WE ARE ON

OSA Therapeutic Laser Applications Technical Group

Measuring Intracranial Pressure Using Diffuse Correlation Spectroscopy

Jana Kainerstorfer, Carnegie Mellon University

Executive Committee




Chair: Elina A. Vitol

Advisor: David R. Busch, UT Southwestern Medical Center at Dallas

Committee Member: Felix Fanjul-Velez, Associate Professor, University of Cantabria

Committee Member: Yannis M. Paulus, Assistant Professor, University of Michigan

Where to find information about the group

Therapeutic Laser Applications Technical Group

https://www.osa.org/en-us/get_involved/technical_groups/bmo/therapeutic_laser_applicat

Journals & Proceedings | Meetings & Exhibits | Explore Membership | Industry Programs | Get Involved | Foundation & Giving | Living History

Home / Get Involved / Technical Groups / Bio-Medical Optics

Therapeutic Laser Applications (BA)

Get Involved

- Virtual Engagement
- Diversity, Equity & Inclusion
- Public Policy
- Chapters and Sections Map
- Technical Groups
  - Bio-Medical Optics
    - Microscopy and Optical Coherence Tomography (BM)
    - Molecular Probes and Nanobio-Optics (BP)
    - Optical Biosensors (BB)
    - Optical Trapping and Manipulation in Molecular and Cellular Biology (BT)
    - Therapeutic Laser Applications (BA)
    - Tissue Imaging and Spectroscopy (BS)
    - Photobiomodulation (BL)

Therapeutic Laser Applications

This group focuses on the use of lasers in surgery or in other treatments of disease. This includes the use of lasers as surgical tools for tissue cutting, welding, and coagulation, as well as the use of optics to initiate cell-damaging photochemical reactions for the treatment of diseases such as cancer. In addition, optics, spectroscopy, and imaging provide unique tools that may allow real-time diagnostics of the efficacy of clinical procedures. For many of these applications, the development of optical tools for appropriate light delivery, especially for fiber-based or endoscopic delivery to tissues that are not directly accessible, is critical. In addition, this group emphasizes basic science studies of the mechanisms by which light can affect tissue in adverse or therapeutic ways.

Upcoming Webinar

Measuring Intracranial Pressure Using Diffuse Correlation Spectroscopy

2 December 2020, 12:00 - 13:00 Eastern Time

Register Now

Announcements

If you are a member of the Therapeutic Laser Applications Technical Group and have ideas for activities and initiatives to help engage this community, please share them with the chair, Elina Vitol.

View OSA Technical Group webinars on-demand at any time or register for any of our upcoming webinars online. Each webinar is an hour long and features a technical presentation on a topic selected by your OSA Technical Groups.

Join our Online Community

Find us on Facebook

Work in Optics

We want you to join us!

Therapeutic Laser Applications Technical Group

- Select **Therapeutic Laser Applications** as one of 5 technical groups of interest at your OSA membership account page
- Attend our networking events, webinars, poster sessions and more!
- Join us on LinkedIn and Facebook to keep in touch
- Interested in presenting your research? Have ideas for technical group events? Want to reach out to your fellow group members?
  - Contact us at elina.vitol@gmail.com or TGactivities@osa.org

** Previous webinars hosted by our group are available for on-demand viewing:*

https://www.osa.org/en-us/get_involved/technical_groups/technical_group_webinars/#ondemand

Group activities in 2020

Therapeutic
Laser Applications
Technical Group

- *April 2020,* **Best Poster Presentation Award** at OSA Biophotonics Congress, in collaboration with several other TGs from Biomedical Optics Division

Award winners:

Arindam Biswas, University of South Florida
Lorenzo Cortese, ICFO-The Institute of Photonic Sciences

- *September 2020,* **Special talk at Frontiers in Optics 2020**

Volumetric imaging of the eye and brain by optical coherence tomography by Bernhard Baumann, Medical University of Vienna

- *October 2020,* ***Webinar***

Photobiomodulation for treatment of traumatic brain injury and other brain disorders by Michael R. Hamblin, Harvard Medical School and Wellman Center for Photomedicine at Massachusetts General Hospital

Welcome to today's webinar

Therapeutic Laser Applications Technical Group

MEASURING INTRACRANIAL PRESSURE USING DIFFUSE CORRELATION SPECTROSCOPY

Jana M. Kainerstorfer, PhD

Associate Professor of Biomedical Engineering
Carnegie Mellon University

December 2, 2020

BIOMEDICAL ENGINEERING
Carnegie Mellon University

Carnegie Mellon University

Non-invasive intracranial pressure sensing with near-infrared light

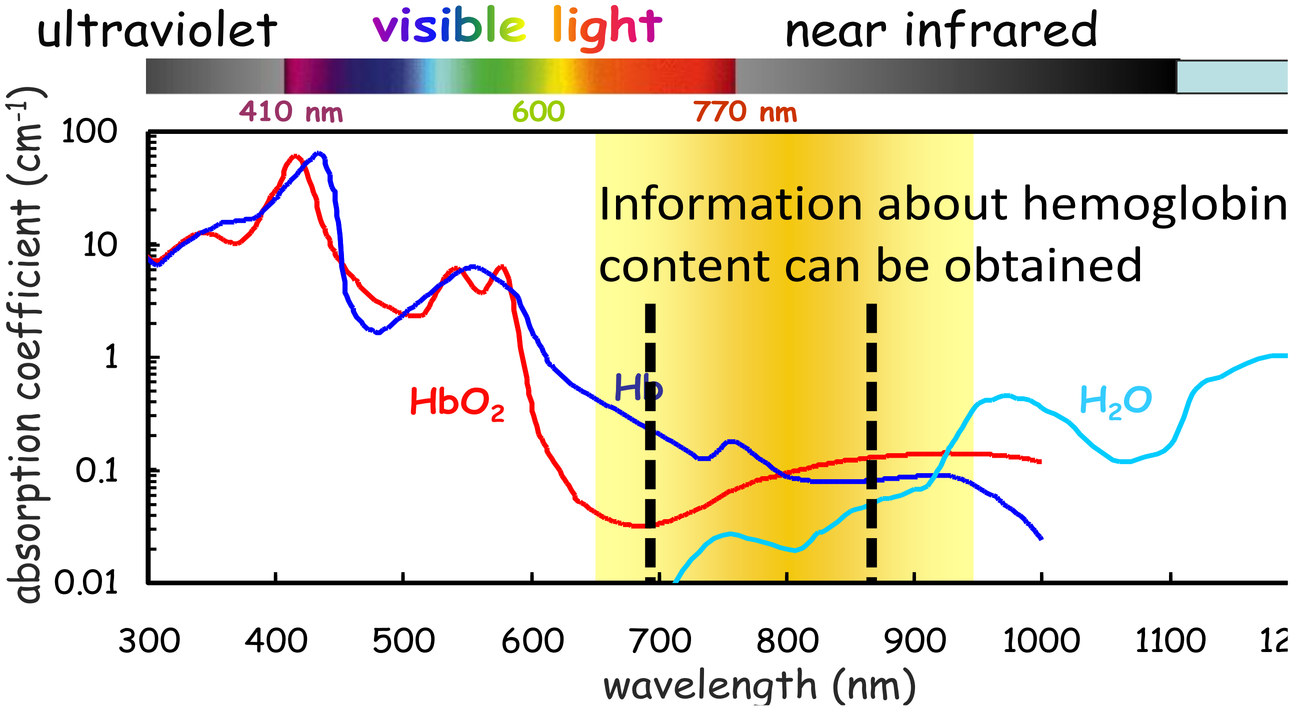
Jana Kainerstorfer, Ph.D.
Associate Professor
Carnegie Mellon University

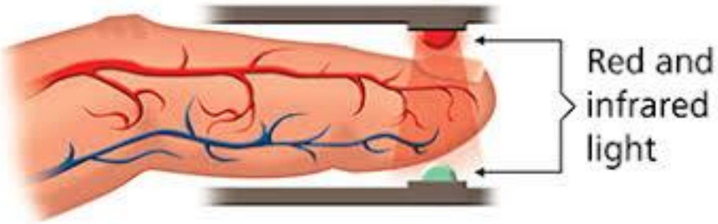
OSA Therapeutic Laser Applications technical group webinar
December 2nd, 2020

