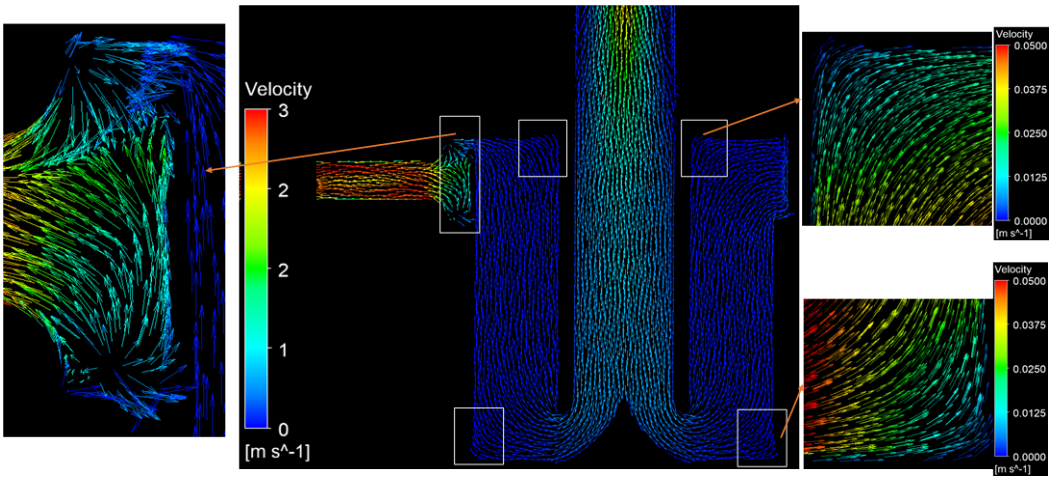

Fig 3: Turbulent flow pattern at the exit

3. <u>Summary:</u>
   - Current pPIAL design can provide 380 ml/min oxygen at flow rate of 5 L/min (assume HCT = 36%);
   - PO2 across the oxygenator is higher than 150 mm Hg;
   - High pressure loss occurs across the oxygenator (ΔP ~ 270 mm Hg);
   - Non-uniform flow exists inside fiber bundle, especially near the bottom and top;
   - Possible stagnation areas are located inside the fiber bundles and housing;
   - Flow is volatile inside the housing, especially near the exit;
   - Fiber bundle is not fully utilized and capacity is excessive.

   Future optimization:
   - Lower the pressure loss across the oxygenator to under 150 mm Hg while maintaining adequate oxygen transfer rate:
     - By reducing the fiber bundle height from 78 mm to ~55-60 mm

        - By adjusting the outer diameter of the fiber bundle
    - Optimize the housing design to minimize the stagnation area and turbulence
        - By changing the flow path where blood exits the fiber bundle to the housing (i.e. adding flow navigators)
        - By changing the exit port size and shape
    - Measure the real waveform from the pulsatile pump and analyze the performance with the measured waveform
    - Simulate the pulsatile flow with physical valves

C. Second pPIAL Design CFD Simulation:

1. CFD model setup: The same as intial design CFD simulation.
2. CFD Result:

1)Pressure distribution: at t = 3.85 s (**Fig 4**)

d. Improved Pressure loss happens mostly inside the fiber bundle
    - ΔP ~ 200 mm Hg

e. Pressure loss after fiber bundle (excluding extended outlet)
    - ΔP ~ 40 mm Hg

2) Velocity field: at t = 3.85 s

- Non-uniform flow and stagnation in top regions have significantly improved, but still exist.
- Turbulent flow pattern at the exit is significantly improved (**Fig 5**)
- Velocity is mostly along the axial direction.
- Excessive fiber bundle surface (PO2 > 150 mm Hg and SO2 >99%).
- When blood flow rate Q_ave = 5 L/min (assume HCT = 36%), the average oxygen transfer rate m_O2 ~ 300 ml/min

