# Wearable Laser Speckle Imaging Sensor for Hemorrhage Detection

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## Abstract

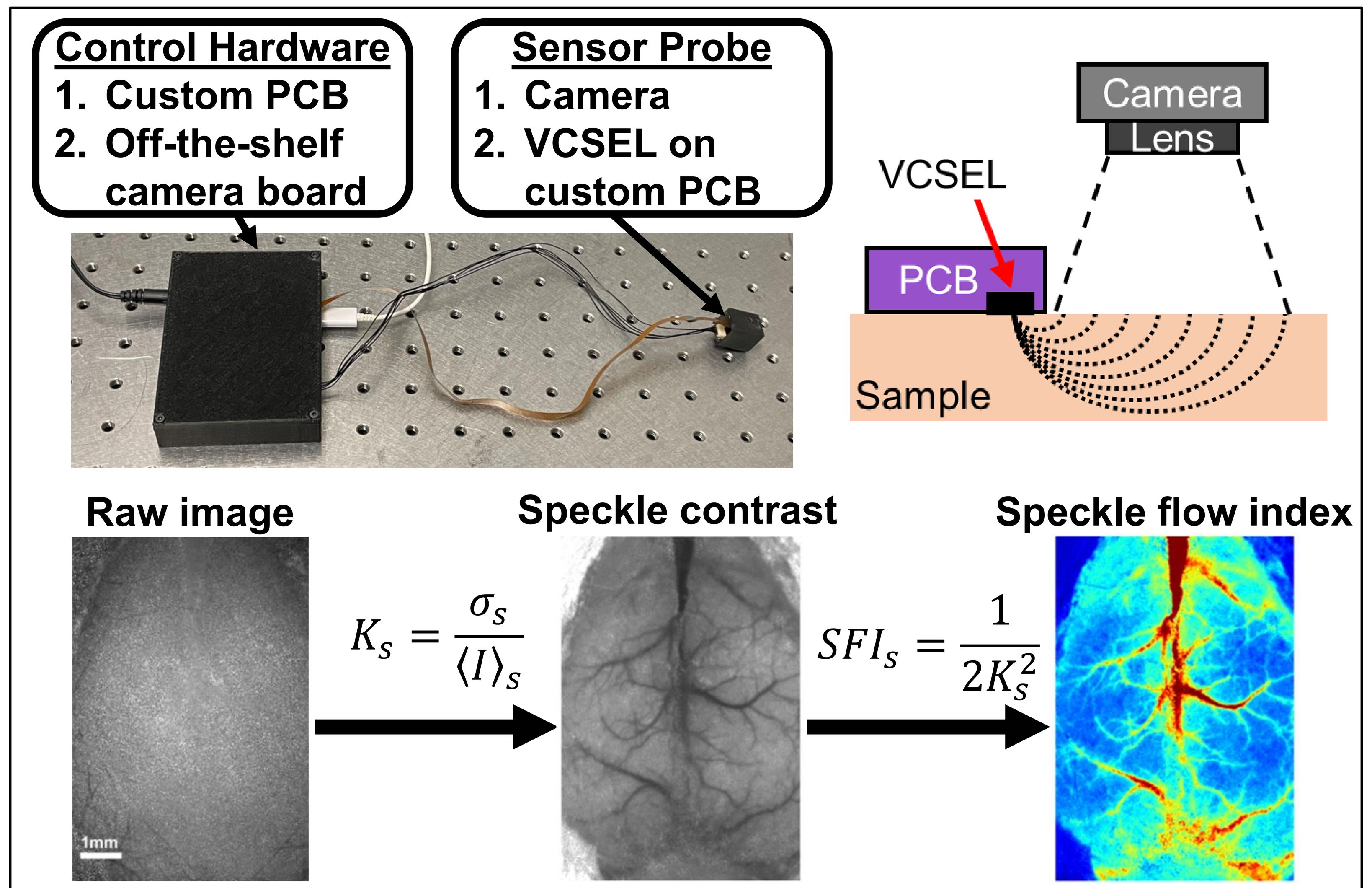
**Background:** Hemorrhage accounts for over 60,000 deaths each year in the US. Timely detection can significantly improve patient outcomes. Blood pressure (BP) is used to monitor hemorrhage, but BP measurements typically rely on intermittent arm cuffs or invasive arterial lines (A-line). **There is a need for continuous, noninvasive measurements of vital signs to inform hemorrhage detection.** Laser speckle imaging (LSI) uses a coherent light source to generate speckle patterns. The speckle patterns can be used to calculate speckle flow index (SFI), a semi-quantitative measure of blood flow. Wearable LSI sensors enable continuous, noninvasive measurement of blood flow.