Biophotonics Lab @ CMU

Hemoglobin concentration in tissue can be quantified with light

- Non-invasive
- Portable systems
- Monitoring at bedside or at home





http://www.nonin.com

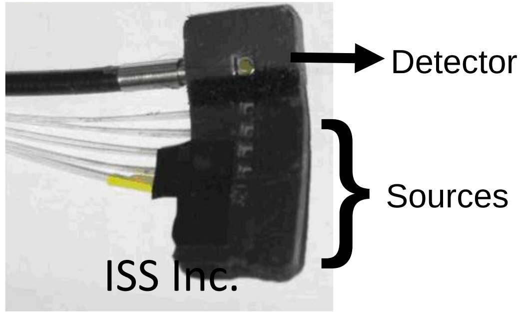
www.medisave.com.au

Near-infrared spectroscopy sensors

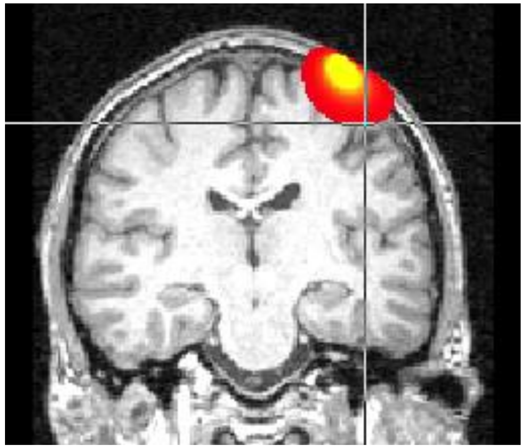
- Commercial instruments exist
- Due to absorption of light, changes in hemoglobin concentration can be measured

http://fnirdevices.com

Optical probe

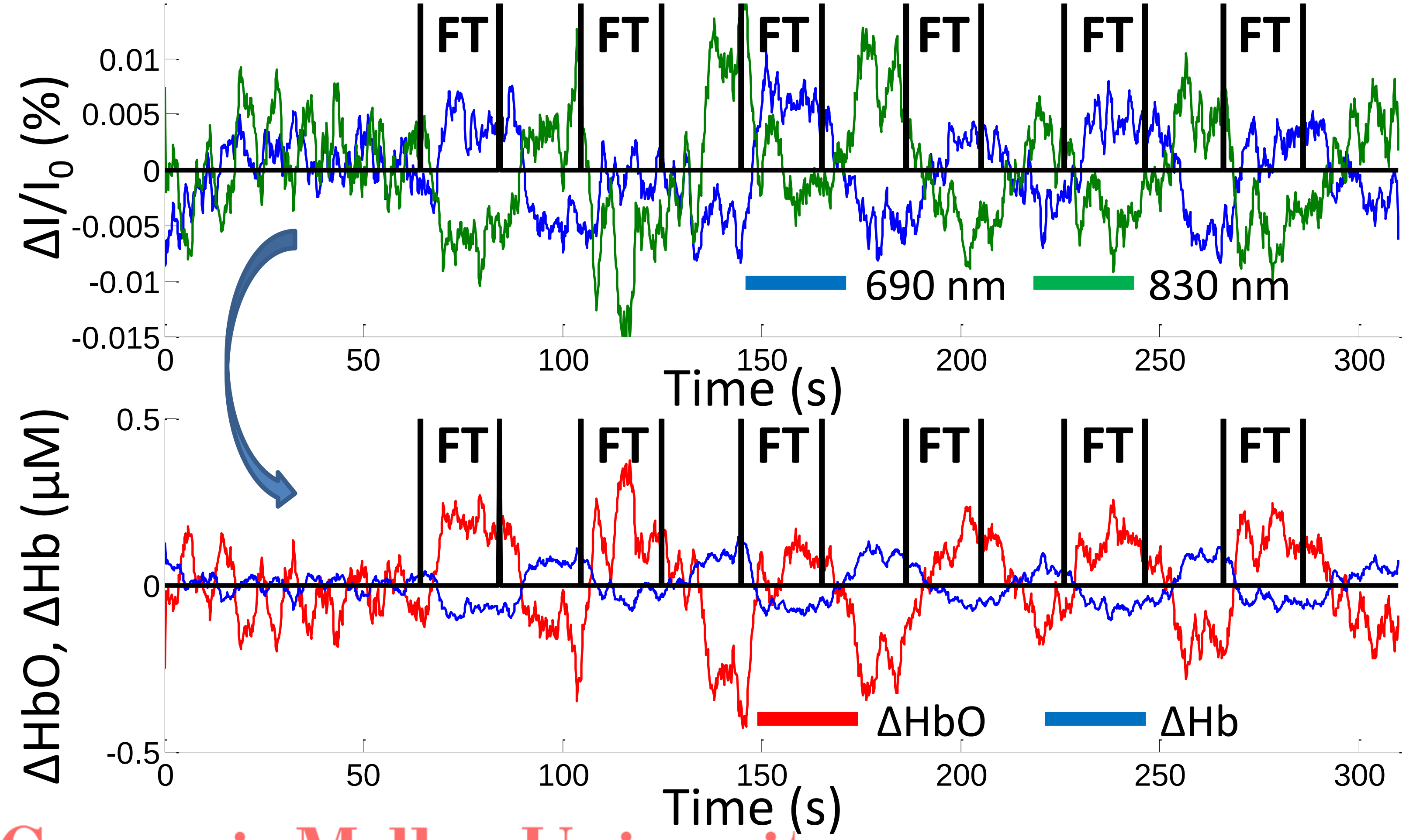


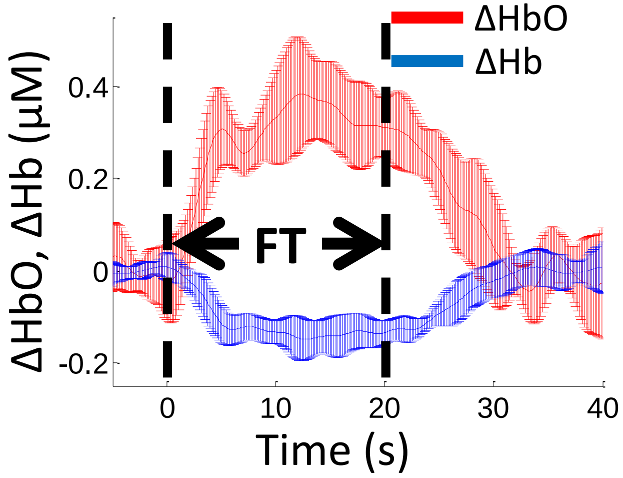
Wearable sensors



Hemoglobin concentration changes during functional activation

Functional Task





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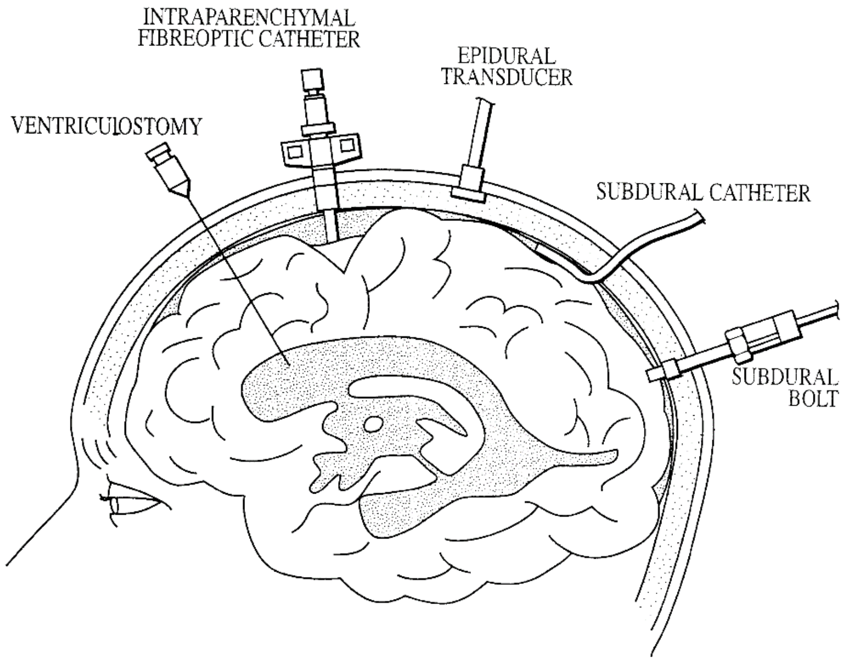
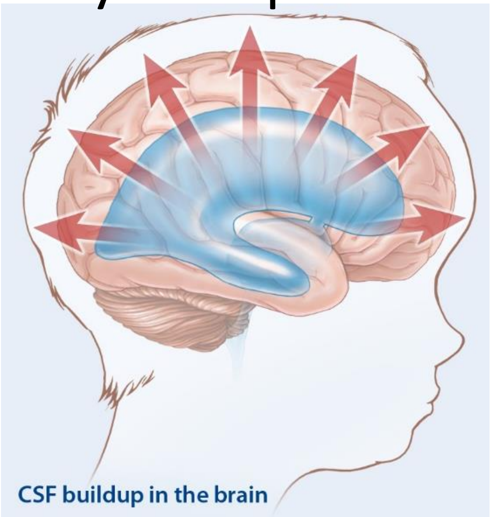
Intracranial pressure and impaired neuronal function