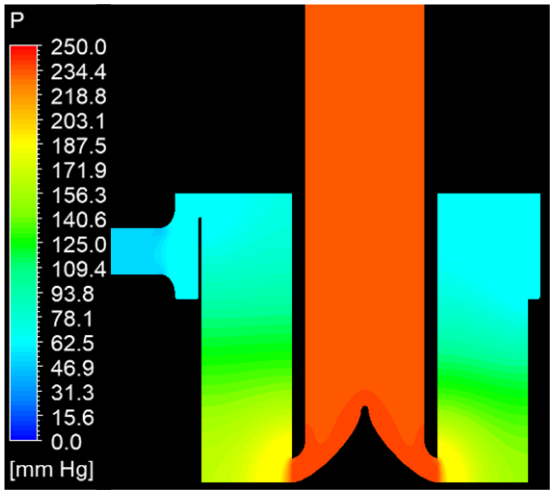

Fig 4: CFD Pressure Distribution

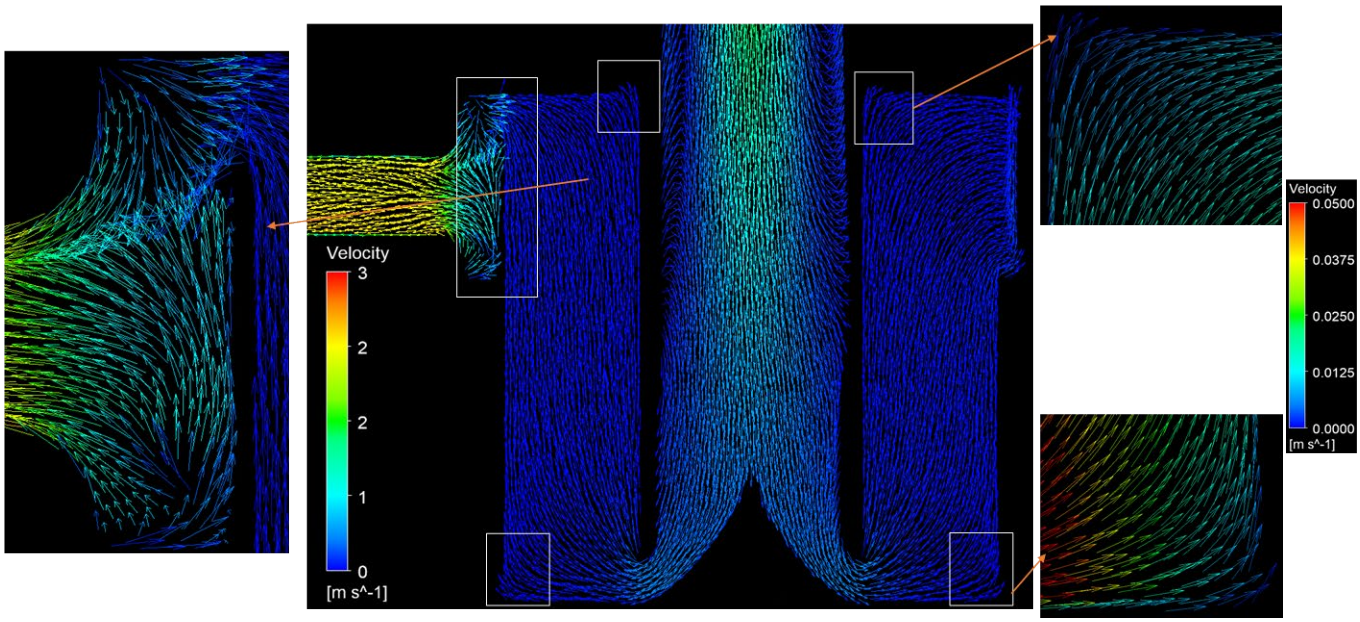

Fig 5: Turbulent flow pattern at the exit end significantly improved.

3. Summary:
   - Current pPIAL design can provide 300 ml/min oxygen at flow rate of 5 L/min (assume HCT = 36%);
   - PO2 across the oxygenator is higher than 150 mm Hg;
   - Pressure loss decreased from 270 mmHg to 200 mm Hg;
   - Non-uniform flow has been significantly improved, but still exists inside fiber bundle, especially near top.
   - Fiber bundle utilization significantly improved, but still excessive.

   Future optimization:
   - Lower the pressure loss across the oxygenator to under 150 mm Hg while maintaining adequate oxygen transfer rate:
     - By reducing the porosity from 0.5 to 0.6
   - Optimize the housing design to minimize the stagnation area and turbulence
     - By changing the flow path where blood exits the fiber bundle to the housing (i.e. adding flow navigators)
     - By changing the exit port size and shape

D. Determined the detailed fabrication process and purchased main materials, parts, and supplies for fabrication.

We have achieved this milestone, which has been applied in Major Task 2

Major Task (Activity) 2: Fabrication of first working prototype of pPIAL and pneumatic console for initial bench test to identify any major flaws

Specific objectives and Significant results:

A. Fabricate first working pPIAL prototype:

1. AL Fabrication Process:
   1) The prototype was made according to the size from CFD calculation. *Polypropylene (PP) hollow fibers* were used.
   2) The pPIAL housing was made from cast PU room temperature vulcanization molding.
   3) The cone-shaped flow-redirector was made from PU molding.

4) PP hollow fibers were packed around the DDCP within the PIAL housing.