**Methods:** We tested the utility of our LSI sensor for hemorrhage detection in rabbits (n=20). We compared our sensor with A-line blood pressure.

**Results:** SFI decreased during hemorrhage and increased during blood resuscitation. This trends similarly to A-line BP.

**Conclusion:** Our data suggests LSI may help improve hemorrhage detection.

## LSI hardware and data processing workflow



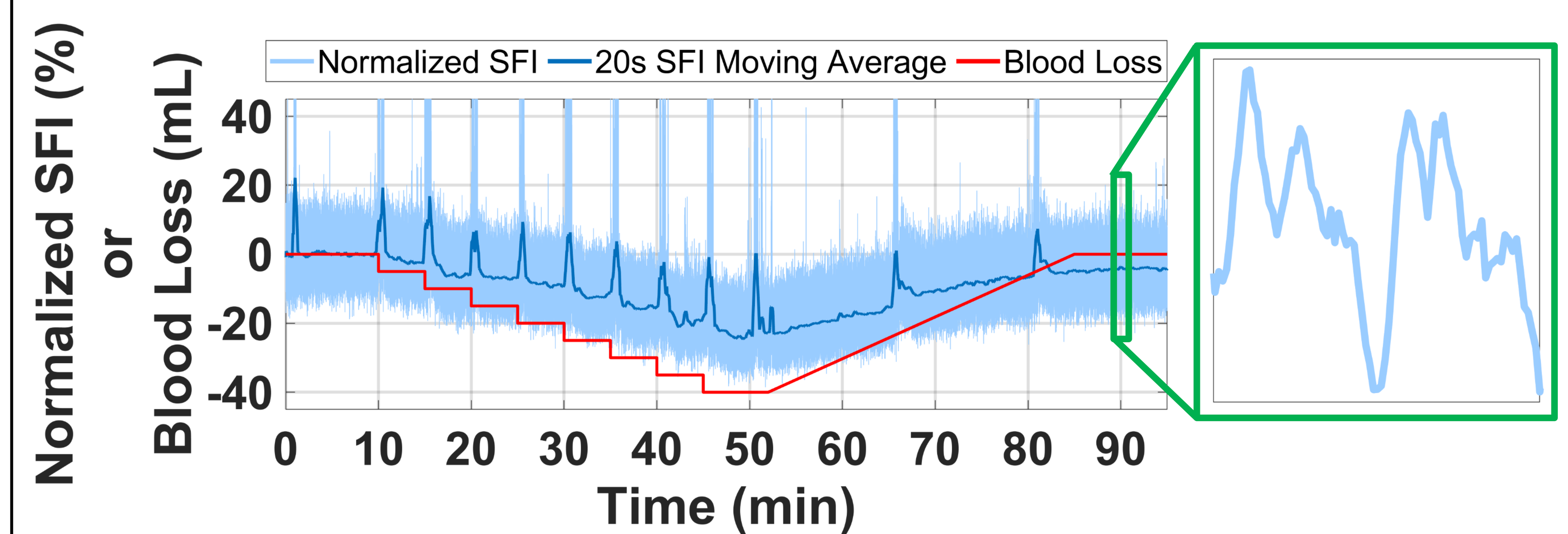

Crouzet et al. Neurophotonics (2023), Crouzet et al. J Biomed Opt (2023)