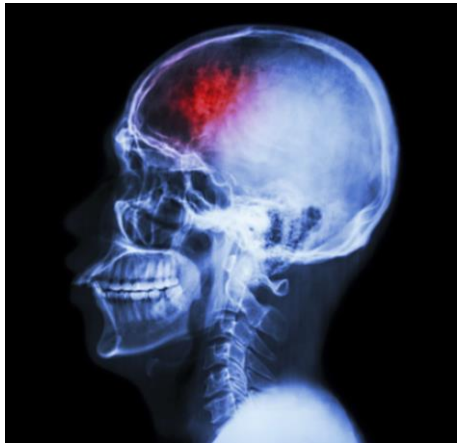


Hydrocephalus



https://www.ohsu.edu

Traumatic Brain Injury

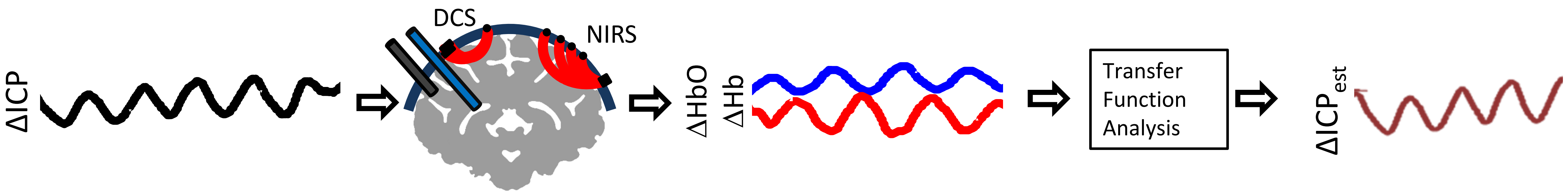


https://www.brainline.org

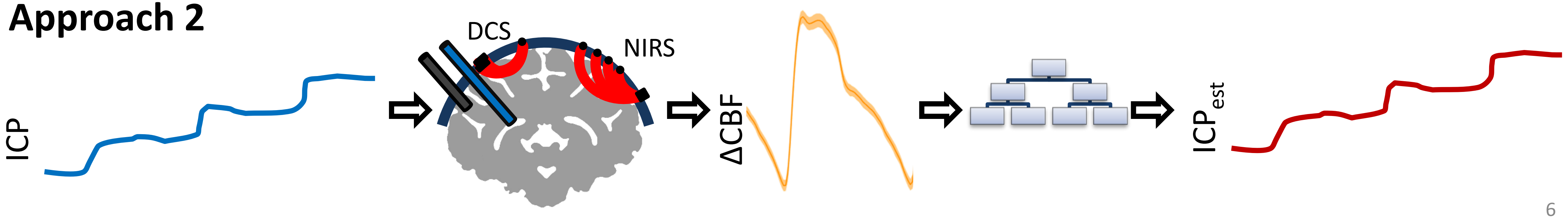
Increased intracranial pressure is associated with worse neurological outcome in patients

Measure hemodynamic changes in the brain to determine intracranial pressure

Approach 1



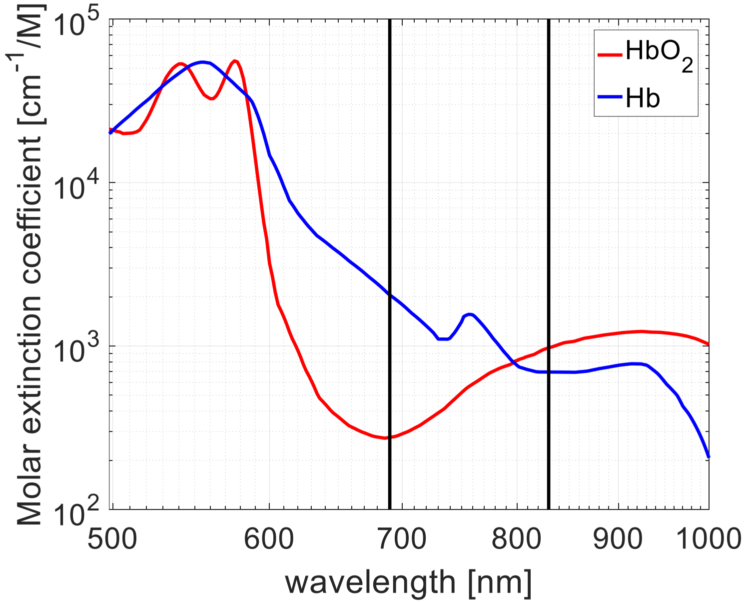
Approach 2



Near-Infrared Spectroscopy

ISS OxiplexTS

- 5 – 50 Hz sampling
- 690nm and 830nm
- 2 detectors
- Source-detector distance ≈ 2cm



http://www.iss.com/biomedical/instruments/oxiplexTS.html

ΔHbO

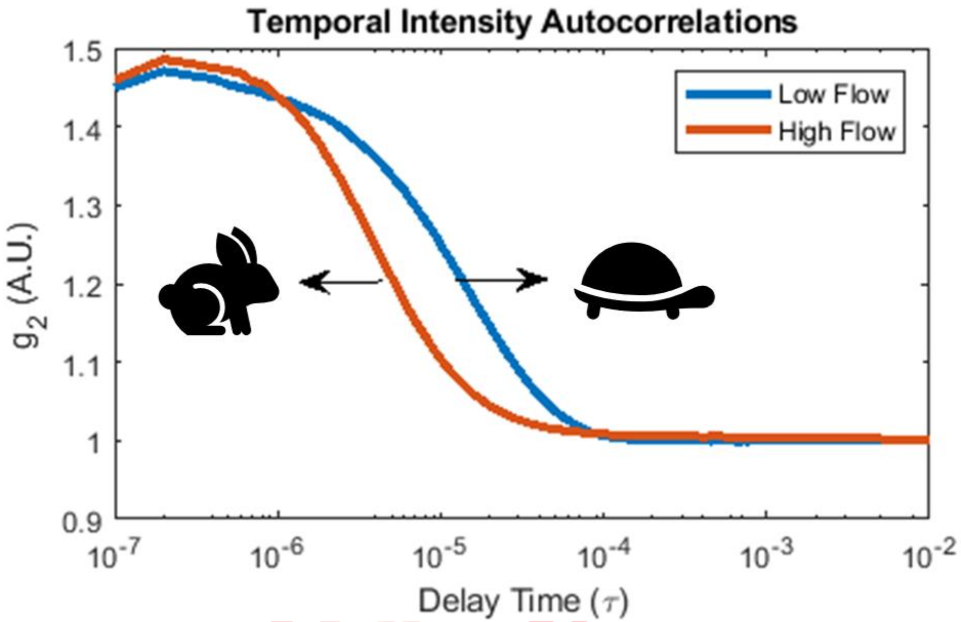
ΔHb

⇐

$$\Delta\mu_a(\lambda) = -\frac{1}{r\mathrm{DPF}}\frac{\Delta I(\lambda)}{I_0}$$

Diffuse Correlation Spectroscopy

- Sampling at 100 Hz
- Long coherence laser
- λ = 785nm or 850nm
- 4 detectors recording at a single location
- Source-detector distance ≈ 2cm