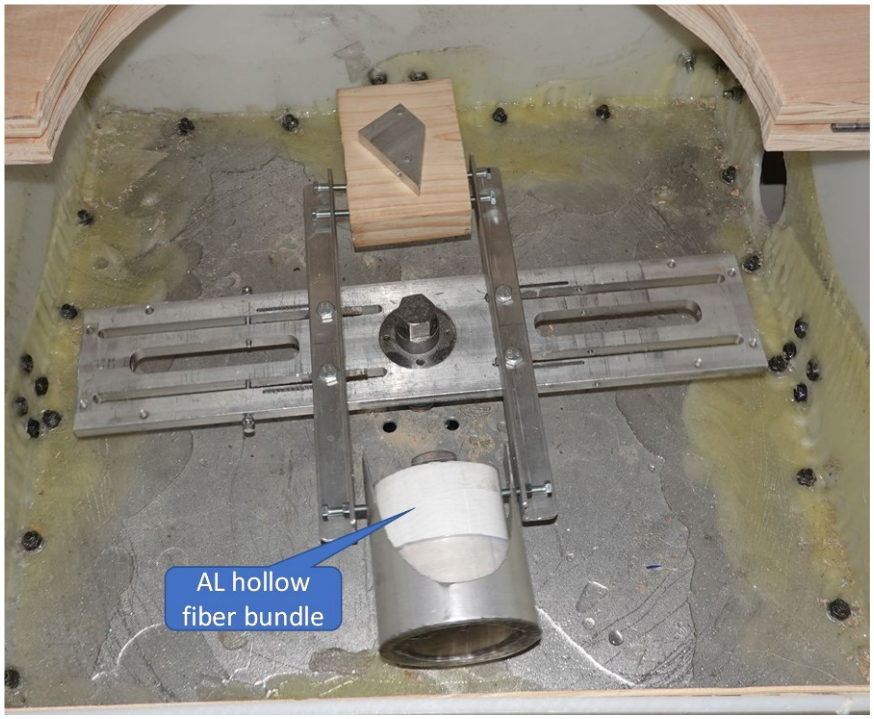

Fig 6: Simplified procedure for AL potting by using modified Centrifuge

5) Two part PU glue was used to pot PP hollow fiber to housing wall in both ends with thickness of ½ inch, separating blood from sweep gas.
6) A potting centrifuge with special potting caps was customized to pot these hollow fiber membrane (HFM) bundles (**Fig 6**).
7) The active HFM bundles inside the pPIAL housing was potted using a two parts PU and spun in the centrifuge at 750 rpm (86 rcf).
8) The PU resin was cured by an overnight heating at 49˚C.
9) The AL potting was then cut to expose the HFM inner lumen for sweep gas to pass through, and both ends of the AL were capped.

2. DDCP Fabrication (**Fig 7**):
   1) The DDCP included one rigid cylinder housing (OD: 38 mm) one flexible soft membrane tubing, and two mechanical valves.
   2) The rigid cylinder housing was made from polycarbonate tube.
   3) One end was capped with a 3/8” blood inlet connector; the other end was wide open to cone flow-redirector (**Fig 8**) on AL end.
   4) The pneumatic connector was installed on the housing side wall. Flexible soft membrane tubing was made from PU dip molding.
   5) Membrane tubing was installed inside rigid housing with two ends sealed on rigid pump housing, forming two chambers. One was the pneumatic chamber between flexible membrane tube and rigid housing, which was connected to the pneumatic console. The other was blood chamber inside flexible membrane tube, extending both ends to blood inlet connector from DLC drainage lumen and wide open outlet to AL.
   6) Two mechanical valves were installed at both ends of flexible membrane tube, controlling blood flow from inlet toward outlet.