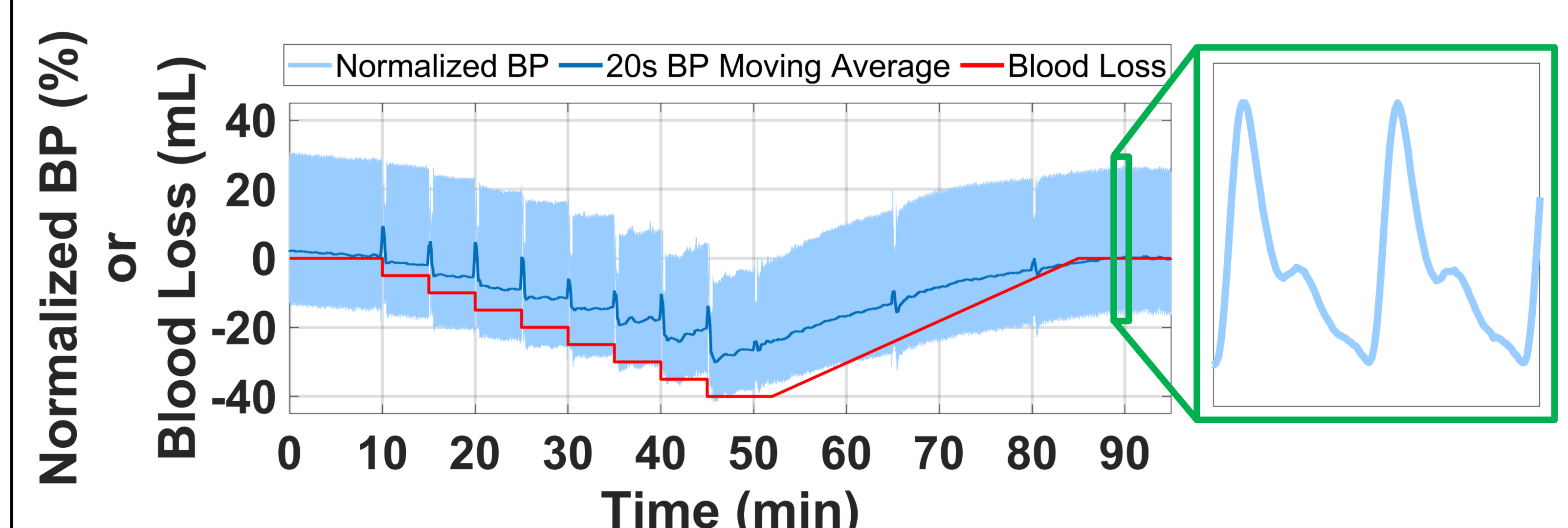
## Experimental protocol

1. **Initial baseline period:** 10-minute acquisition
2. **Hemorrhage period:** Withdraw 5 mL of blood every 5 minutes
3. If systolic blood pressure <55 mmHg, begin resuscitation period
4. **Resuscitation period:** Reinfuse blood at 1 mL/min
5. **Final baseline period:** 10-minute acquisition

