In Vivo Infrared Sensing for Enhanced Treatment of Traumatic Injury

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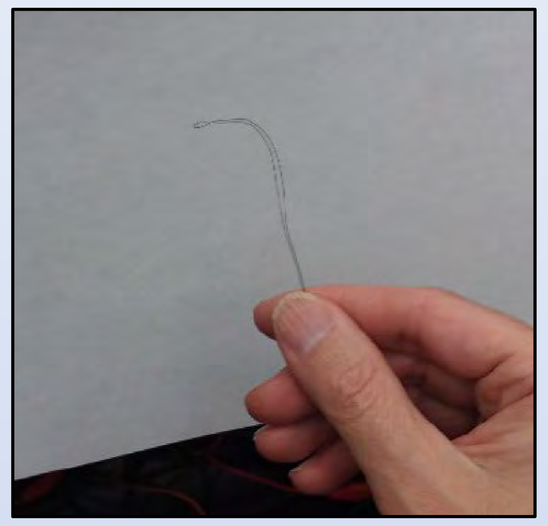
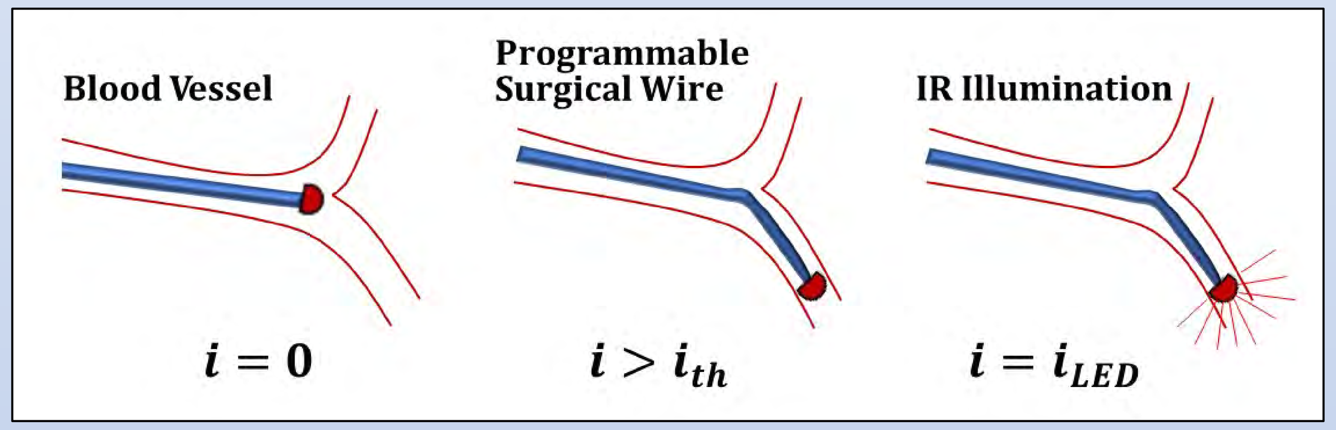
Approach

Attachment of infrared (IR) sensors to the tips of current-activated shape-memory alloy wires for endovascular insertion into the brain or other injured regions to monitor oxygenation levels real time for patient stabilization and treatment