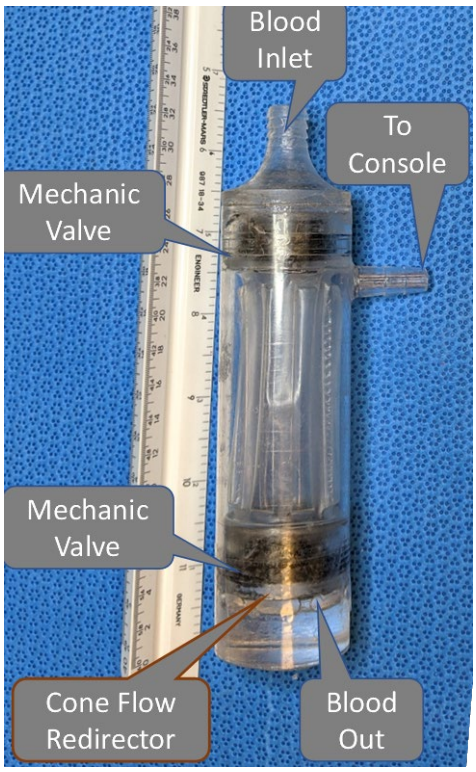

Fig 7: DDCP Prototype

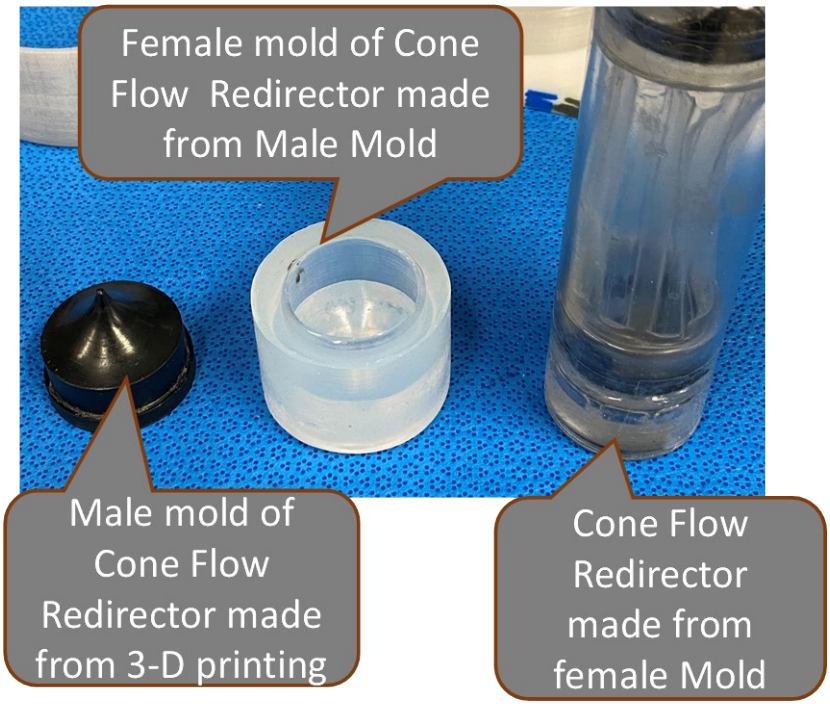

Fig 8: Fabrication of Cone Flow Redirector, which connects to DDCP

3. Asemble of PIAL prototype

The above hollow fiber bundle, housing, and DDCP has been assembled to form a complete PIAL prototype (**Fig 9**).

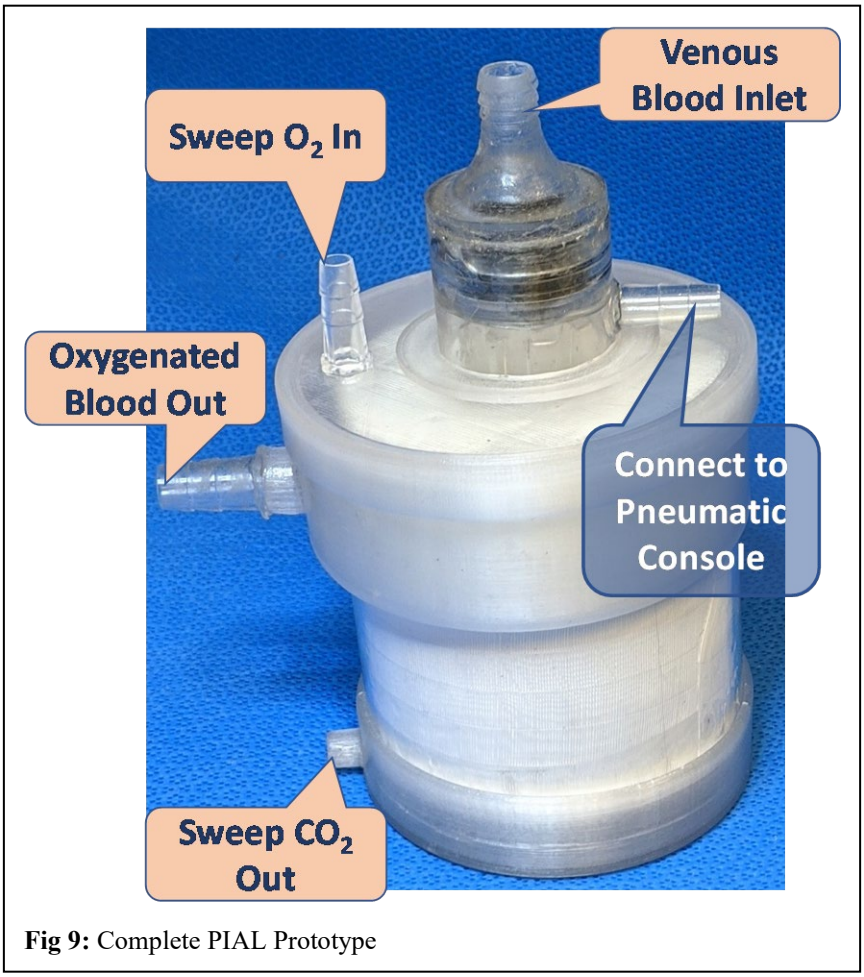

Fig 9: Complete PIAL Prototype

B. Pneumatic Console Fabrication (Fig 10):

A Texas Instrument MSP430 Microprocessor (MCU) is used as a central controller, enabling the use of a variety algorithm and digital control function. The user interface and system monitor is a 9" LCD touch screen.