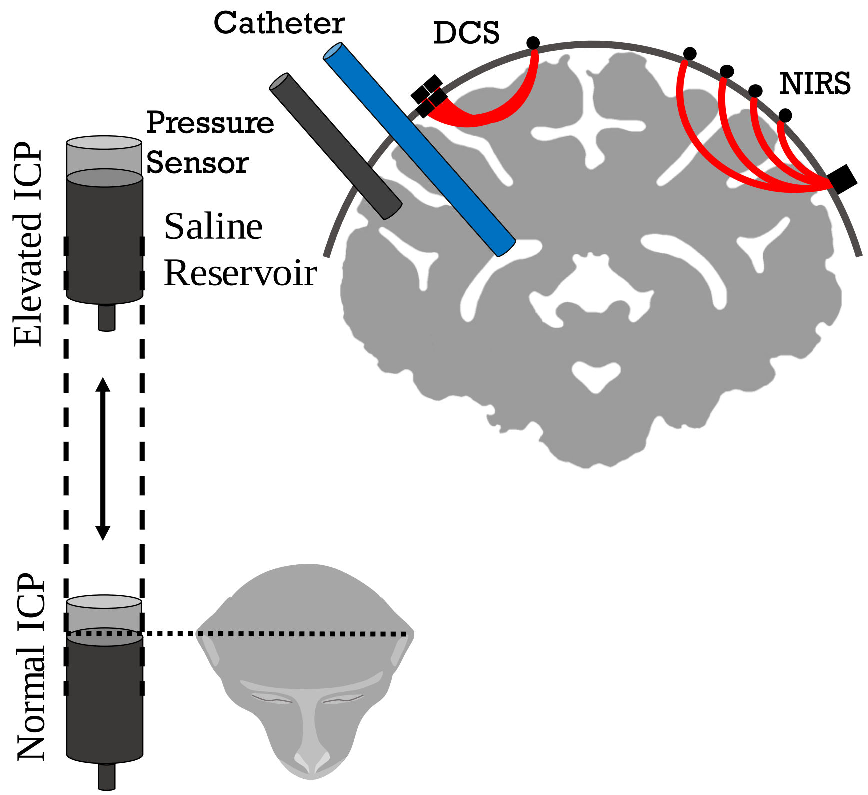


System built in-house

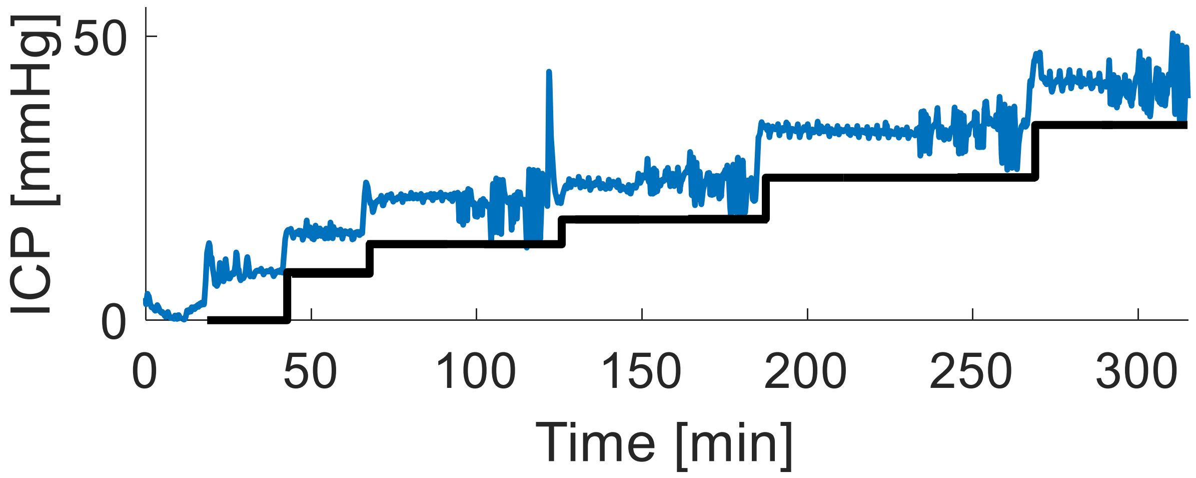
$$g_2(\tau) = \frac{\langle I(t) \cdot I(t+\tau) \rangle}{\langle I(t) \rangle^2} \Longrightarrow \Delta\text{CBF}$$

Animal model

- Non-human primate model

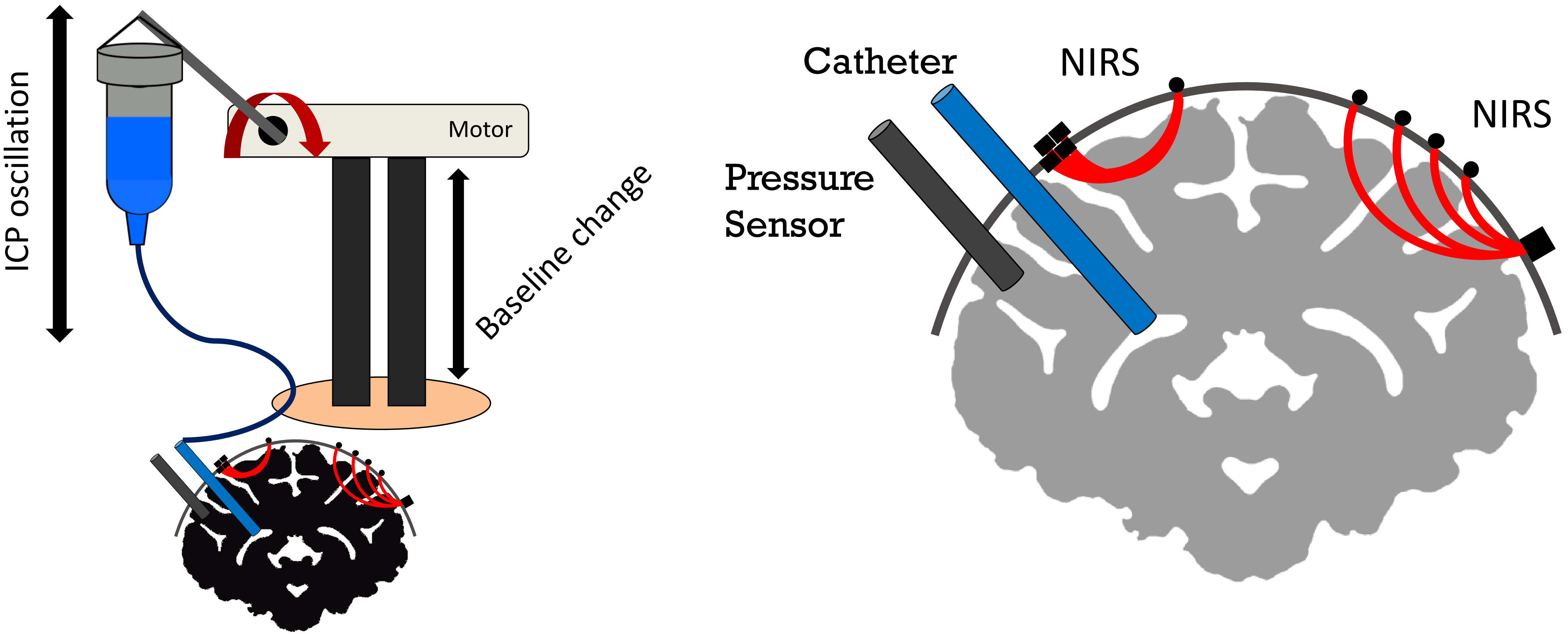


- Diffuse Correlation Spectroscopy
  Blood Flow
- Near-Infrared Spectroscopy
  HbO, Hb



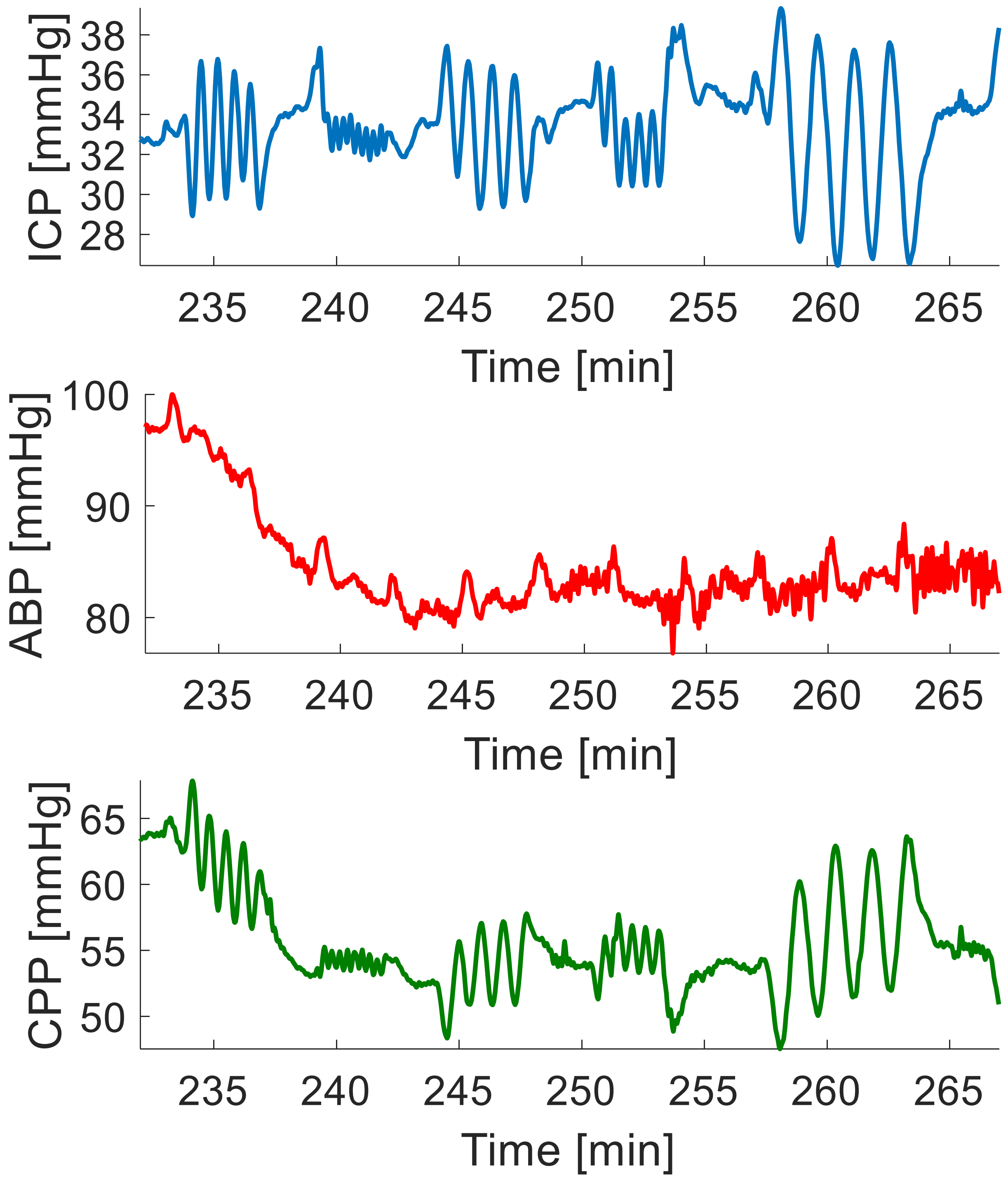
Animal study to induce intracranial pressure changes

