Pulsatile Flow Loop for Characterization of Venous Valves

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Introduction to Venous Valves and Associated Illness

Venous valves are bi-leaflet one-way valves primarily found in the small veins of the lower leg. They act as check valves, preventing blood from pooling in the feet due to hydrostatic pressure from gravity. When damaged by acute injury or chronic illness, venous valves may suffer the reduction or elimination of this functionality, resulting in a condition called Chronic Venous Insufficiency (CVI). This in turn leads to painful and debilitating swelling, ulcers, and in extreme cases, amputation of the affected limb.

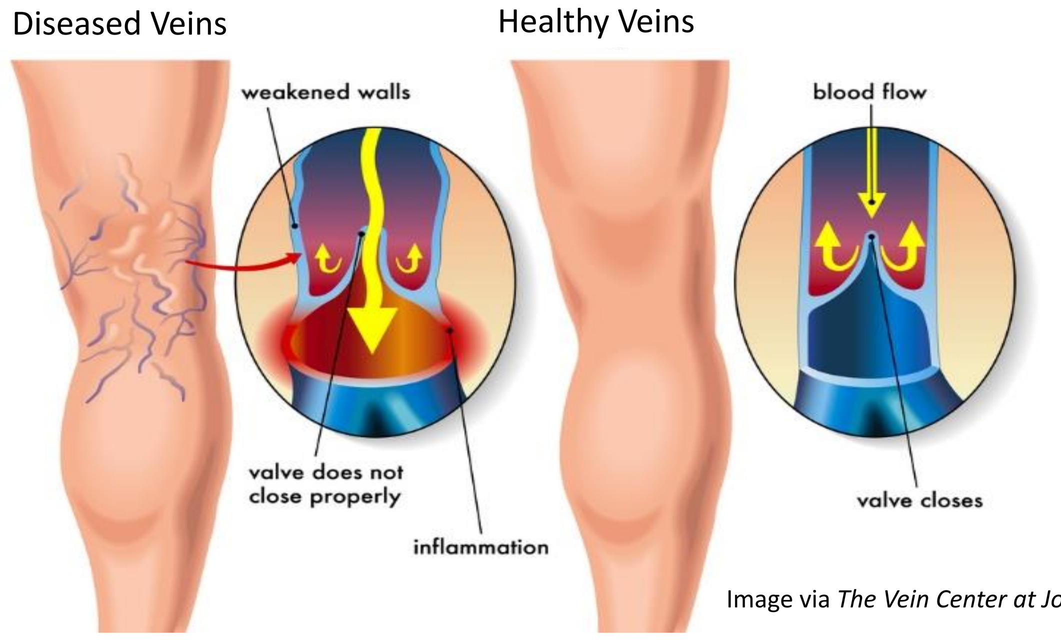
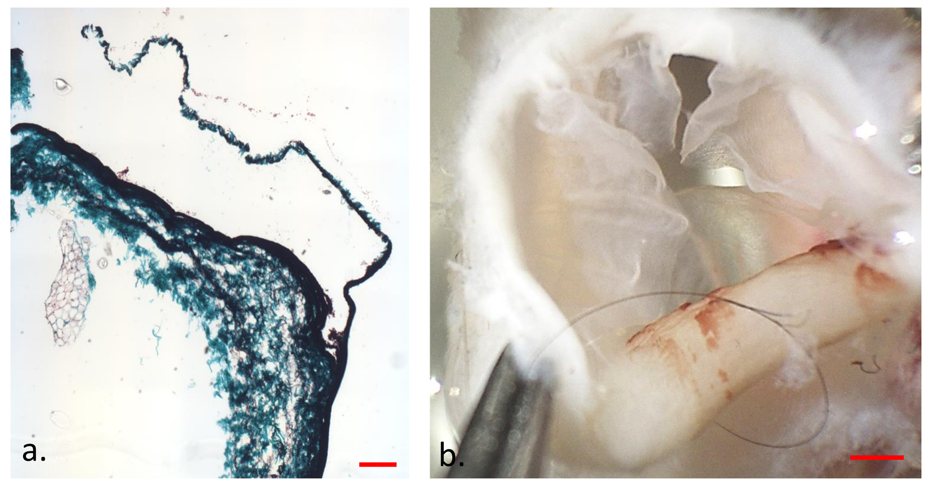