- The Microprocessor-based digital feedback control system design has:
  a) Independent power supply to support whole system
  b) Read Digital Pressure Sensors
  c) Voltage outputs, which control actuators and solenoids (Pressure Regulator, 3-Way electromagnetic valve, etc.)
  d) Control algorithm to provide stability and accuracy
  e) Secure communication between MCU and LCD touch screen monitor
  f) Capability to remember latest control parameters even after power off
  g) Peripheral circuit board designed to meet the system requirement
- Pulsatile pump controller data includes:
  a) Pump Frequency (BPM): 10 to 150
  b) Systolic/Diastolic Ratio (%) 40 to 90
  c) Air Pressure applied to pump (mm Hg)
  Systolic 150 to 500
  Diastolic -25 to -150
- A 9" LCD touch screen monitor is used for user interface and system monitoring:
  a) Displays control parameters, which could be modified via the touch screen
  b) System ON/OFF control

c) Display real time pressure data graphically
d) Display alarm and warning signal

We have assembled the above components and have proven execution of designed function (**Fig 10**).

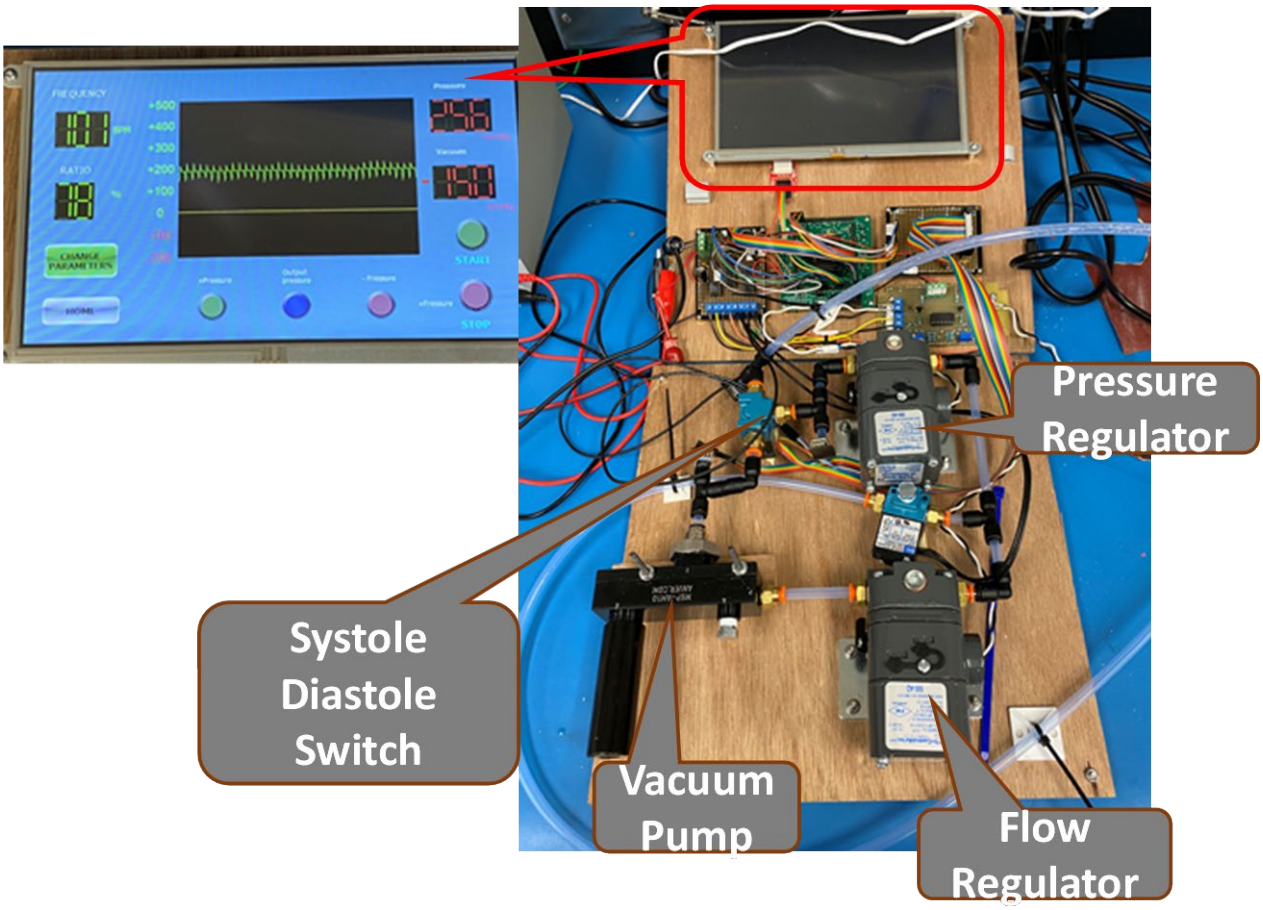

Fig 10: The initial experiment showed fully functional pneumatic console.