- Non-Human Primates with invasive pressure sensor



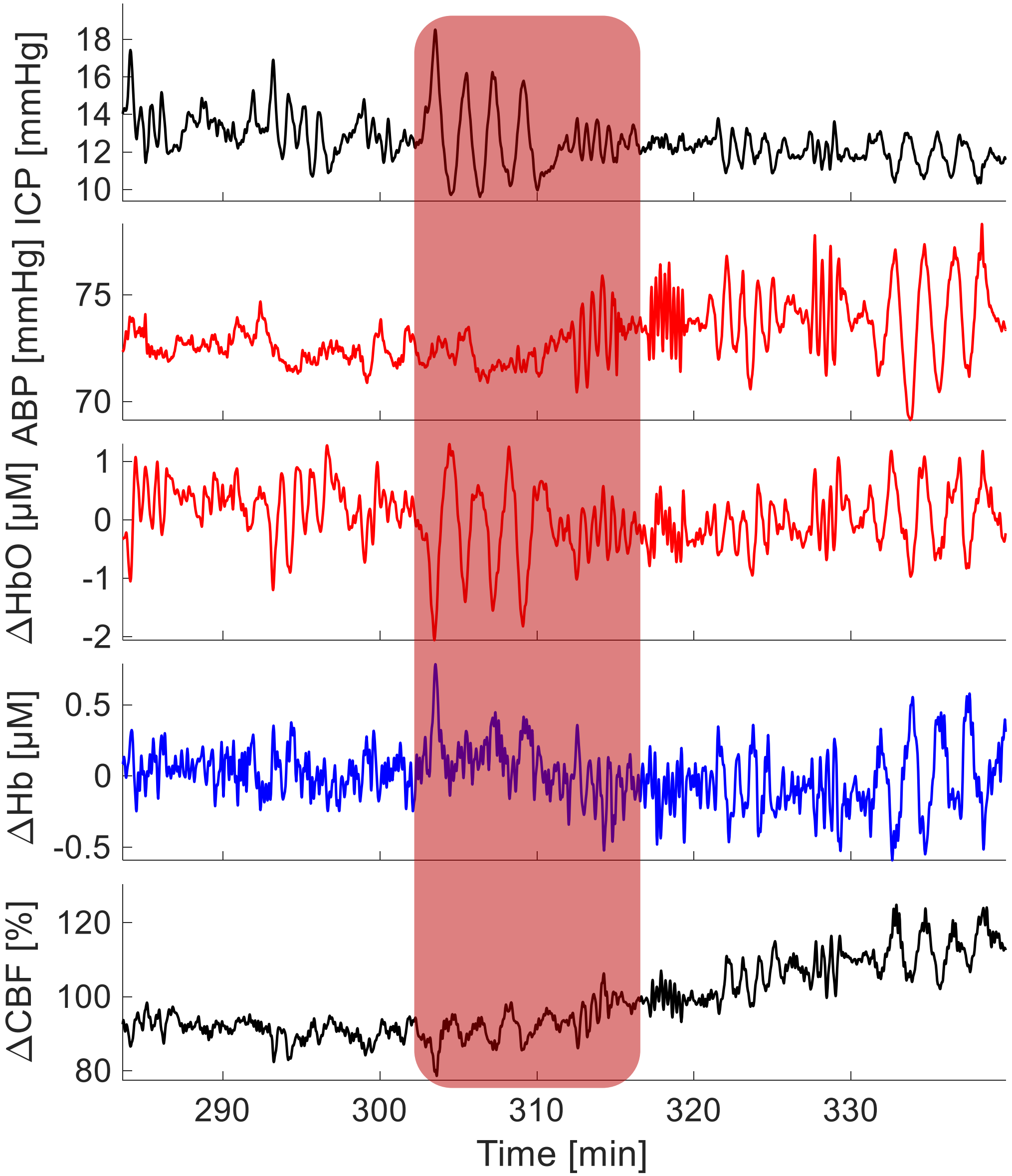
Example

- Cerebral Perfusion Pressure
  - CPP = MAP - ICP
- Blood pressure doesn't respond to oscillation
- 0.01 – 0.06 Hz oscillations are induced



Example data of induced ICP and ABP oscillations

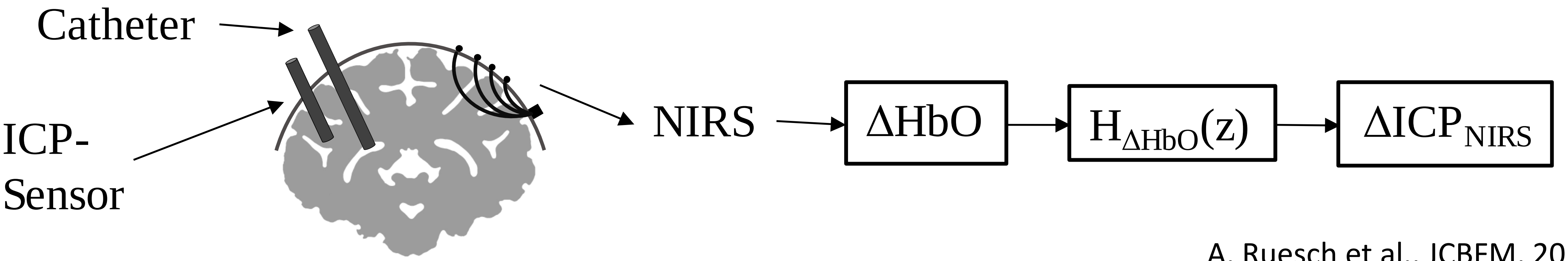
- Fluid pressure oscillation translate to cerebral hemodynamic changes



Transfer function analysis for non-invasive ICP

- Non-parametric
- Frequency domain
- Discrete value
- 2 Zeros, 4 Poles
- Least-square error fit of parameters

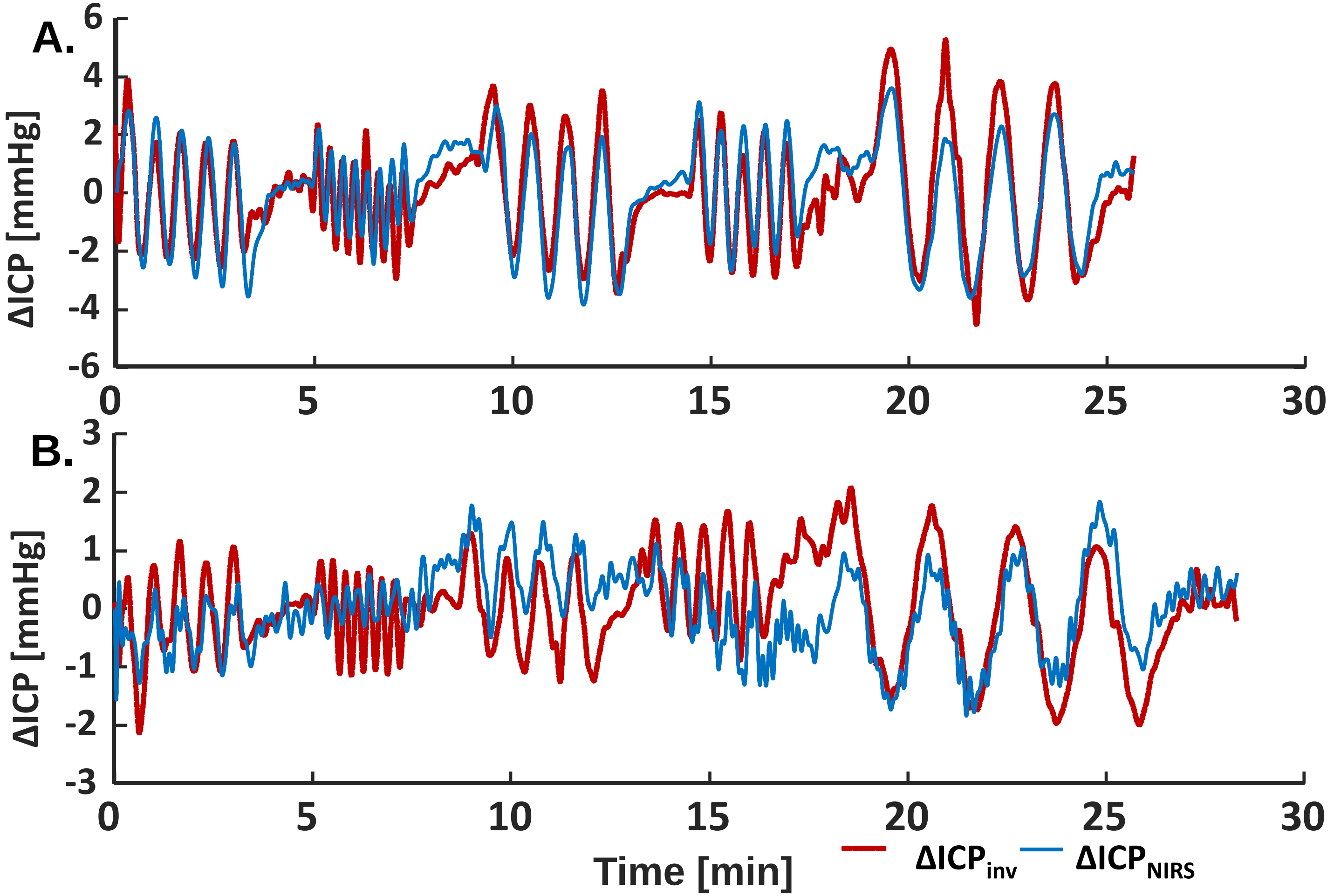
$$H_{\Delta HbO}(z) = \frac{-0.22z + 0.22}{z^4 - 1.9z^3 + 0.22z^2 + 1.33z - 0.65}$$



