# Computed Tomography Circulation Phantom to Assess Hyperdynamic Flow Rates


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## Motivation and Problem Statement

A CT phantom is a device used to calibrate Computed Tomography machines by acting as a "stand in" for human tissues [1]. Most phantoms currently in use are static; they do not allow for dynamic flow. Some patients obtaining a CT scan may need a circulatory support device, such as a VA-ECMO (veno-arterial extracorporeal membrane oxygenation) [2] device. There is a clinical need for a CT phantom with dynamic flow capabilities to study the correct ways to conduct CT vascular imaging for patients on ECMO devices. This phantom should model the inflow and outflow of an ECMO patient and have capabilities to simulate the addition of contrast media into the vascular system. Ultimately, this device will help medical personnel to better understand the flow of CT contrast through a patient on an ECMO machine, as the circulation flow rate of an ECMO patient differs from a patient not on ECMO [3].

## Fundamental Equations and Definitions

- The design addresses the need for a dynamic flow CT Phantom that models ECMO blood flow interaction with iodinated contrast agent fluid
- Hagen-Poiseuille Equation[4]:

$$\Delta P = \frac{\pi r^4 Q}{8\eta L}$$

Describes the variables that contribute to pressure difference in the system: a critical variable

- Reynold's Number[5]:

$$Re = \frac{\rho V L}{\eta}$$

A number to classify the flow into turbulent or laminar: determines mixing capabilities

- Hounsfield Unit (HU): A relative quantitative measurement for CT images indicative of the attenuation coefficient of radiation within materials [6].

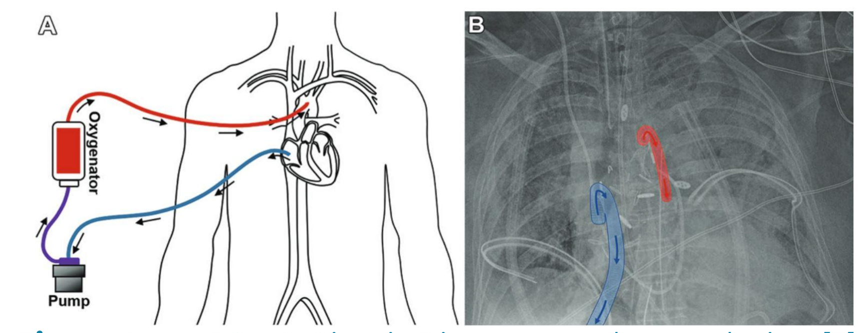


*Figure 1: VA-ECMO Circuit Diagram and cannulation [3]*

## Design Criteria

- A CT phantom with the main components of the heart pertaining to VA-ECMO
- A pump and fluid flow system that models an ECMO device, complete with adjustable flow rates and phantom connectability
- An iodinated contrast injector access point
- A mechanism to fill and empty the fluid
- Easily cleaned
- Circuit supports flow of 3.0-4.0 L/min [7]
- HU enhancement values between 300 and 800[8]
- Able to run for 2 minutes at a time
- Maximum weight of 500 lbs