Specific Aim 2: To Evaluate pPIAL in vitro Gas Exchange Efficiency and Pump Performance

Major Task (Activity) 1: Initial bench test with 37% glycerin.

Specific objectives and Significant results:

A. Finish design of benchtop mock loop:

We have finished the detailed design of benchtop mock loop as shown in **Fig 11**. The pPIAL prototype and pneumatic console will be tested in a mock circuit with 37% glycerin. Besides the pPIAL and pneumatic console, the mock circuit will include gravity reservoir, volume measuring container, and an additional AL (AffinityTM AL) for deoxygenation. The Affinity heater will be used to maintain circuit temperature at 37°C.

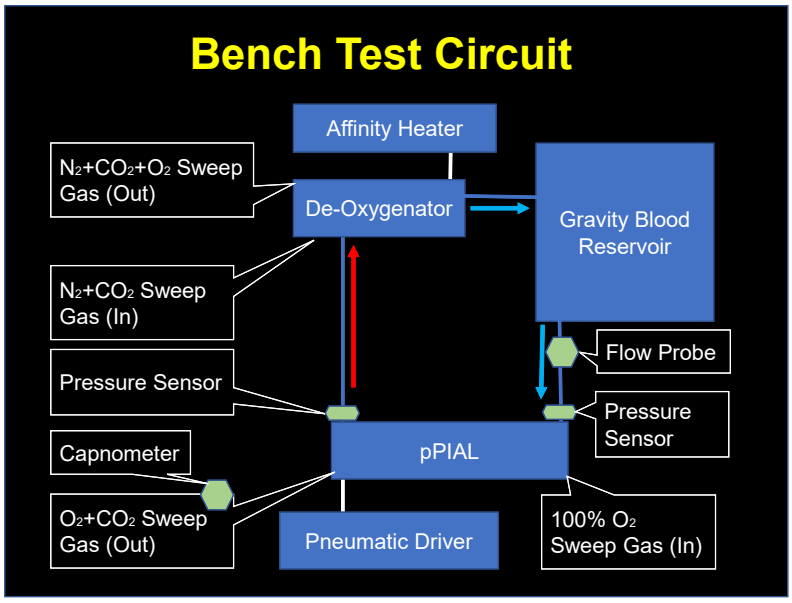

Fig 11: In vitro mock circuit for bench test.

B. Finish assembly of benchtop mock loop

We are ready to put all the components and parts together for the benchtop mock loop. However, we are waiting for completion of pPIAL and pneumatical console working prototype for testing in this mock loop.

Specific Aim 3: To Evaluate the in vivo Performance of pPIAL in Sheep

Specific objectives and Significant results:

Major Task (Activity) 1: IACUC/ACURO protocol approval:

A. IACUC Approval:

- IACUC animal protocol submitted on 04/19/2019
- IACUC animal protocol approved on 05/20/2019
- Amendment to IACUC animal protocol submitted on 09/12/2019
- Amendment to IACUC animal protocol approved on 09/20/2019

B. ACURO Approval:

- Following documents were sent to ACURO on 05/31/2019: 1) ACURO Animal Use Appendix, 2) Signed PI Assurance, 3) approved IACUC animal protocol, 4) IACUC approval documentation, and 5) most recent USDA inspection report
- ACURO requested additional documents/information on 09/11/2019
- Amended IACUC protocol with approval letter sent to ACURO on 09/25/2019
- ACURO approval on 09/30/2019

No animal studies on this ACURO protocol have taken place because the pump integrated artificial lung prototype needs to be fabricated at a quality sufficient for animal testing. As per the SOW document, the animal studies are planned for Year 2 and Year 3 of the project.

Overall Summary:

In this first year of the DoD grant, we utilized computational fluid dynamics (CFD) simulation to refine the original design, not only for least potential of blood damage and thrombogenicity, but also for best performance of pumping and oxygenation. Based on the refined design, we established the technique/methodology to fabricate a high quality, complete working pPIAL system prototype, including the artificial lung, integrated pneumatic pump, and pneumatic pump console. Using this fabrication methodology, we made an initial pPIAL system prototype. Our first year solid achievements smooth the continuation of next two years proposed research, including in vitro bench testing and long-term animal evaluation. Due to the simpler, paracorporeal circuit, the pPIAL system will be easily deployed in the battlefield. The considerably shorter blood tubing connection will make the transport of ARDS warfighters much safer. The combined rapid deployment of respiratory support and safe transport for more comprehensive treatment will likely decrease ARDS mortality in these soldiers.

What opportunities for training and professional development has the project provided?

Nothing to Report

How were the results disseminated to communities of interest?