A. Ruesch et al., JCBFM, 2019
A. Ruesch et al., BOEx, 2020

Relative changes in ICP extracted with NIRS

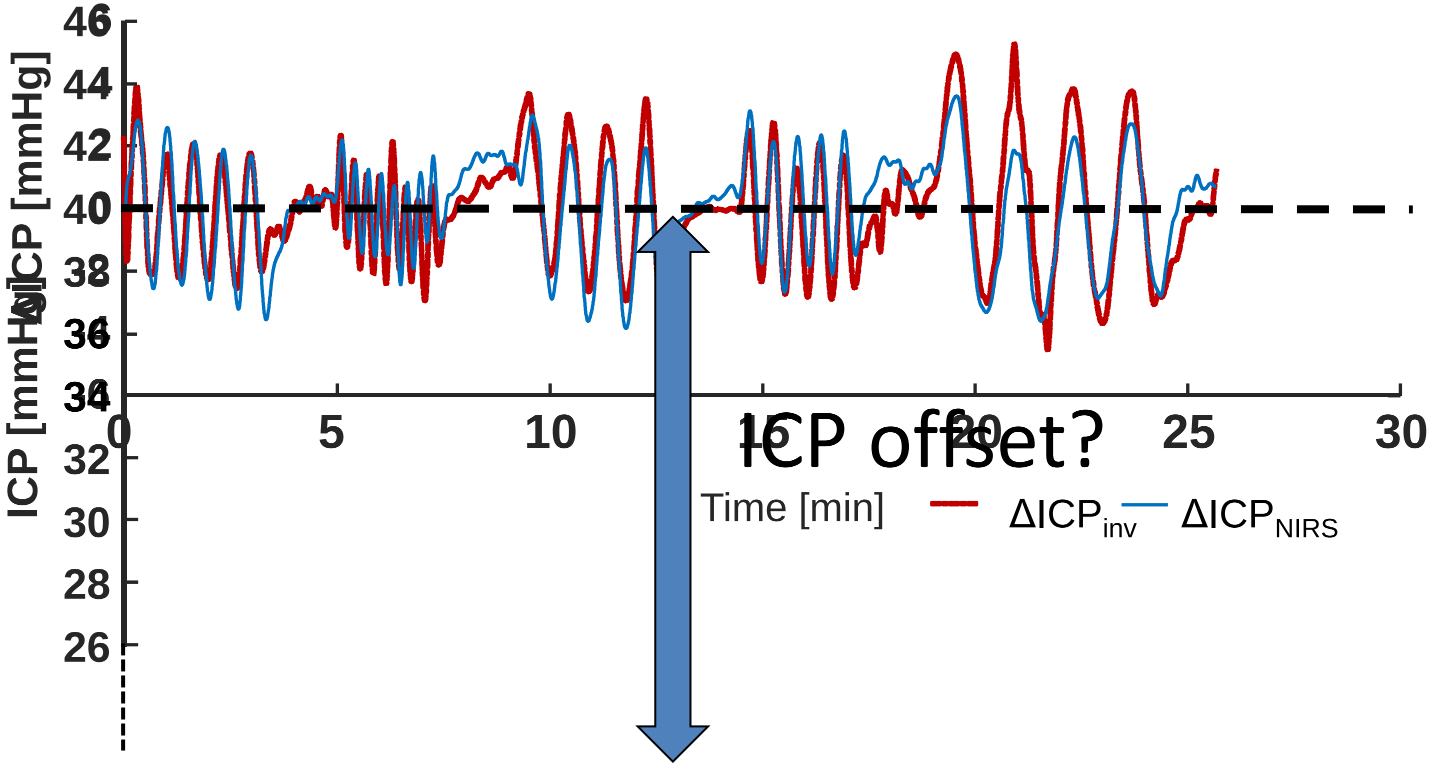
- Example of two different animals at high ICP (40mmHg)
- Application of transfer function to low-pass (fc=0.1Hz) filtered data
- Good fit of invasive ICP measurement and transfer function output



A. Ruesch et al., JCBFM, 2019
A. Ruesch et al., BOEx, 2020

Non-invasive pressure sensing is possible

- Transfer function approach allows:
  - non-invasive dynamics of ICP
  - High temporal resolution
  - Small magnitudes



- What is missing:
  - Detection of pathologic ICP
  - Offset detection of ICP

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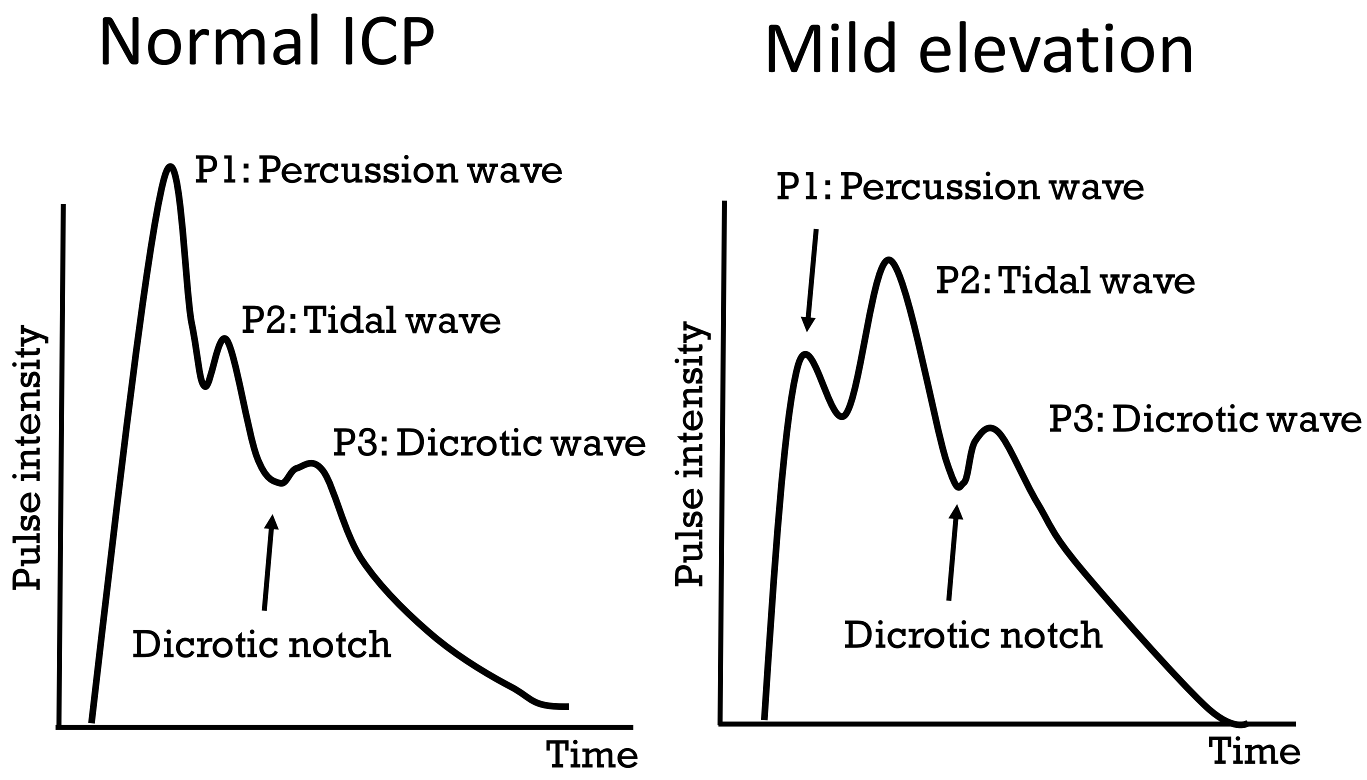
A. Ruesch et al., JCBFM, 2019
A. Ruesch et al., BOEx, 2020