## Final Design

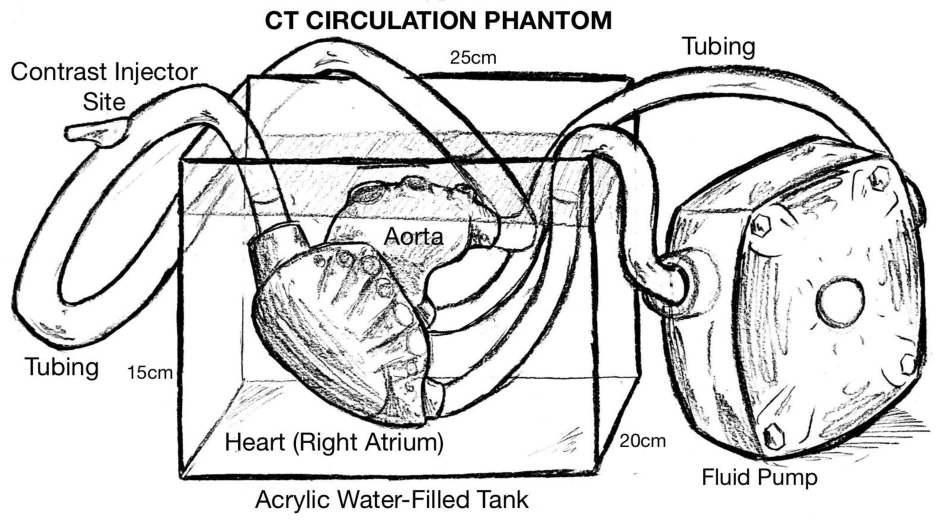


***Figure 2:** Sketch of final design. including components and dimensions*

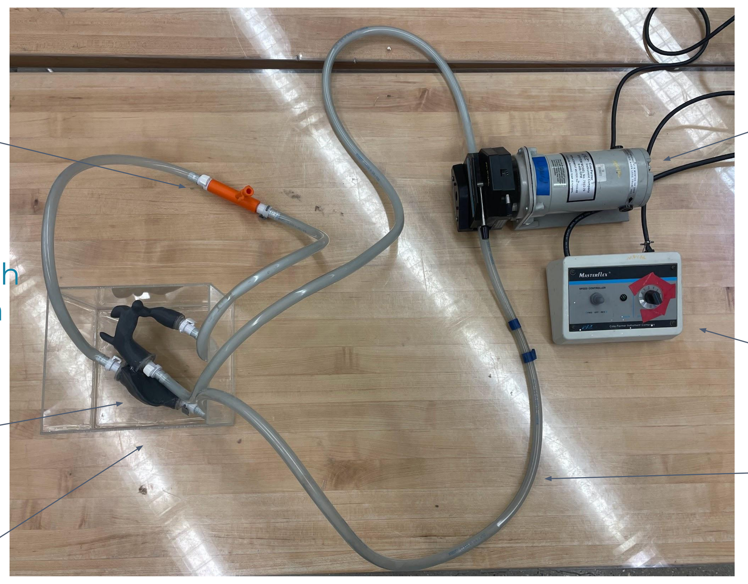


***Figure 3:** Completed circulation phantom*

## Testing Methods

- Flow Rate Testing
  - Goal: correlate pump speeds to volume output
  - Filled the tubing with water to ensure an accurate reading, each speed was turned on for 15 seconds and the water output was collected into a vessel.
  - The volume of the water was measured and the weight recorded, then converted to volume
  - Three trials were run at each speed
- Flow Rate Verification
  - Goal: ensure that the actual flow rate matches the expected flow rate
  - Using a flowmeter
  - Compare values to initial tested values and adjust dial accordingly.
- CT Scan Testing
  - Goal: Verify that attenuation of contrast in the flow phantom is similar to that of a real patient
  - Run circuit for 30 seconds prior to contrast injection. This will mimic a patient on ECMO.
  - Begin CT scan, start contrast injection after 5 seconds.
    - CT series scan: 24 series with 86 pictures per series. This includes multiple scans/passes of the same area over time.
  - Create plot using Hounsfield Units from various scans of the same location.