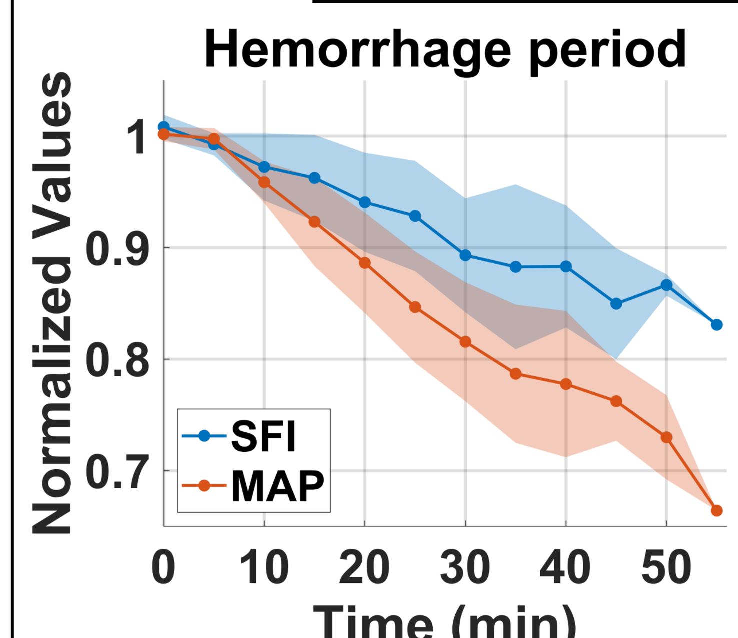
## SFI and BP during hemorrhage

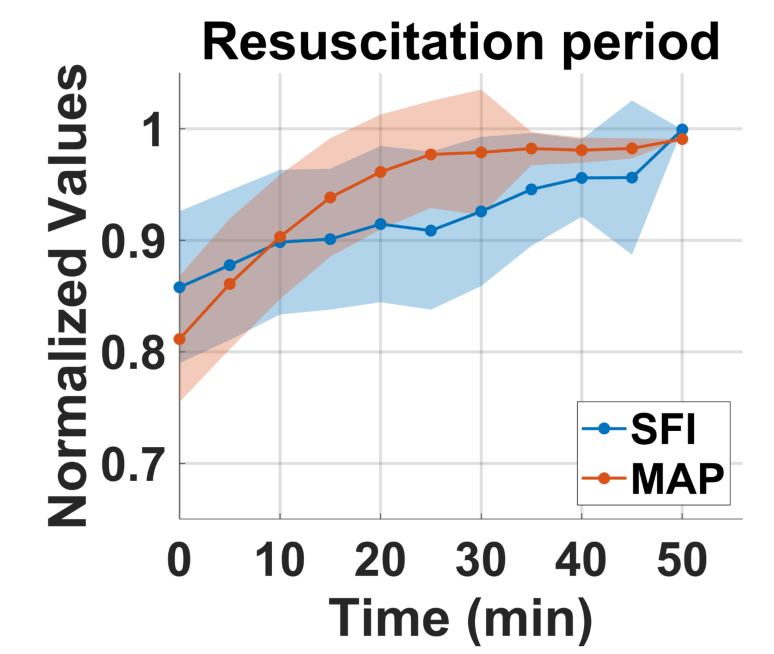
### Time course of SFI and BP during hemorrhage experiment