Nothing to Report

What do you plan to do during the next reporting period to accomplish the goals?

1. Fabrication of pPIAL and pneumatic console working prototypes for full bench test and short-term i*n vivo* sheep test.
   1) Fine tune and finalize pPIAL design utilizing CFD simulation
   2) Fabricate working pPIAL prototypes based on above final design
   3) Trouble shoot potential bugs and fabricate final working pneumatic console prototypes
2. Finish the initial bench test of pPIAL and its console with 37% glycerin
3. Finish full short-term benchtop test with bovine blood
   1) Finish bench test for pPIAL pump/gas exchange performance and biocompatibility test.
   2) Identify potential problems for prototype modification.
4. Finish one month pPIAL durability benchtop test with 37% glycerin

4. IMPACT:

What was the impact on the development of the principal discipline(s) of the project?

Short-Term Impact: The short-term impact will be the development of a new simple and reliable pPIAL system with proven gas exchange efficiency and pump performance. This will lay the foundation for GLP animal studies for FDA investigational device exemption (IDE) approval for clinical trials and the eventual completion of clinical trials for FDA approval for clinical use in ARDS patients. **Long-Term Impact:** Due to the simpler, paracorporeal circuit, the pPIAL system will be easily deployed in the battlefield setting. The considerably shorter blood tubing connection will also make the transport of warfighters with ARDS from combat theaters to regional medical centers much safer. The combined rapid deployment of respiratory support and safe transport will likely decrease the mortality of acute lung injury in these soldiers.

What was the impact on other disciplines?

Our pPIAL circuit may also pave the way for a truly ambulatory respiratory support system to enhance the recovery of chronic lung disease patients from acute exacerbation and to improve end stage lung disease patients physical condition for better lung transplant outcomes.

What was the impact on technology transfer?

Nothing to report

What was the impact on society beyond science and technology?

Nothing to report

5. CHANGES/PROBLEMS:

Changes in approach and reasons for change

None

Actual or anticipated problems or delays and actions or plans to resolve them

Employee Hiring Delay

During the first six months, we experienced delays in hiring staff. Two W-Z Biotech, LLC employees had to be hired by the University of Kentucky (UK) due to a Kentucky state law prohibiting UK from subcontracting with W-Z Biotech. Mr. Topaz was hired in December 2019 and Mr. Shao was hired in September 2019. There was also a delay in hiring Mr. Zhuang who was hired in December 2019. Additionally, we had trouble finding an appropriate post-doctoral scholar and a graduate student in biomedical engineering. We found an appropriate post-doctoral scholar in March, but the hiring process was delayed due to COVID-19 hiring restrictions at the University of Kentucky. This post-doctoral scholar was hired in July. An appropriate biomedical engineering graduate student at UK has also been found, and she has recently begun work on this project.

Delay in Materials Procurement

For the artificial lung fabrication, we experienced great difficulty in purchasing the polymethylpentene (PMP) hollow fibers from the sole manufacturer due to the huge demand of ECMO for COVID -19 induced severe ARDS. This is the major reason we were unable to complete the first pPIAL prototype in time. Fortunately, an oxygenator company is willing to help us with PMP fiber since they have great interest in our technology. Therefore, we will be able to continue our DOD project as scheduled. We also experienced a delay in obtaining additional hollow fiber material for the artificial lung fabrication.

Changes that had a significant impact on expenditures

Delays in hiring, as described above, have impacted expenditures.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Significant changes in use or care of human subjects

Not applicable, no human subject studies proposed in this project.

Significant changes in use or care of vertebrate animals

There have been no significant changes in the use or care of vertebrate animals.

Significant changes in use of biohazards and/or select agents

Not applicable, no hazards or select agents will be used in this project.

6. PRODUCTS:

- **Publications, conference papers, and presentations**

Journal publications.

Nothing to report. This project is in the early stage of device fabrication.

Books or other non-periodical, one-time publications.

Nothing to report. This project is in the early stage of device fabrication.

Other publications, conference papers and presentations.

Nothing to report. This project is in the early stage of device fabrication.

- **Website(s) or other Internet site(s)**

Nothing to report.

- **Technologies or techniques**

Nothing to Report

- **Inventions, patent applications, and/or licenses**

Nothing to report. The Principle Investigator (DW) and a Co-Investigator (JZ) already have a patent for the technology to be developed in this project.

- **Other Products**

Nothing to Report.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Name: Dongfang Wang, MD, PhD
Project Role: Principal Investigator
Nearest person month worked: 6
Contribution to Project: Dr. Wang led efforts on pPIAL design/fabrication and the *in vitro* bench testing set-up. He also provided supervision/insight on parts and supplies purchases for fabrication.
Name: Joseph Zwischenberger, MD
Project Role: Co-Investigator
Nearest person month worked: 1
Contribution to Project: Dr. Zwischenberger provided key input regarding the pPIAL design.
Name: Cherry Ballard-Croft, PhD
Project Role: Co-Investigator
Nearest person month worked: 6
Contribution to Project: Dr. Ballard-Croft assisted with pPIAL fabrication supplies purchases, *in vitro* bench testing set-up, and IACUC protocol submission and revision.

