# Developing a Real-Time, Axially Resolving Optical Monitor of Spinal Cord Blood Flow

UTSouthwestern Medical Center

Feng Gao[1], David R. Busch[1], Chia Chieh Goh[2], Wei Lin[2], Arjun G. Yodh[3], Thomas F. Floyd[1]

1. Anesthesiology and Pain Management, Neurology and Neurotherapeutics, University of Texas Southwestern, Dallas TX

2. Biomedical Engineering, Stony Brook University, Stony Brook, NY 3. Physics and Astronomy, University of Pennsylvania, Philadelphia, PA

## Abstract

Spinal cord ischemia is a devastating surgical complication. We developed an optical probe that continuously monitors spinal cord hemodynamics along multiple locations in porcine model.

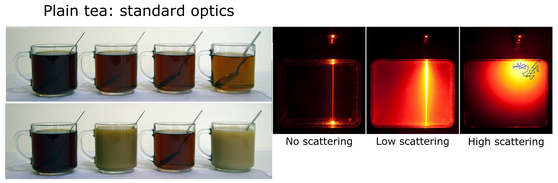
## The Problem

Only 55% of patients with spinal cord ischemia (SCI) survive past 5 years. Currently, the only intra-op spinal cord monitoring available are somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP). These techniques do not detect immediate ischemia, rather reflect delayed cellular injury.

## Our Solution

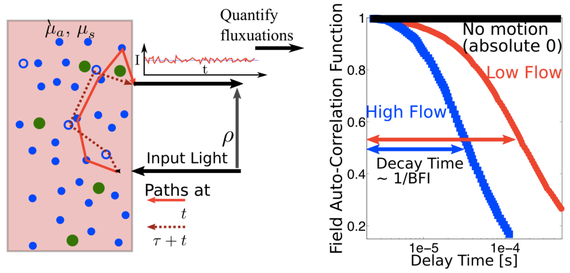
Develop a device that continuously monitors spinal cord blood flow in real-time and localizes focal ischemia.

## Diffuse Optics




(Left) Light transmits through low-scattering media (tea) easily, but not through high scattering media (milk). (Right) Demonstration of light path in high scattering media (milk).

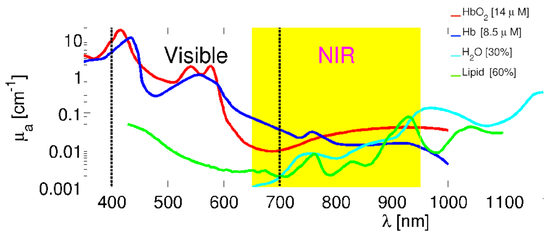
## Measuring Blood Flow: Diffuse Correlation Spectroscopy




(Left) Coherent light enters tissue and bounces off scatterers (e.g. RBCs) before reaching detector. The difference in distance travelled by photons produces phase interference. Slight shifts in optical path caused by motion of scatterers (e.g. blood flow) produce fluctuations in detected intensity. (Right) Auto-correlation function, which quantifies these fluctuations, decays more rapidly with high blood flow, providing a higher blood flow index (BFI).

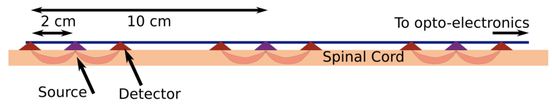
Summary of diffuse correlation spectroscopy validation papers: www.physics.upenn.edu/yodhlab/dcs/

## Measuring Oxygenation: Diffuse Optical Spectroscopy

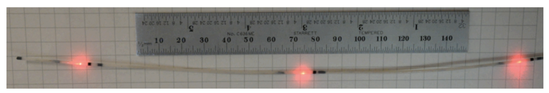



Absorption spectra of oxyhemoglobin (red), deoxyhemoglobin (blue), water (cyan), and lipid (green) in human tissue.

## Probe




Probe Schematic. Total of 3 light sources, each with a pair of detectors. The proximal probe connects to single photon counting detectors and multi-wavelength lasers.

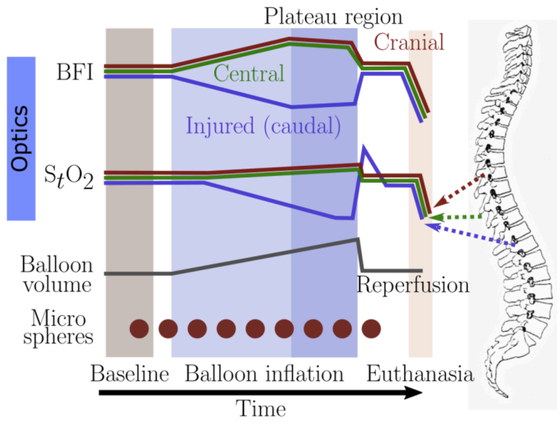


Probe Photo. Light sources illuminated. Radio-opaque markers in black.

