Ultra Low Cost Artificial Lung

Jack Forman[1,2], Katherine Forrester[1,3], Andre Gutierrez[1,4], Beichen Liu[1,3], Rena Mu[1,3]

[1]Department of Biomedical Engineering, [2]Department of Materials Science and Engineering,
[3]Department of Chemical Engineering, [4]Department of Mechanical Engineering

Clinical Need

Acute Hypercapnic Respiratory Failure (AHRF)

- Occurs when lungs are unable to remove CO_2 from the blood
- Excess CO_2 can cause blood pH to drop below normal pH 7.35[1]
- Many possible underlying causes
  - Damaged lung tissue, COPD, emphysema, etc.[2]
  - Imbalance between the load and capacity of respiratory muscles[1]
- Must be treated in an intensive care unit (ICU) while underlying cause is also addressed.

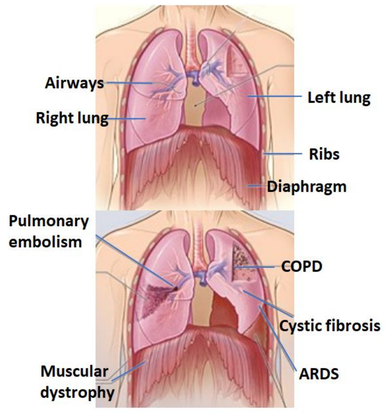

Figure 1: Conditions and underlying causes that can result in respiratory failure. AHRF is a specific kind of respiratory failure.[3]

Hemolung RAS Overview

- Air pumped through fibers in cartridge
- Gas exchange allows CO2 to diffuse from blood into air

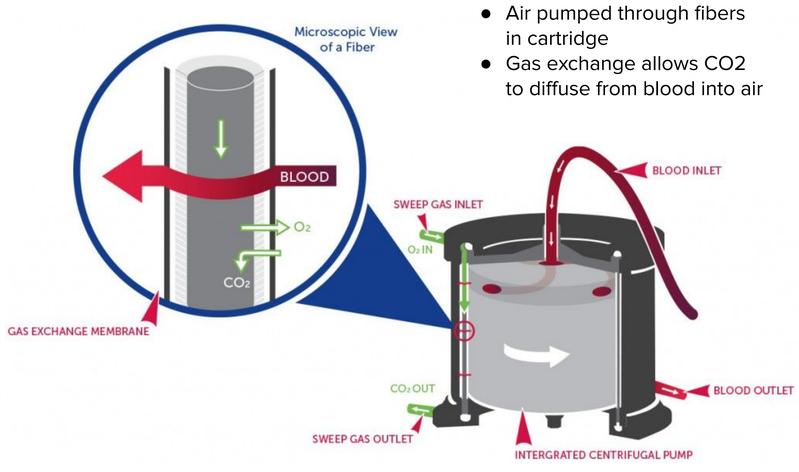

Figure 2: Mechanism behind CO_2 removal in the ALung Hemolung RAS artificial lung device.[4]

Needs Statement

A way to **improve the accessibility of treatment** for patients with acute hypercapnic respiratory failure in developing countries through **reducing the cost of an artificial lung** as a bridge to permanent treatment by **simplifying its control system and streamlining ALung's existing design**.

Design

Updated Cartridge Design

- Altered design for more compact and simplified overall device

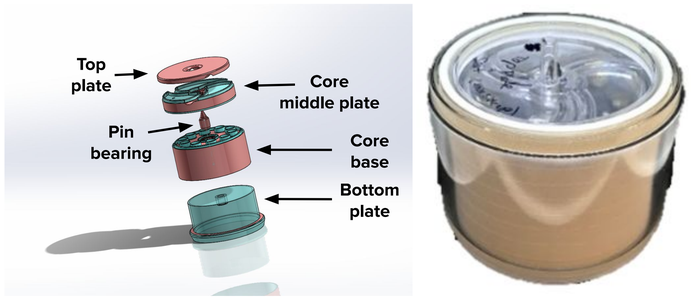

Figure 3: The exploded view of the redesigned cartridge (left) and the finished cartridge after all of the parts have been fabricated and assembled (right).

Sensors

- Selected based on recommendation by ALung

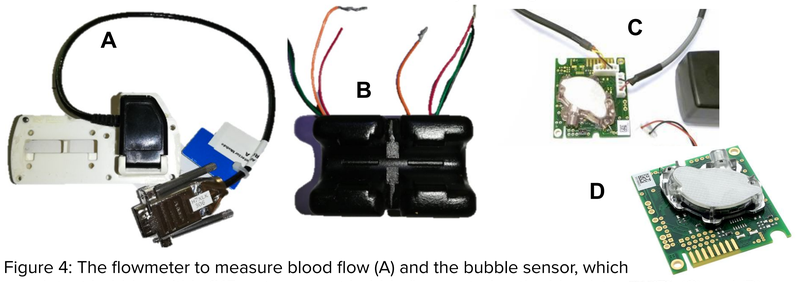

Figure 4: The flowmeter to measure blood flow (A) and the bubble sensor, which can detect bubbles within 215 µs to prevent bubble from entering the bloodstream (B). (C) and (D) show the proposed CO2 in-line sensor to be integrated in future iterations, where (C) would be in-line and (D) for calibration..

