Time-Critical Hemorrhage Monitoring and Control with Novel Wearable Sensor Device

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Background

- Delayed recognition of hemorrhage is a major cause of potentially preventable death in combat and prolonged casualty care
- Hemorrhage may be detectable in arterial waveforms
- Arterial waveforms cause crossover signal in nearby veins
- We are developing a hemorrhage-detection device that uses peripheral venous pressure (PVP) with embedded machine learning and AI algorithms to identify blood loss
- We are using tissue-mimicking benchtop phantoms to test the impact of anatomic and mechanical factors on crossover signal in the vein (Figure 1)
- In combination with benchtop models, we are using porcine hemorrhage experiments to characterize the crossover signal

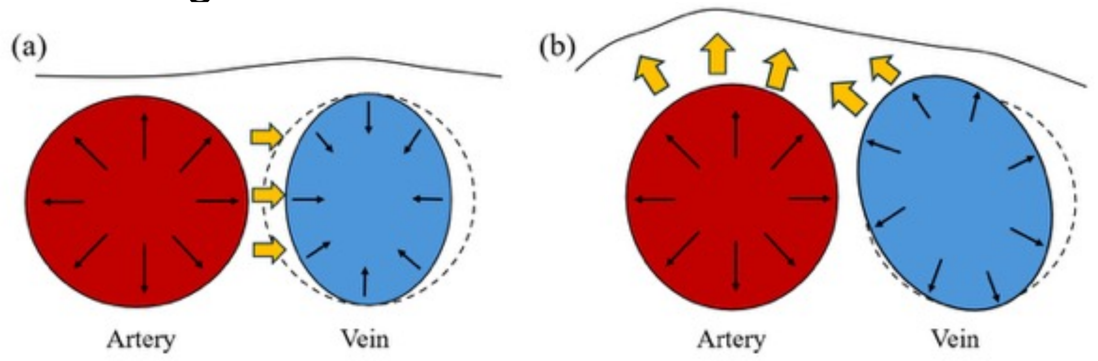

Figure 1: Example: Artery expansion can (a) compress the vein or (b) expand the vein depending on geometry

Objectives

- Develop and test physiologically relevant benchtop models for characterization of arterial pulsations
- Combine and compare device performance under benchtop model with preliminary porcine data

Methods

- Gelatin phantoms with embedded artery and vein channels developed for repeated physiologic testing.
- Arterial channel was driven with pulsatile flow at 80–120 mmHg and low/med/hi heart rate, while the venous channel was maintained @ 9-11 mmHg static pressure
- Final platform was used to test the effects of vessel size, artery-vein spacing, tissue depth, gel stiffness, simulated skin and bone, arterial pressure, and 1 mm silicone vessel walls on venous pressure crossover. Results compared with preliminary porcine data of device testing.

Benchtop Testing System

Example of human tissue mimicking flow phantom containing two straight hollow channels with the following characteristics:

- Gel 0 (E = 0.57MPa)
- Vein surface depth (blue) is 3mm
- Artery surface depth (red) is 6mm
- Center-to-center vessel distance is 17mm

Flow Loop System Setup:

- Arterial Pressure: 80-120mmHg
- Venous Pressure: 9-11mmHg
- Pulsatile flow provided by ViVitro SuperPump system
- Frequency Testing at 0.2, 0.5, and 1Hz
- Collection time was 10min