Background

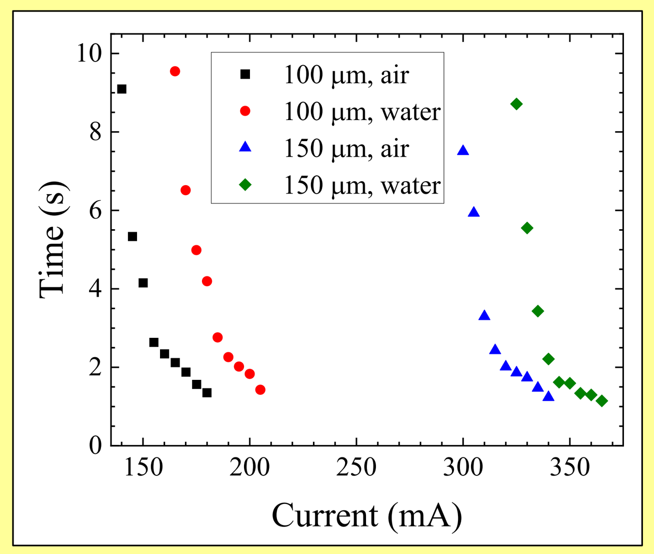
Timing is crucial for stabilizing a brain injury or embolizing splenic or hepatic arteries in injured soldiers. A smooth and efficient endovascular navigation system would **reduce trauma** induced by incisions or needling into the skull. Surgeons and field medics would benefit from **rapid, efficient wire insertion** and devices at the leading tip that would enable them to **navigate arterial blockages** or **identify injured tissue** or stagnant blood through measurement of biomarkers to determine oxygenation of the local fluid or tissue. Such a system offers great potential for **long-term treatment of recovering soldiers and veterans** in definitive care facilities, as well as the potential for **compact, robust, easier-to-use systems for patient stabilization** and **improved monitoring** of key biomarkers at combat support hospitals.

Impact

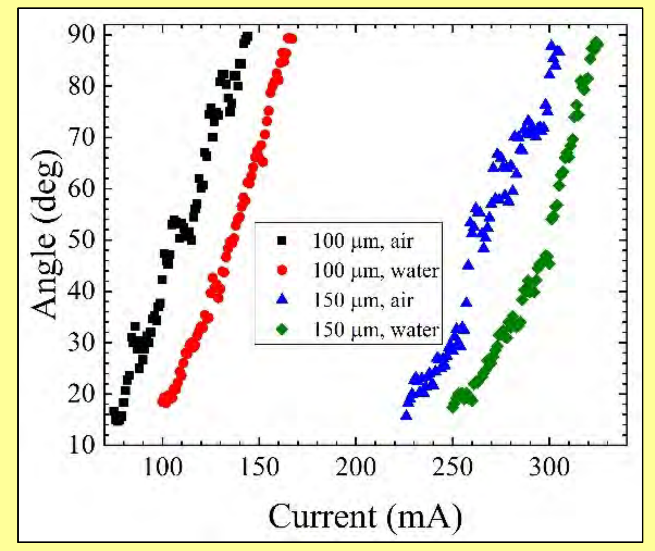
- Improved navigation to and monitoring of biomarkers (e.g., oxygen) at treatment site
- Reduced time to reach treatment site, increasing successful treatment and survival rates in patients
- Better prolonged field care before soldiers can be evacuated to a more comprehensive hospital.
- Capability to transition the technology from definitive, longer-term comprehensive care facilities to automate/remotely control arterial navigation and *in vivo* sensing for treatment in remote locations, including combat support hospitals to stabilize and monitor patients.
- Greater sensitivity to deep cavity bleeding.
- Enhanced treatment of aneurysms and monitoring of tumor growth, benefitting long-term care of veterans following their service.

Endovascular Navigation

Malleable wires that can readily conform to the arteries through which they are being guided pose minimal danger of piercing the blood vessel through which the medical personnel is navigating. The device will be tapered to facilitate navigation as arteries continue to narrow up in the brain. The shape memory alloy Nitinol is programmed to bend at the tip in order to navigate branches in arteries. The tip is resistively heated by applying current, and we have demonstrated this bending in air (photograph, left) as well as water, as the ultimate goal is to navigate in blood-filled arteries.



The time taken for Nitinol wire to achieve the programmed bend angle as a function of current input in air and water. Each data point represents the average of ten trials.