Controller

- Controller components completely integrated together with prototype
- Demonstrates ability to power prototype with simpler circuitry and cheaper parts

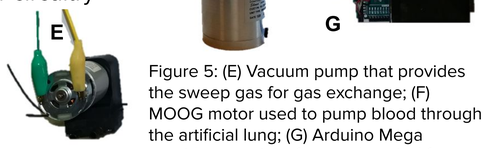

Figure 5: (E) Vacuum pump that provides the sweep gas for gas exchange; (F) MOOG motor used to pump blood through the artificial lung; (G) Arduino Mega provides user interface and control for motor, pump, and sensors.

Updated Housing

- Housing design is scalable for future design modifications
- Controller components are all contained in back compartment

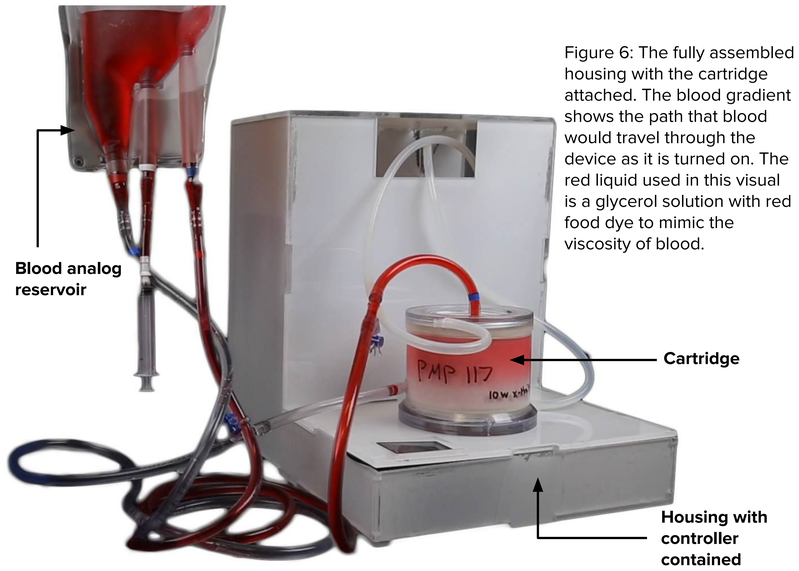

Figure 6: The fully assembled housing with the cartridge attached. The blood gradient shows the path that blood would travel through the device as it is turned on. The red liquid used in this visual is a glycerol solution with red food dye to mimic the viscosity of blood.

Results

Cost Savings

- Over **85%** cost reduction from ALung's designs
  - Simplified controller
    - Reducing the number of sensors used
  - Potential savings from injection molded parts

Gas Exchange

- During testing for CO_2 removal, our prototype was able to remove CO_2 at **79%** of the rate that Hemolung RAS is able to.

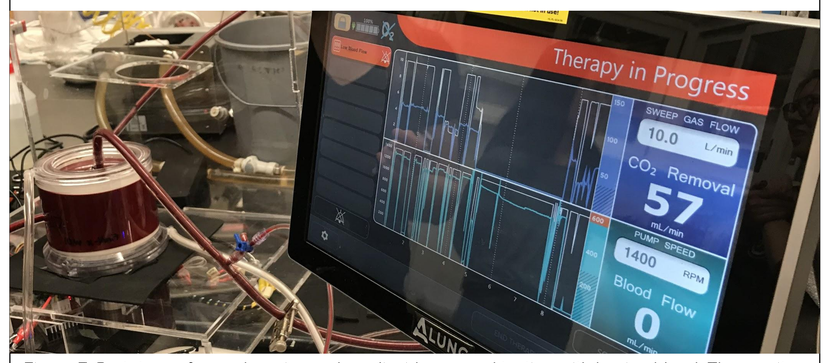

Figure 7: Prototype after undergoing carbon dioxide removal testing with bovine blood. The monitor shows the resulting carbon dioxide removal rate to be 57 mL/minute.

Future Work

- Find and implement a more powerful motor driver to provide better motor speed control to achieve similar flow rate as Hemolung
- Integrate remaining sensors into the system and perform testing to verify their performance
- Conduct more testing to assess hemolysis, gas exchange, and motor performance

Acknowledgements

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References

1. Dwarakanath, Akshay, and Mark W. Elliott. "Noninvasive Ventilation in the Management of Acute Hypercapnic Respiratory Failure." European Respiratory Society, European Respiratory Society, 1 Sept. 2013,
2. Patel, Bhakti K. "Respiratory Failure - Lung and Airway Disorders." Merck Manuals Professional Edition,
3. "Respiratory Failure." National Heart Lung and Blood Institute, U.S. Department of Health and Human Services, www.nhlbi.nih.gov/health-topics/respiratory-failure.
4. Gillies, M, et al. "Study Manual for the REST Trial: Protective Ventilation with Veno-Venous Lung Assist in Respiratory Failure." Http://Www.nictu.hscni.net, 10 Feb. 2016.

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