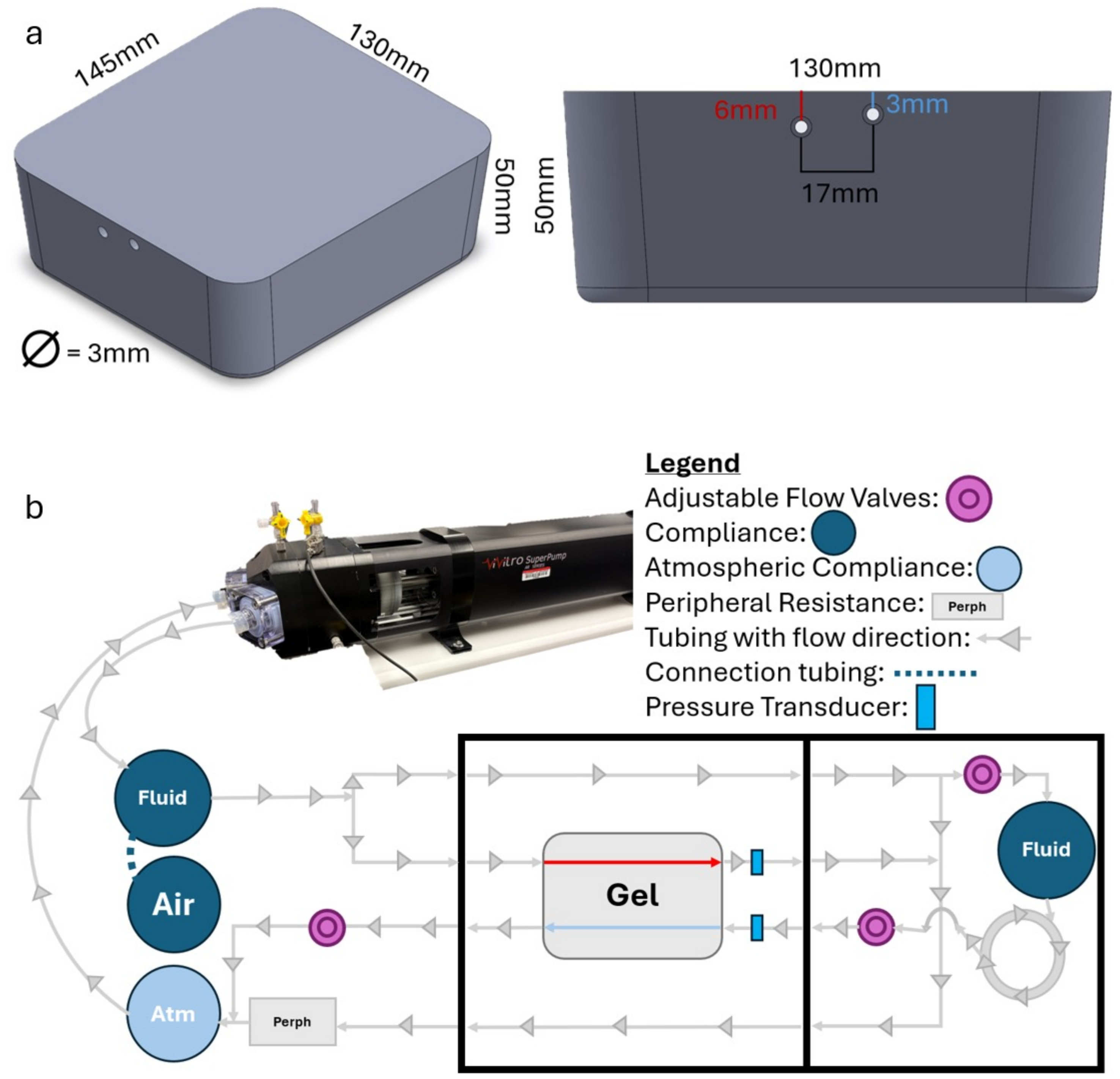

Figure 2: (a) Flow Phantom used for device testing; (b) Flow Loop System created for device testing.
Transducer (Figure 4) was introduced in the blue vein model in the system.