## Experimental Methods

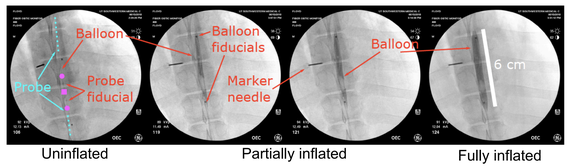
1. Diffuse optical and correlation spectroscopies were utilized to probe spinal cord hemodynamics in a porcine model under an IACUC approved protocol.
2. Fiber-optic probe was inserted into the epidural space through L3/4 laminotomy and advanced to injury zone under fluoroscopic guidance.
3. Baseline blood flow and oxygenation data were obtained.
4. Hypercarbia and hypoxia were induced through hypoventilation; serial blood gas measurements tracked arterial and mixed venous CO2, O2, and hemoglobin saturation.
5. Focal spinal cord ischemia was induced through stepwise inflation of a balloon catheter in the epidural space; blood flow was independently measured via microsphere injection at each inflation level
6. Spinal cord was harvested following euthanasia for microsphere counting

## Balloon Inflation Time Course



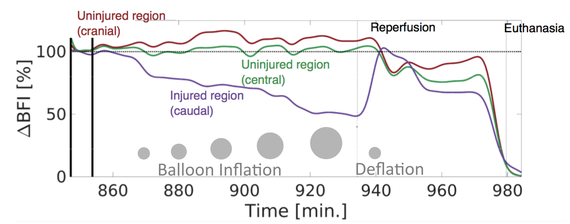

(Top) Expected experimental time course during balloon inflation with change in blood flow (BFI), tissue oxygen saturation (StO2), balloon volume, and microsphere injections. Data was collected at three levels along the spine. In this example, the balloon was inflated at the caudal (lowest) region.

## Intra-op Balloon Inflation



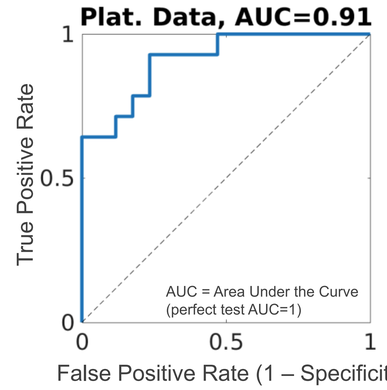

Inflation of epidural balloon under fluoroscopy.

## In Vivo Blood Flow Monitoring



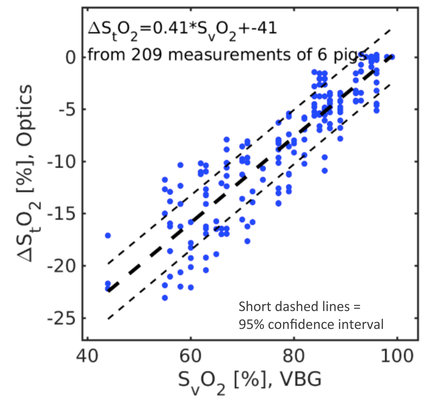

In vivo time course of blood flow at 3 spinal levels, with schematic of balloon inflation. In this example, the epidural balloon was inflated in the caudal region, which demonstrated a significant (50%) drop in blood flow. Blood flow recovered upon balloon deflation.

## Blood Flow Confirmation With Microspheres




Receiver operating characteristic curve demonstrating the diagnostic ability of probe in detecting > 50% decrement in flow by microspheres.

## Spinal Cord Oxygenation




During hypercarbia/hypoxia, tissue oxygen saturation measured in spinal cord tightly correlated with mixed venous oxygenation. (It is impractical to measure jugular oxygenation in pigs due to different cerebral venous anatomy).

## Conclusion & Future

We developed a fiber optic probe that can continuously monitor spinal cord blood flow and oxygenation at multiple levels. This technology holds potential in alerting clinicians of early spinal cord ischemia to prevent injury. In the future, we plan to conduct survival surgeries and incorporate aortic stent injury models.

## Funding

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