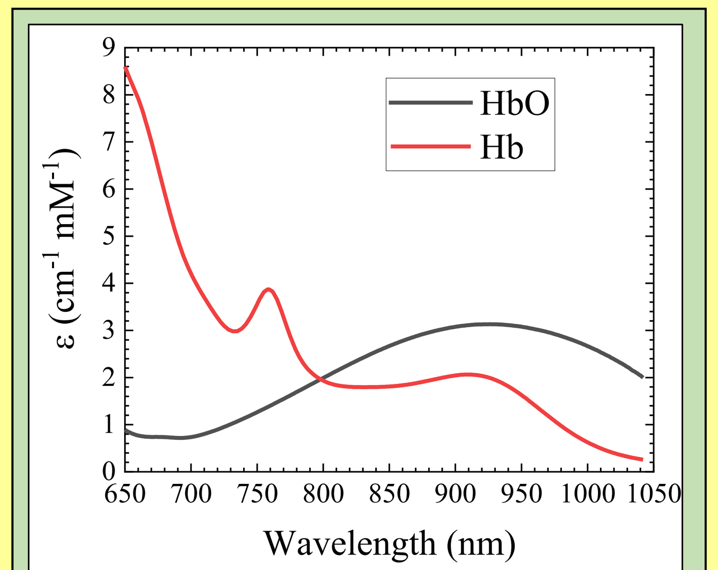


The bend angle of Nitinol wire for varying injected current levels in air and water. Each data point represents the average of three trials.

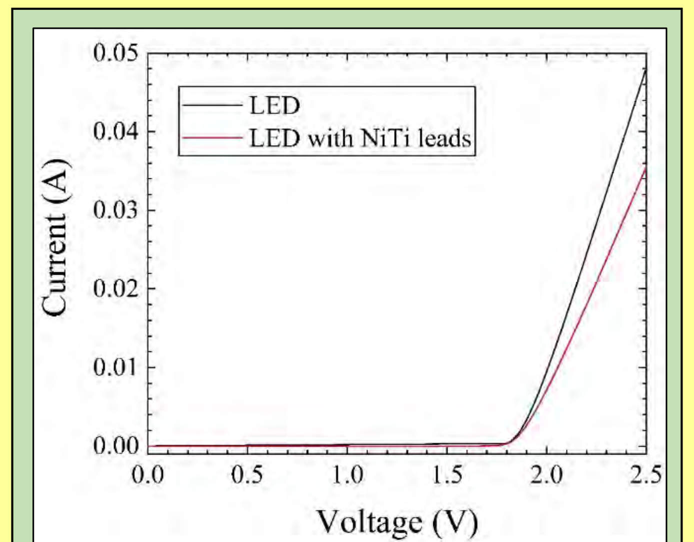
This programmable surgical wire device will enable greater measurement sensitivity by at least doubling the penetration depth at which monitoring of oxygenation levels and other biomarkers can occur, as well as enhanced capability to treat aneurysms through angulation or navigate arterial blockages.

Infrared Sensing

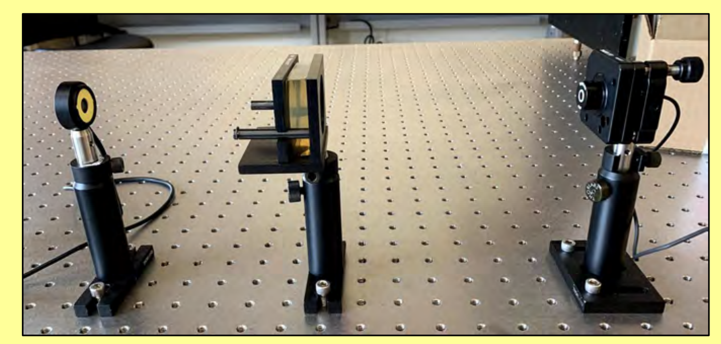
Employing IR LEDs with wavelengths on either side of the absorption crossover will enable sensitive differential measurement of oxygenation levels to distinguish pooled blood from flowing blood, as well as to differentiate oxygenated vs. necrotic tissue. IR sensors attached to the tip of the surgical wire may be used to identify blockages or injured tissue.