Name: Michael Sekela, MD
Project Role: Co-Investigator
Nearest person month worked: 0.1
Contribution to Project: Dr. Sekela provided input on the pPIAL design from a cardiothoracic surgeon's perspective.
Name: Vincent Sorrell, MD
Project Role: Co-Investigator
Nearest person month worked: 0.1
Contribution to Project: Dr. Sorrell advised on the logistics of echocardiography in sheep.
Name: Peter Morris, MD
Project Role: Co-Investigator
Nearest person month worked: 0.1
Contribution to Project: Dr. Morris provided input on pPIAL design from pulmonologist's perspective.
Name: Stephen Topaz, BSE
Project Role: Co-Investigator
Nearest person month worked: 2
Contribution to Project: Mr. Topaz supervised the pPIAL design and fabrication.
Name: Zhongjiang Zhuang, BSE, MS
Project Role: Co-Investigator
Nearest person month worked: 8
Contribution to Project: Mr. Zhuang worked on pPIAL pump/console fabrication and bench test set-up.
Name: Zeng Shao, BS, MS
Project Role: Engineer
Nearest person month worked: 12
Contribution to Project: Mr.Shao assisted with pPIAL pump/console fabrication and bench test set-up.
Name: Li Li, MD
Project Role: Post-Doctoral Scholar
Nearest person month worked: 9
Contribution to Project: Dr. Li assisted with design and set-up of bench test and supply procurement.
Name: Amal Alotaibi, MD
Project Role: Post-Doctoral Scholar
Nearest person month worked: 1
Contribution to Project: Dr. Alotaibi assisted with the set-up of the bench test.
Name: Zongjun Wu, PhD
Project Role: Principal Investigator of Subcontract
Nearest person month worked: 1
Contribution to Project: Dr. Wu directed the initial and second CFD simulations.
Name: Jiafeng Zhang, PhD
Project Role: Research Associate of Subcontract
Nearest person month worked: 6
Contribution to Project: Dr. Zhang performed the initial and second CFD simulations.

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

A NIH Phase I SBIR grant subcontracted to the University of Kentucky ended on 02/29/2020. The PI (DW) and Co-Is (JZ, CBC, ST) received funding from this grant.

What other organizations were involved as partners?

Nothing to Report

8. SPECIAL REPORTING REQUIREMENTS

COLLABORATIVE AWARDS: Not Applicable

QUAD CHARTS: Not Applicable

9. APPENDICES:

PR181510: Development of a Paracorporeal Pump-Integrated Artificial Lung for Transport of Warfighters with Acute Respiratory Distress Syndrome (ARDS)

PI: Dongfang Wang, University of Kentucky, KY
Budget: $3,906,819.00
Topic Area: Technology/Therapeutic Development
Mechanism: W81XWH18PRMRPTTDA

Research Area(s): SCS Coding:1600
Award Status: Year 1: 08/15/2019-09/14/2020

Study Goals:

Our ultimate goal is to develop a simple lung support system with no need of long blood tubing connection for the safe ARDS warfighter transfer from combat theaters to regional medical centers. **Our objective** is to design one device (pPIAL) to replace separate AL and bulky pump. This one-piece compact pPIAL allows attachment to patient body (paracorporeal/wearable), eliminating the long tubing connection and associated high blood resistance/trauma and mitigating cannula dislodgement/catastrophic cannula decannulation.

Specific Aims:

Specific Aim 1: To Develop and Fabricate a pPIAL Working Prototype with Pneumatic Console. In this specific aim, a pPIAL and its console will be developed. The pPIAL will consist of an AL and an integrated pump.

Specific Aim 2: To Evaluate pPIAL *in vitro* Gas Exchange Efficiency and Pump Performance. In this specific aim, the pPIAL prototype will be bench tested in a mock circuit for its pump and gas exchange performance.

Specific Aim 3: To Evaluate the in vivo Performance of pPIAL in Sheep: In this specific aim, the paracorporeal AL circuit will consist of the pPIAL prototype, the AvalonElite® double lumen cannula, and short blood tubing connection. This circuit will be tested in sheep for 6 hours (n=10) and for 2 weeks (n=10) to evaluate pPIAL *in vivo* gas exchange and pump performance.

Key Accomplishments and Outcomes:

Publications: none to date

Patents: none to date

Funding Obtained: none to date

1) Finished initial and second CFD simulations. 2) Based on the CFD results, pPIAL system was redesigned. 3) Established pPIAL system fabrication methodology. 4) Made initial pPIAL system prototype.