## Results

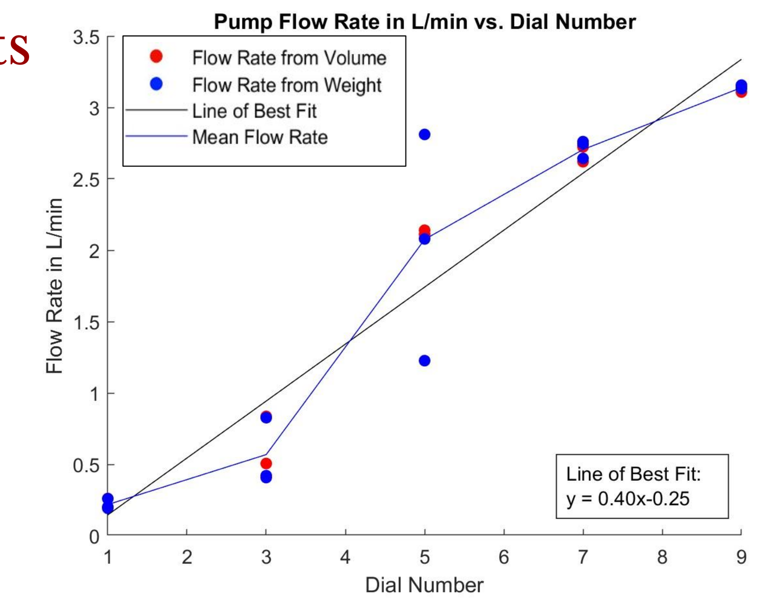


***Figure 4:** Flow rates measured from three calculated flow rate tests which recorded both volume and weight*

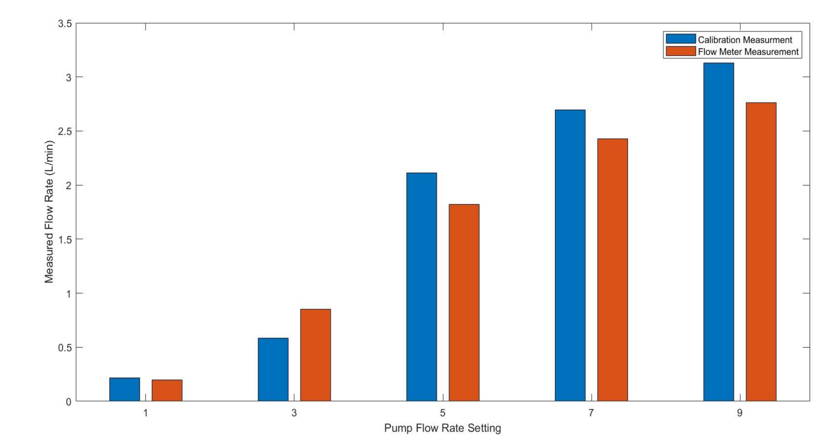

***Figure 5:** Flow rates measured in calculated testing versus with flow meter. Two-Sample T-Test says that the samples fail to reject the null hypothesis. There is no significant difference between the groups.*

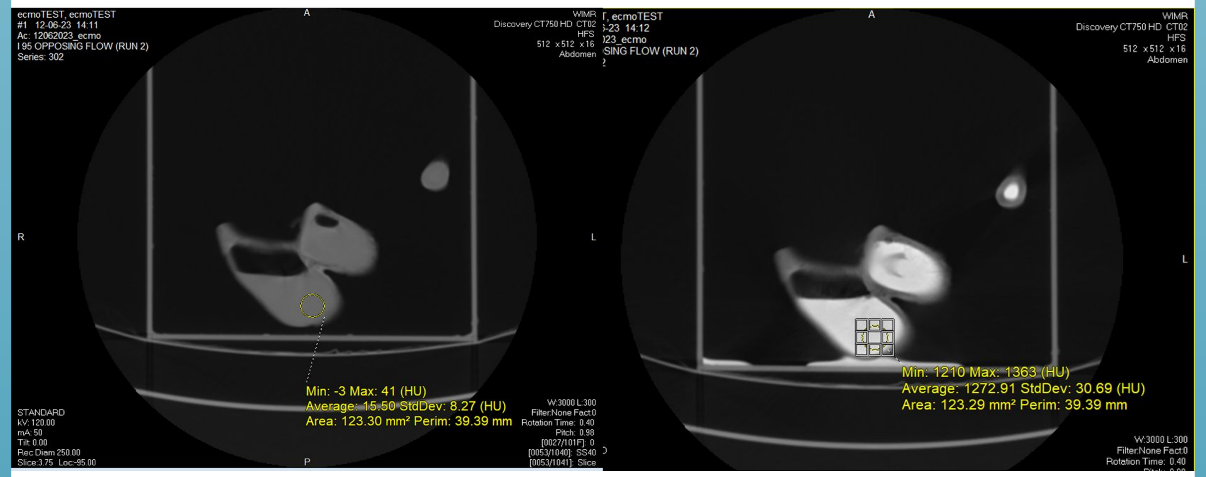

***Figure 6:** Side by side CT images of the phantom (3 L/sec) at different times during the scan. Left image is prior to addition of contrast agent, the right image after.*