Pulse waveform change with pressure

- ICP waveform changes with ICP baseline
- Tidal wave increases due to impedance change
- **Our Hypothesis:**
  – Same impedance change will also influence cerebral blood flow (CBF) pulse wave



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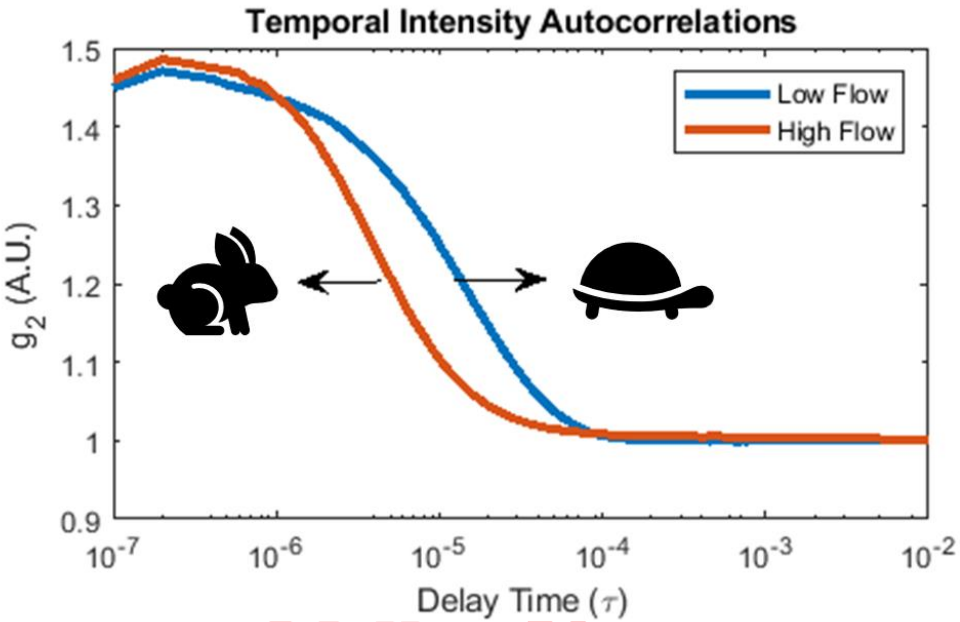
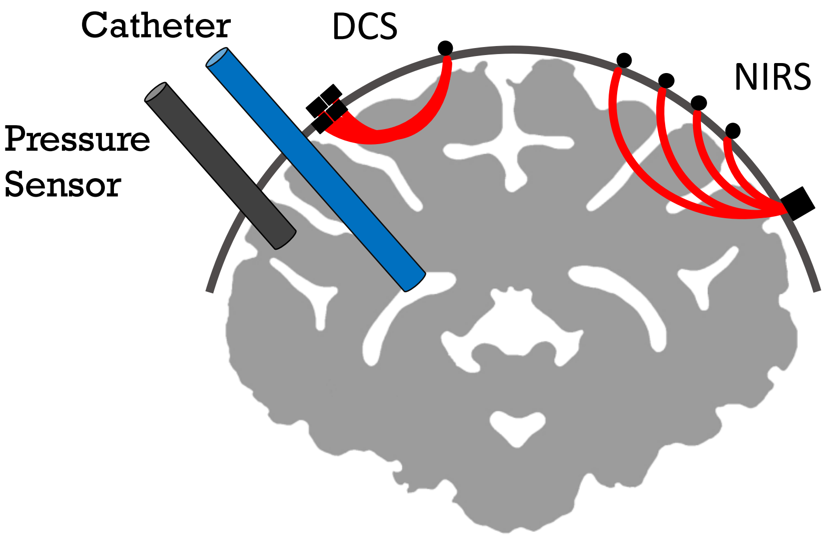
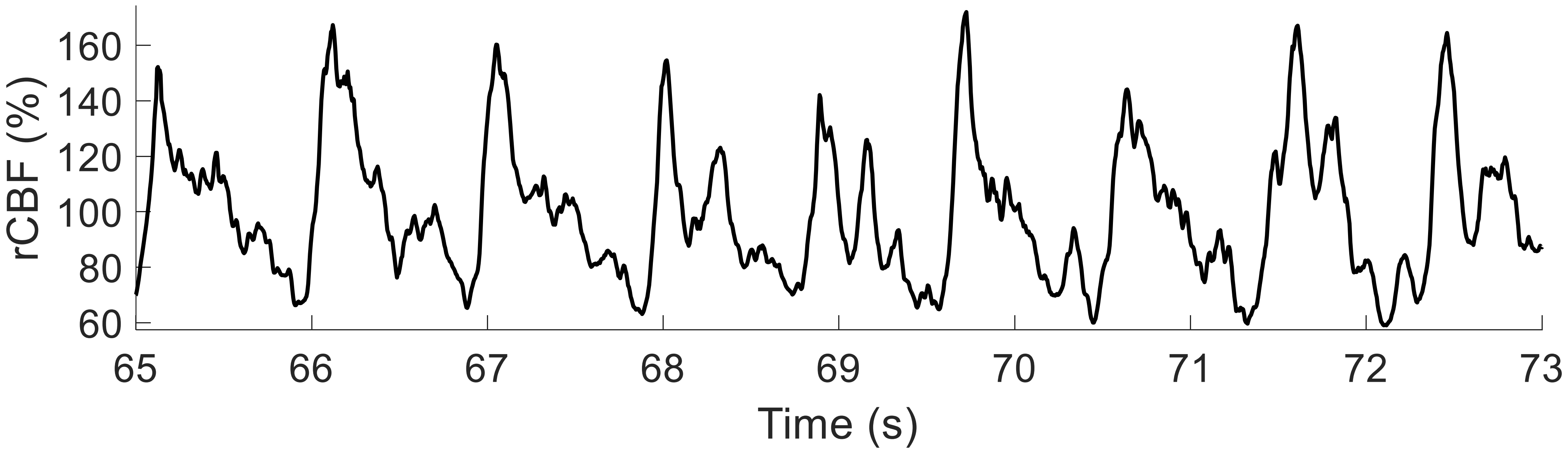




$$g_2(\tau) = \frac{\langle I(t) \cdot I(t+\tau) \rangle}{\langle I(t) \rangle^2} \Longrightarrow \Delta\text{CBF}$$

Diffuse Correlation Spectroscopy

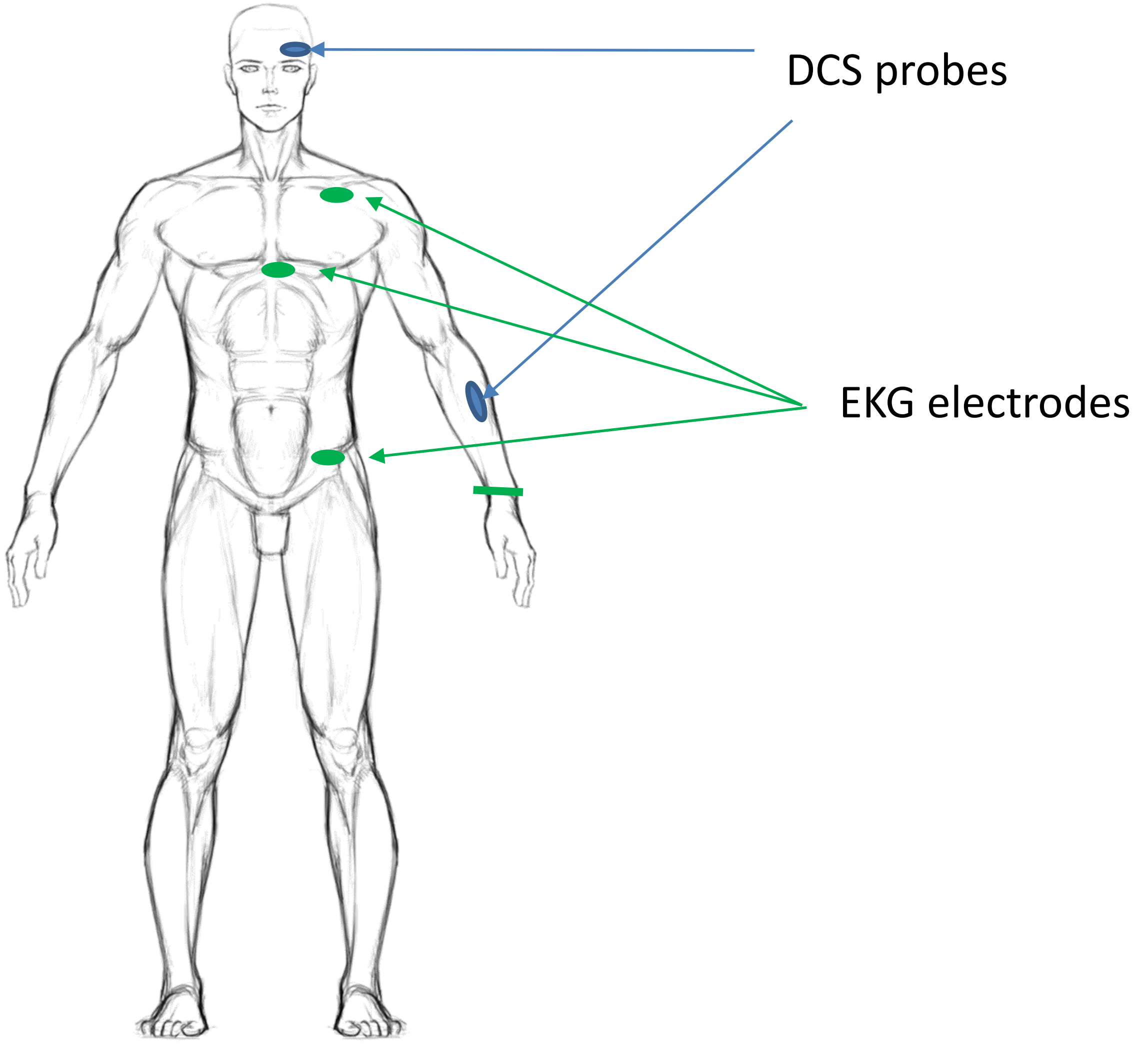
- CBF changes in the microvasculature
- Beat to beat CBF changes can be monitored