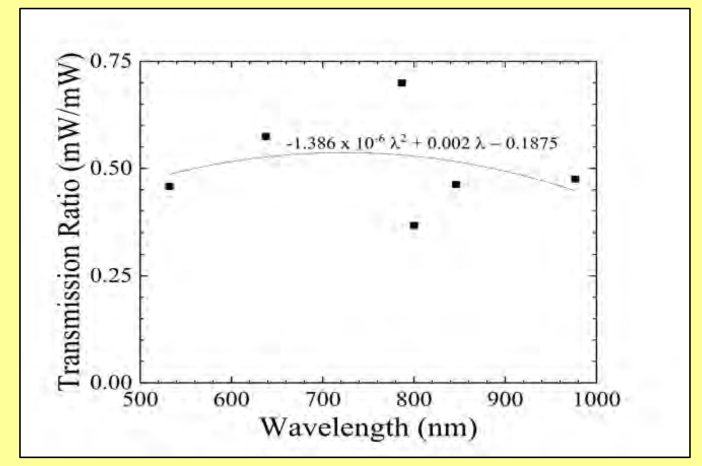


Extinction coefficient vs. wavelength for oxyhemoglobin (HbO) and deoxyhemoglobin (HB), for nominal tissue concentration of 50 μM. [Bigio & Fantini]



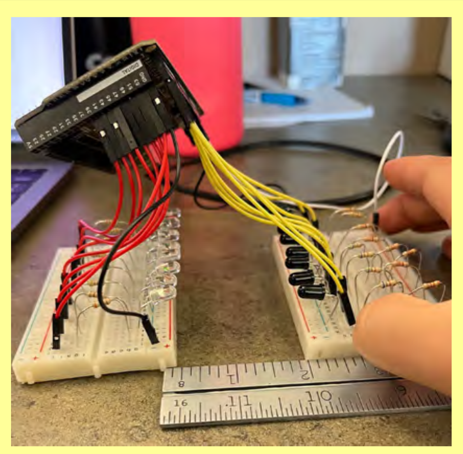
Current (A) vs. voltage (V) for a light emitting diode without (black) and with (red) 10-cm-long Nitinol leads.



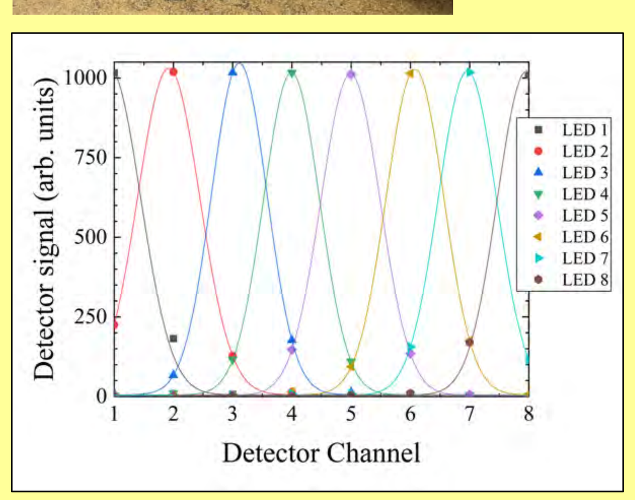


A gelatin phantom with channels for fluid flow provides a safe medium for testing. Preliminary measurements of IR transmission through a slab of gelatin have been performed using near-IR diode lasers (setup left, results right).