Image via *The Vein Center at Johns Creek*

Current treatment options for the disease are unsatisfactory, and mechanical and tissue-engineering approaches are being examined to address this deficiency. However, relatively little research exists on the behavior of venous valves within their unique physiological environment. As such, this project sought to create a testing system to mimic the conditions faced by these valves, in order to understand the design requirements for future prosthetic valves.



a) Histological section of vein and venous valve. The red scale bar is 400 µm in length. The leaflet has a thickness of less than 35 µm.

b) Close-up of vein interior with translucent leaflets intact. The red scale bar has a length of 3.50 mm.

Loop Design Criteria

Low Loop-Induced ΔP

- System shall exhibit low pressure drop under non-pulsatile flow through silicone tubing or native vein segment. (Pressure Tx2 – Pressure Tx1 ≈ 0 mmHg, with an allowable maximum of 10 mmHg).

Baseline Pressure

- Baseline pressure ≥ adult standing physiological pressure of 80 ± 5 mmHg. Higher is acceptable, as venous pressure is increased dramatically by standing up or performing Valsalva's maneuver.

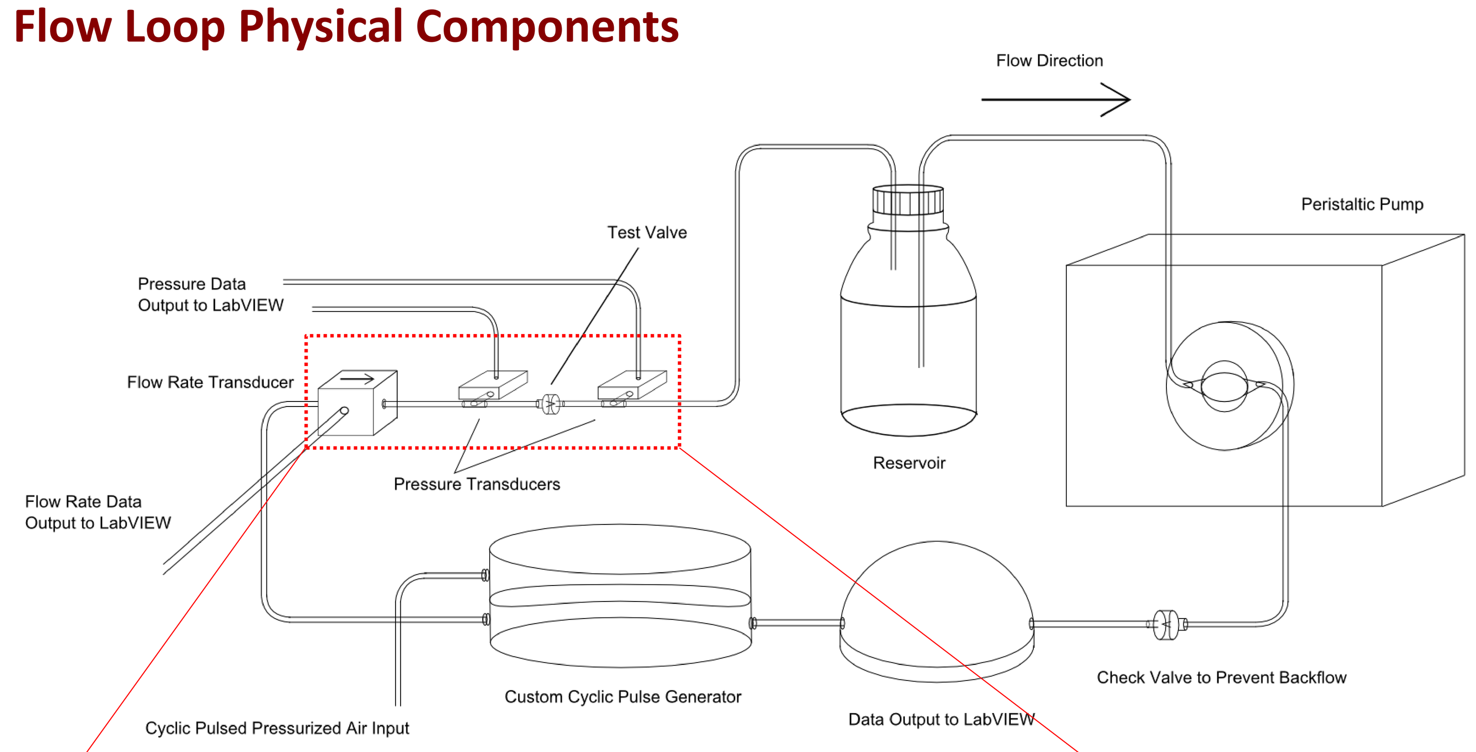
Flow Rate

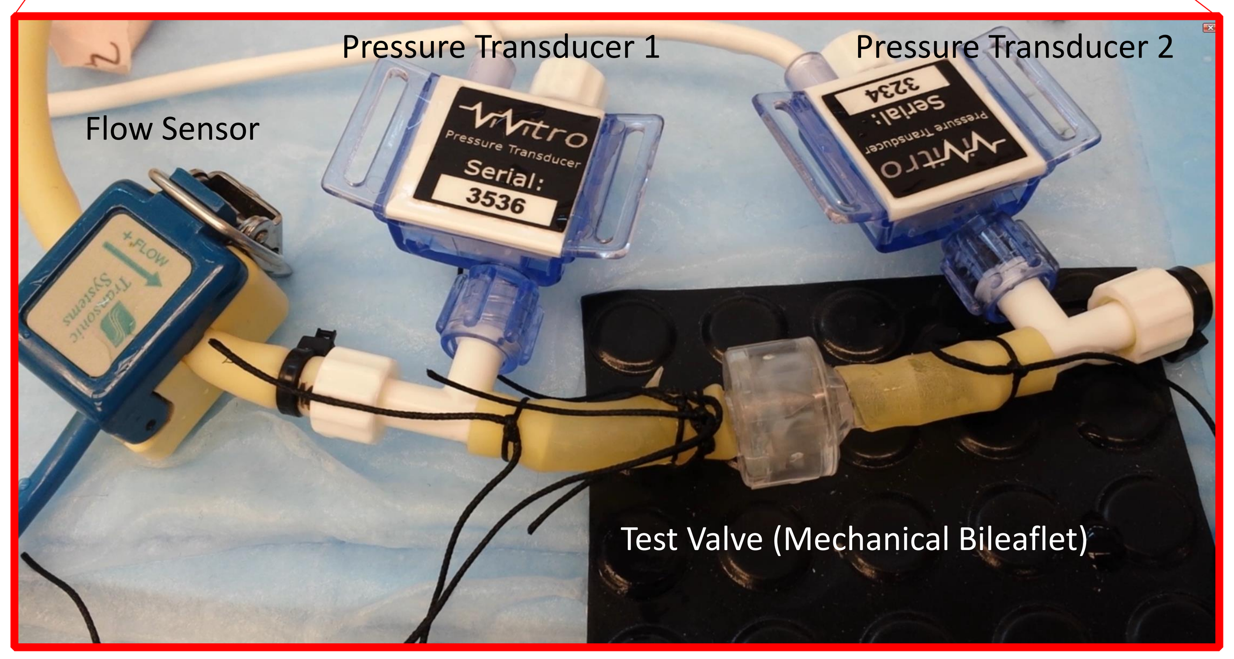
- Flow rate shall be 400 – 800 mL/min, based on physiological calf pump stroke volume and cadence. (10 – 20 mL/stroke * 40 strokes/min).

Data Acquisition and Recording

- System shall be controlled by an intuitive yet powerful LabVIEW Virtual Instrument interface.