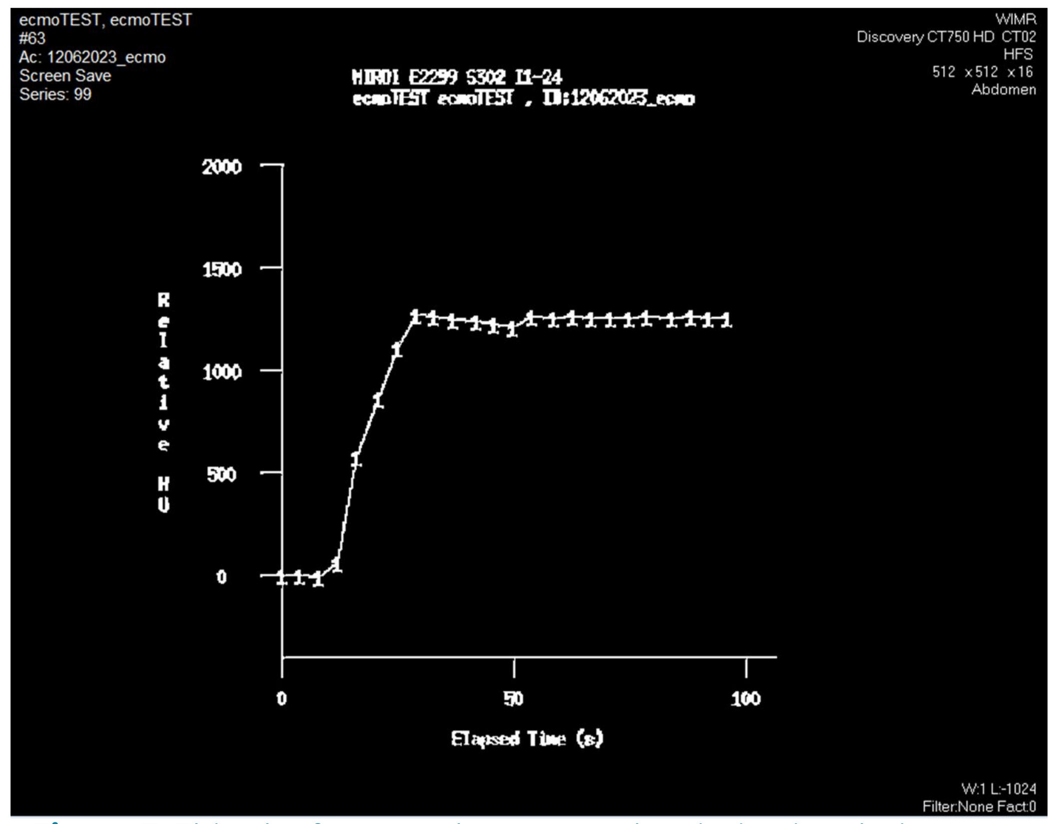


***Figure 7:** This plot features the temporal variation in relative Hounsfield Units for the region of interest in the scans in figure 6-1*

## Future Work

**Fabrication:**

- Obtain and incorporate a VA-ECMO device, or a higher power pump into the flow phantom
- Design a new pump system that could simulate partial heart function with flow against VA-ECMO circuit
- Create a more anatomically accurate fluid circuit in order to better represent the flow patterns seen in humans
- Switch to a rubber injector piece to ensure a tight seal with no leakage

**Testing:**

- Perform more trials through the CT scanner in order to obtain more accurate and normalized results
- Use a fluid in the circuit that is more similar in composition to human blood than water to better understand how the iodinated contrast is mixed and distributed in a patient

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## Conclusion

- Given the resources, budget, and time frame the product was satisfactory to the clients needs
- Future work needs to be done to improve the accuracy and precision of the device

## References


[1]"What Are Imaging Phantoms?" *NIST*, April 19, 2018. https://www.nist.gov/physics/what-are-imaging-phantoms.

[2] M. S. Choi, K. Sung, and Y. H. Cho, "Clinical Pearls of Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock," Korean Circ. J., vol. 49, no. 8, pp. 657–677, Jul. 2019, doi: 10.4070/kcj.2019.0188.

[3]Rao, Prashant, Zain Khalpey, Richard Smith, Daniel Burkhoff, and Robb D. Kociol. "Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock and Cardiac Arrest." *Circulation: Heart Failure* 11, no. 9 (September 2018): e004905. https://doi.org/10.1161/CIRCHEARTFAILURE.118.004905.

[4] "Poiseuille's Law." Accessed December 7, 2023. https://sciencedemonstrations.fas.harvard.edu/presentations/poiseuilles-law.

[5] V. Streeter, Fluid Mechanics, 3rd ed. McGraw-Hill, 1962.

[6] DenOtter, Tami D., and Johanna Schubert. "Hounsfield Unit." In *StatPearls*. Treasure Island (FL): StatPearls Publishing, 2023. http://www.ncbi.nlm.nih.gov/books/NBK547721/

[7] Rao, Prashant, Zain Khalpey, Richard Smith, Daniel Burkhoff, and Robb D. Kociol. "Venoarterial Extracorporeal Membrane Oxygenation for Cardiogenic Shock and Cardiac Arrest." *Circulation: Heart Failure* 11, no. 9 (September 2018): e004905. https://doi.org/10.1161/CIRCHEARTFAILURE.118.004905.

[8] T. P. Szczykutowicz, "CT Contrast Parameters for the Medical Physicist," Sep. 21, 2023



***Figure 8:** This image shows the phantom loading into the CT Machine*