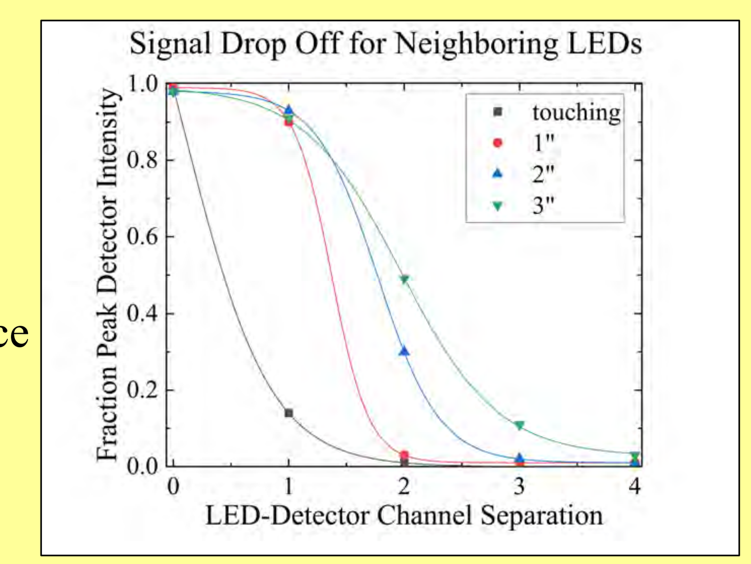
LED Testing

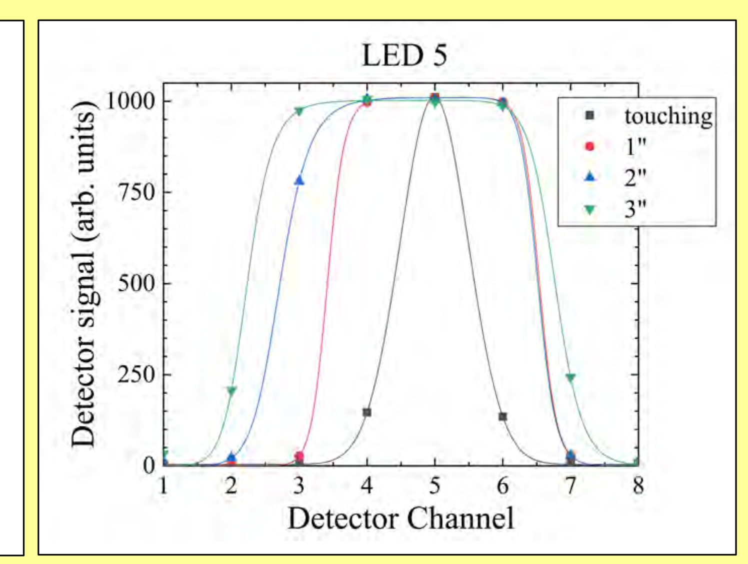


Testing with visible LEDs for proof-of-concept and protocol development will be followed by a transition to near-IR emitters and detectors. This approach allows for the use of currently available micro-LEDs in the visible range. For the data shown here, a set of infrared LEDs were set up across a row of detectors. Each LED was turned on and off one at a time and measured by each detector. Measurements were taken for distances ranging up to 7.5 cm (3").



- Detector signal corresponding to when each LED is turned on (left, bottom)
- As the distance increases, the peak measurement becomes less sharp (far right)
- Increase in distance increases divergence to neighboring detectors as expected, resulting in larger signal at distant detectors (right)





Shape Memory Alloy Challenges

- Employ a shape memory alloy with a switching temperature around 45°C, higher than body temperature but not so high as to heat surrounding blood or tissue
- Apply a biocompatible coating that is sufficiently flexible to navigate the wire

IR Challenges

- Balance size of the IR emitters and detectors with required current levels to power the sensors while minimizing the heat
- Develop solder/appropriate electrical connections that allow for good electrical conduction without altering the materials properties of the wire by applying too much heat

Future Work

- Development of a two-wire prototype
- Navigation through a tube, then a blood vessel, and then a live specimen (e.g., rat)
- Voice-activated navigation and control system
- Employing higher activation temperature wire to cauterize or embolize wounds for patient/soldier stabilization

References

[1] L. J. Olafsen, B. Jones, L. Sparks, H. H. Nguyen, A. Tanner, K. E. Schubert, J. S. Olafsen, S. Dayawansa, E. Fonkem, and J. H. Huang, "Current-controlled Nitinol wire for improved arterial navigation," *Proceedings of the SPIE* **10868**, 108681E (2019).

[2] L. J. Olafsen, J. S. Olafsen, and I. K. Eaves, "Time-dependent spatial intensity profiles of near-infrared idler pulses from nanosecond optical parametric oscillators," *Applied Physics B* **124**, 110 (2018).

[3] I. J. Bigio and S. Fantini, Quantitative Biomedical Optics: Theory, Methods, and Applications (Cambridge Texts in Biomedical Engineering). Cambridge: Cambridge University Press.

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