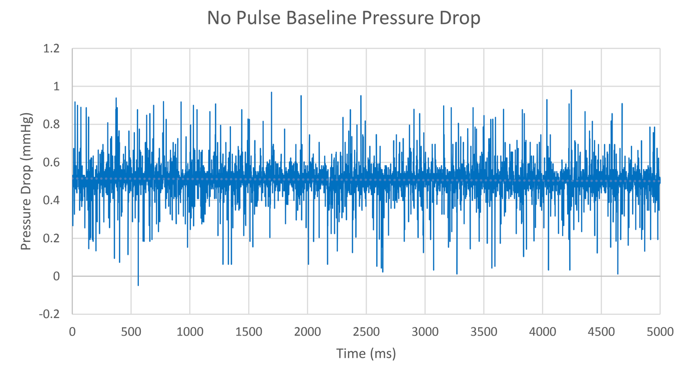
Flow Loop Physical Components



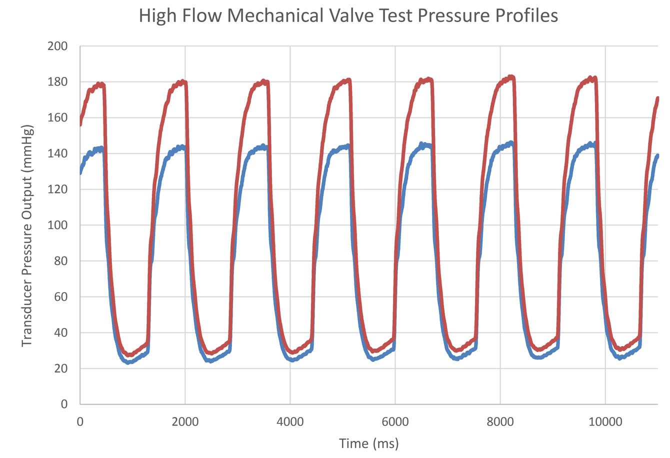


For video of the system in action, scan the QR tag to the right ►

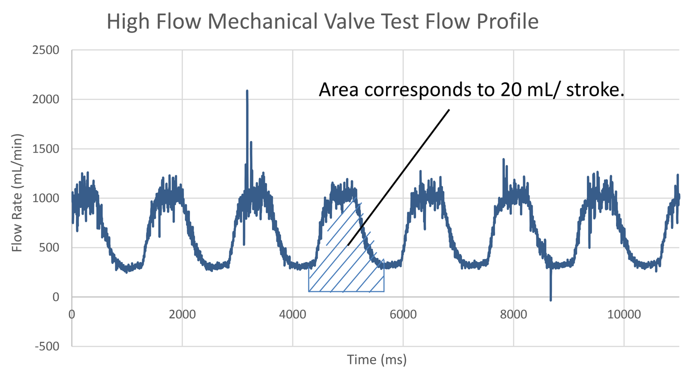
Loop Testing – Pressure and Flow Rate



This graph illustrates the fulfillment of the first design criterion. Average reported pressure drop across a silicon sleeve (~6.3 mm internal diameter, ~0.8 mm thickness) was 0.52 mmHg.



This graph demonstrates the fulfillment of the second design criterion. The red and blue curves correspond to upstream and downstream pressures, respectively, and average to 93 mmHg and 81 mmHg.



This plot demonstrates the system's ability to produce pulses at the correct flow rate and volume per stroke. Integrating the area under pulses yields a value of ~20 mL. Pulses are spaced at 40 Hz, yielding a flow rate of 13.3 mL/min.

Future Research Outline

Future work will involve the use of this test system to characterize ovine veins and venous valves. Tests will be conducted to determine minimal valve opening pressure and physiological pressure drop, among others.

Additional looped and static testing configurations may be created by adding or removing transducers, while retaining the same control software. This will allow testing for burst strength, valve reflux, and cyclic lifespan (durability), under a variety of flow conditions and pressures.

Finally, a mount will be fabricated to allow positioning of the test valve and transducers vertically, to mimic the orientation of venous valves *in vivo*.

Conclusions

- The test system created in this work meets all performance and usability criteria set out in the design requirements
- The system design and data acquisition software allows for modularity, and many testing modes will be supported for future studies
- Further optimization is needed to more accurately mimic the hydrostatic forces acting on the test valve

References

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Acknowledgements

The author wishes to acknowledge and thank the University of Minnesota's UROP grant program for funding this research.

Additional thanks are extended to Doctors Robert Tranquillo and Zeeshan Syedain for their mentorship and technical support throughout this project.