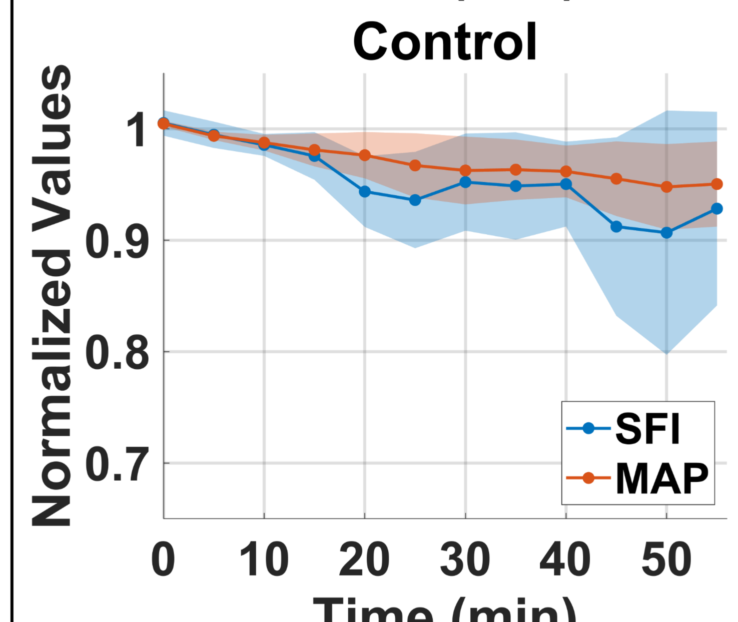



### SFI and MAP decrease with blood loss and increase with blood reinfused




**Correlation coefficients (r)**

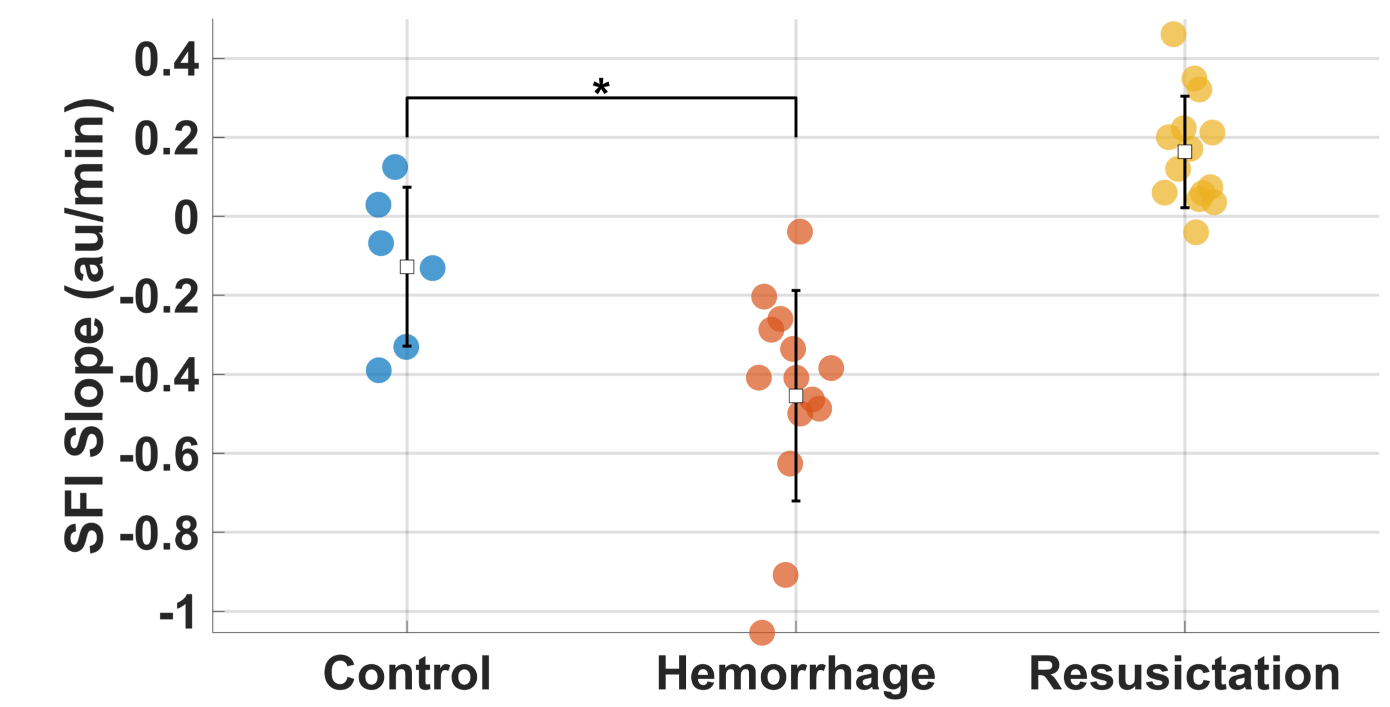
| | Hemorrhage period | Resuscitation period |
|---|---|---|
| SFI | -0.84 ± 0.23 | 0.63 ± 0.33 |
| MAP | -0.99 ± 0.01 | 0.93 ± 0.07 |