Crossover Signal Results

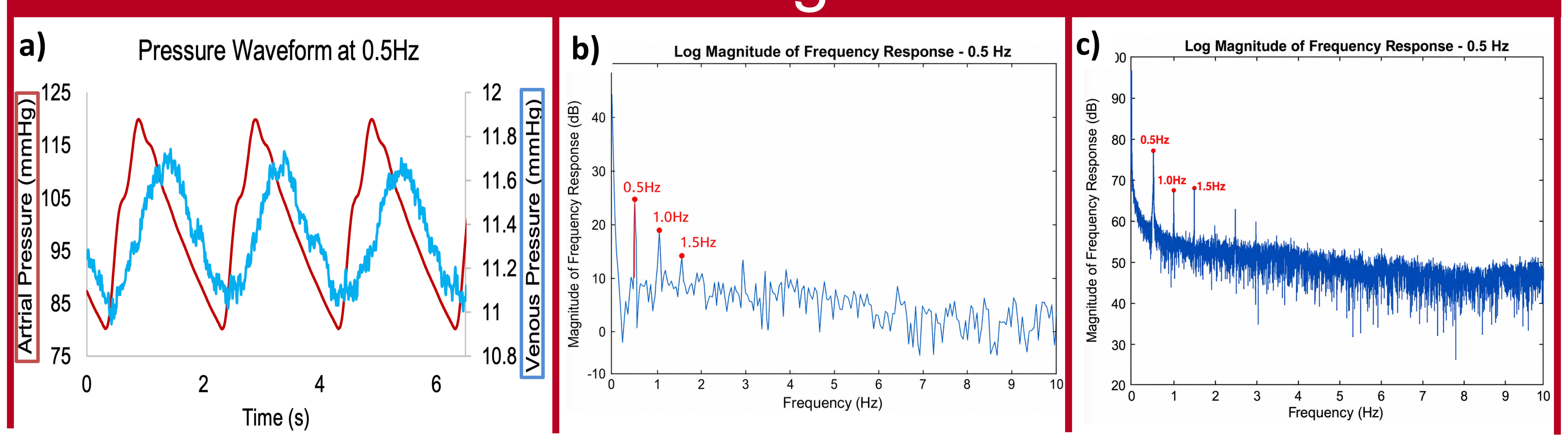

Figure 3: (a) Exemplar Pressure waveform collected from the system's fluid filled pressure transducers @ 0.5Hz; (b) Fast Fourier Transform (FFT) of the venous pressure signal from the ViVitro system's fluid filled pressure transducer for cyclic frequency of 0.5Hz; (c) FFT of cyclic frequency tested at 0.5Hz) from the device shown in Figure 4

Device Specifications

- Millar's PHB225 1F MEMs absolute pressure sensor
- Adjustable gain: 960 V/V – 15,360 V/V
- ***Device Size: 1.0" x 1.0"***
- USB-C for power supply and serial communication.
- MATLAB GUI: Waveform display, data recording, bridge balancing, gain adjustment, and offset control.

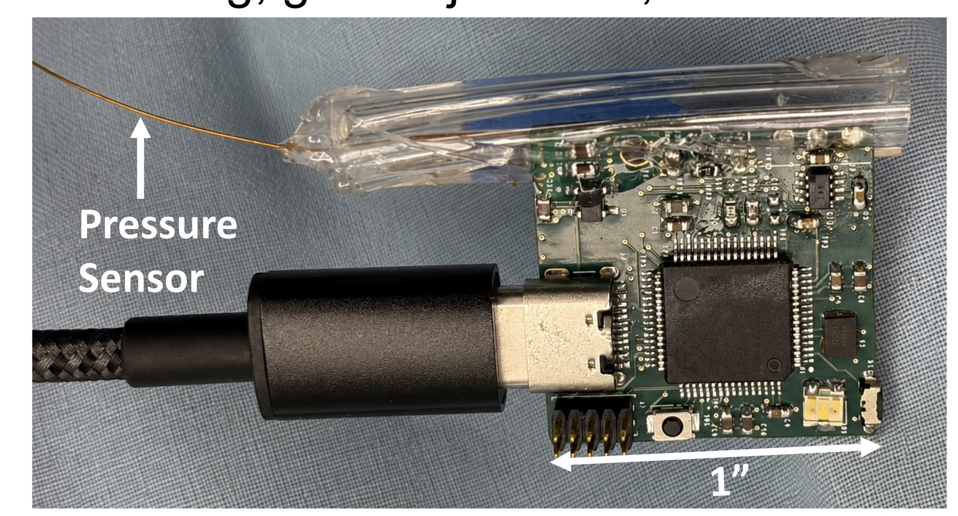

Figure 4: Assembled Prototype Device. The USB-C cable is only connected when device communicates with testing computer. LEDs on device indicate blood volume status

Conclusions

- Benchtop gel systems are useful for development and validation of hemorrhage-detection device
- Results provide a solid mechanical foundation for continuing understanding of crossover signals
- Complementary porcine hemorrhage experiments show promise for early hemorrhagic detection
- This supports eventual translation of the device for detecting blood loss during combat casualty care, evacuation, and other austere settings.

Acknowledgements

- CDMRP Award # HT9425-24-1-0189 (PR231853)
- Arkansas Research Alliance

References

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2026 Military Health System Research Symposium (MHSRS), August 2026, Kissimmee, Florida, USA