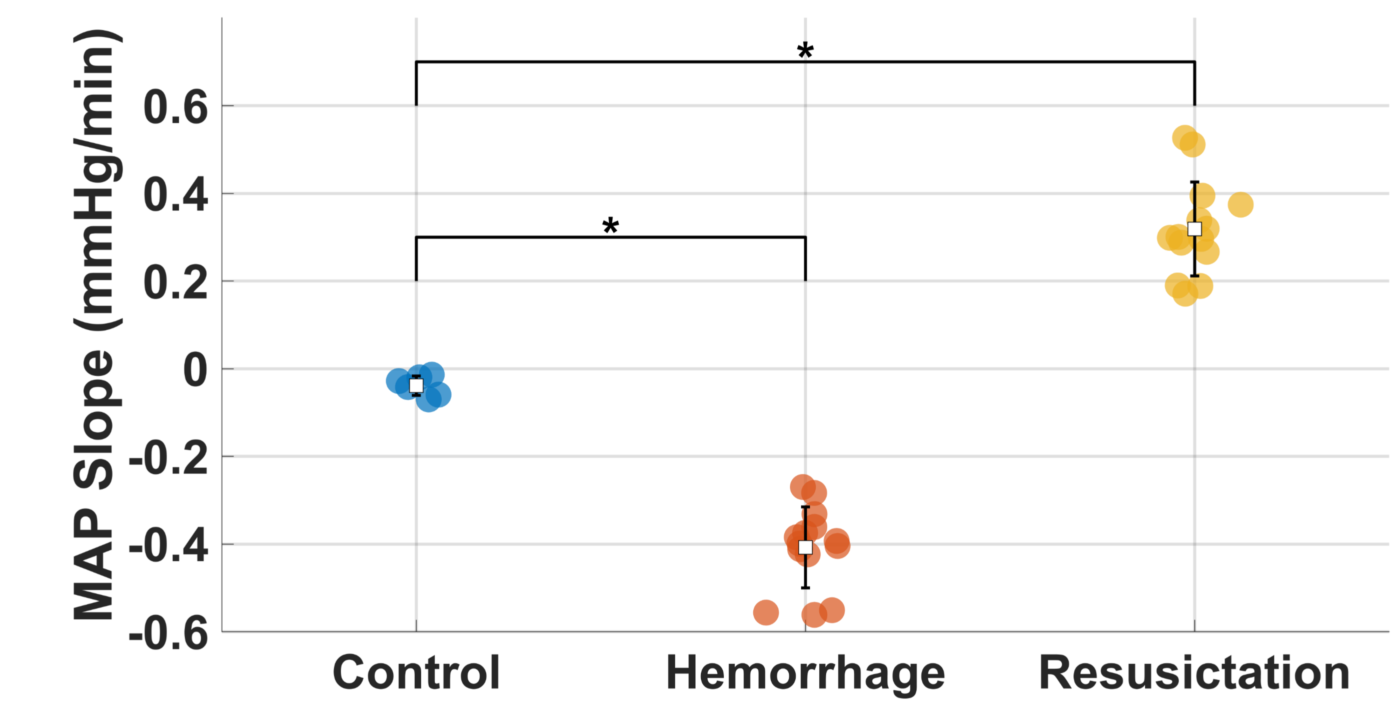
Graphs show the average value at each time point with the shaded regions showing standard deviation (n=14 for hemorrhage and resuscitation, n=6 for control). Table shows average correlation coefficients with standard deviation.

**Takeaway:** SFI and MAP correlate with blood loss during the hemorrhage phase. SFI and MAP correlate with blood reinfused during the resuscitation phase.

## Slope of SFI and BP during hemorrhage

### Slope of SFI and BP are significantly different during hemorrhage when compared to control




Graphs show the slope of SFI or MAP during each experimental condition (n=14 for hemorrhage and resuscitation, n=6 for control). Error bars are standard deviation.
* indicates p<0.05 using Wilcoxon rank sum test.

**Takeaway:** The change in SFI and MAP over time during blood withdrawal can be used to detect hemorrhage.

## Conclusions

- SFI follows a similar trend to MAP in response to hemorrhage and resuscitation.
- Changes in SFI and MAP correlate with the amount of blood loss and the amount of blood reinfused.
- The slope of SFI over time during blood withdrawal can be used to detect hemorrhage. Future work will investigate the lower limit of detection for hemorrhage using SFI.
- Our data suggests LSI can be used as a continuous, noninvasive tool for monitoring vital signs that can inform hemorrhage detection.

## Acknowledgements

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