Pulse Averaging - Setup

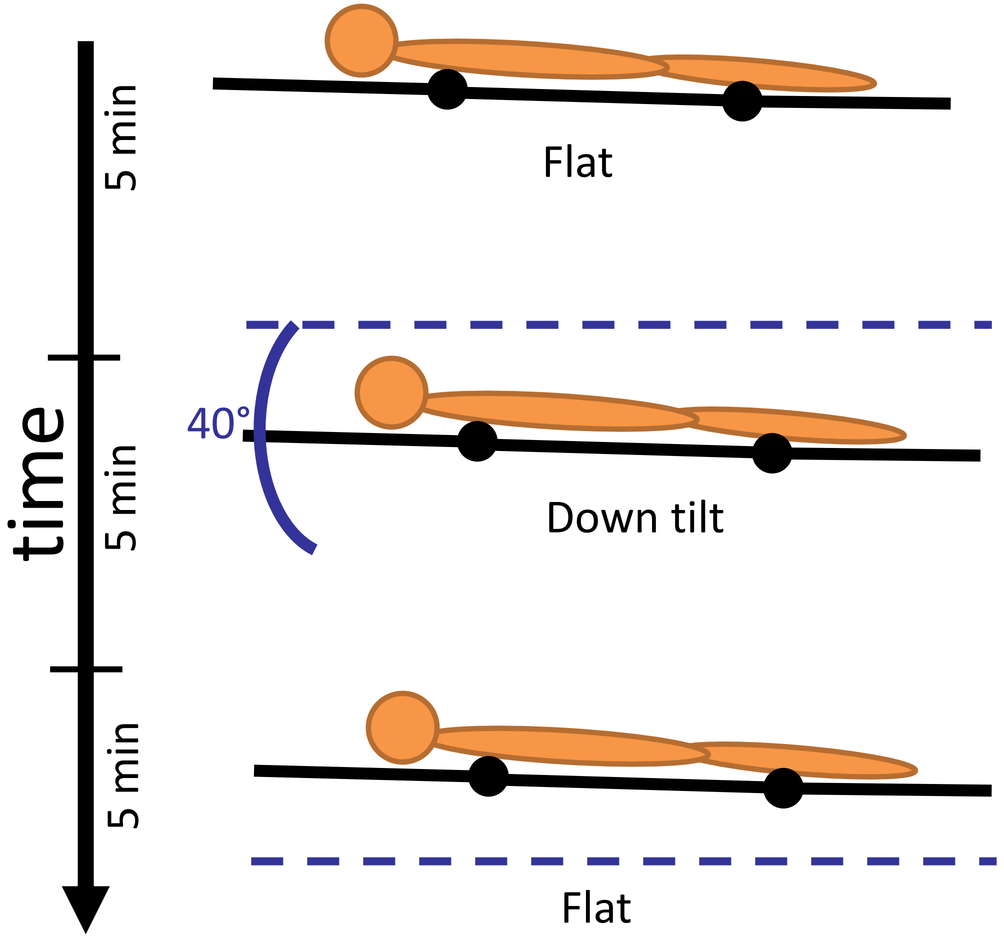
- DCS placed on forehead and arm
  - d = 2.5cm
  - λ = 850nm
  - 4-bundled 'few' mode fibers (5.8μm)

- EKG tags 60 pulses



Blood Flow Changes with Head of Bed Tilting

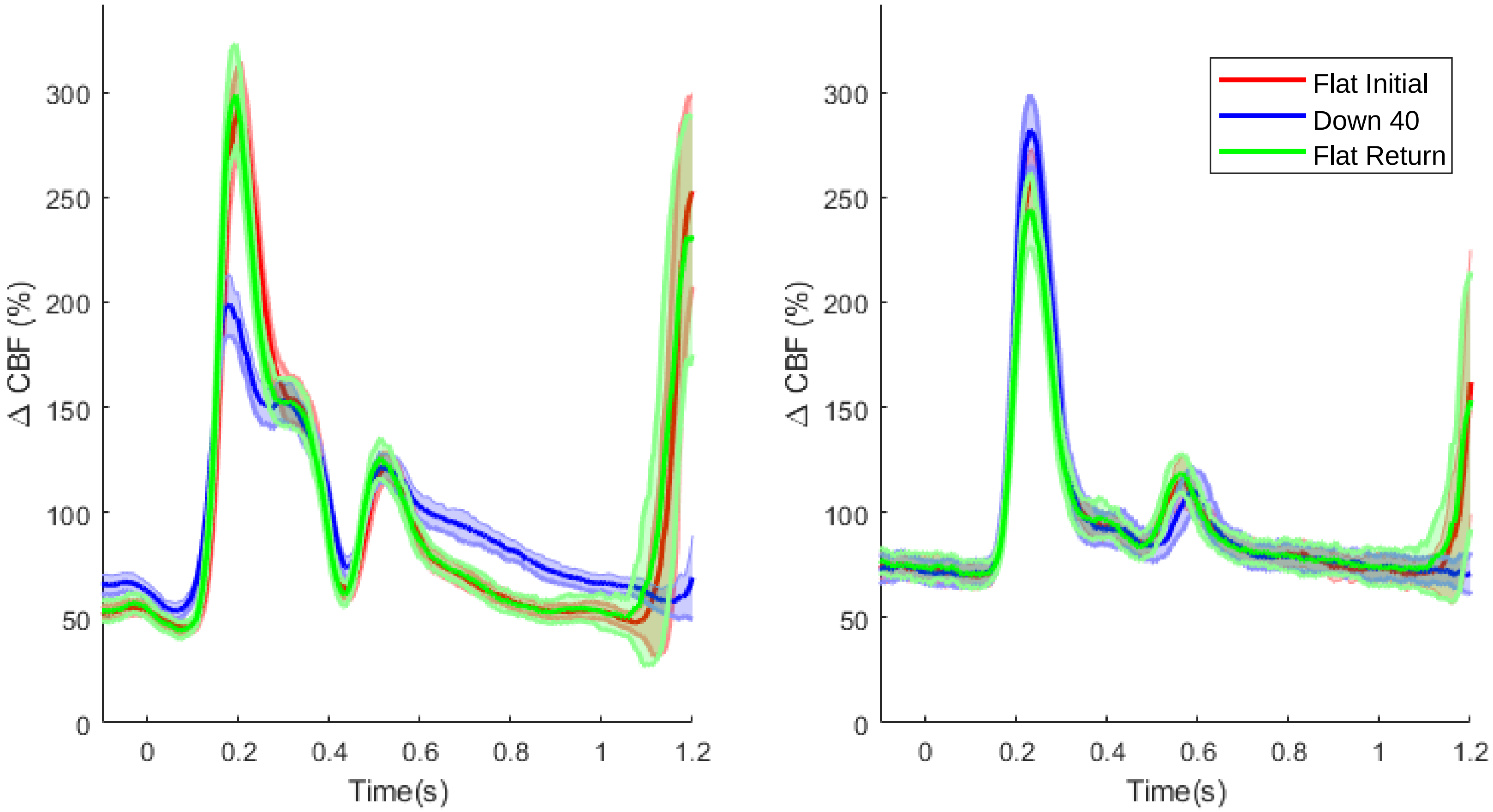
- Can we measure the local microvasculature impedance?
  - Can this be indicative of disease state?
- DCS placed on the head and arm
- Increase ICP by inversion



Human results – Head of Bed Tilting

- 100 pulses averaged at 50Hz bandwidth

- Head shows morphological change in flow when tilting
- Arm shows little change in flow



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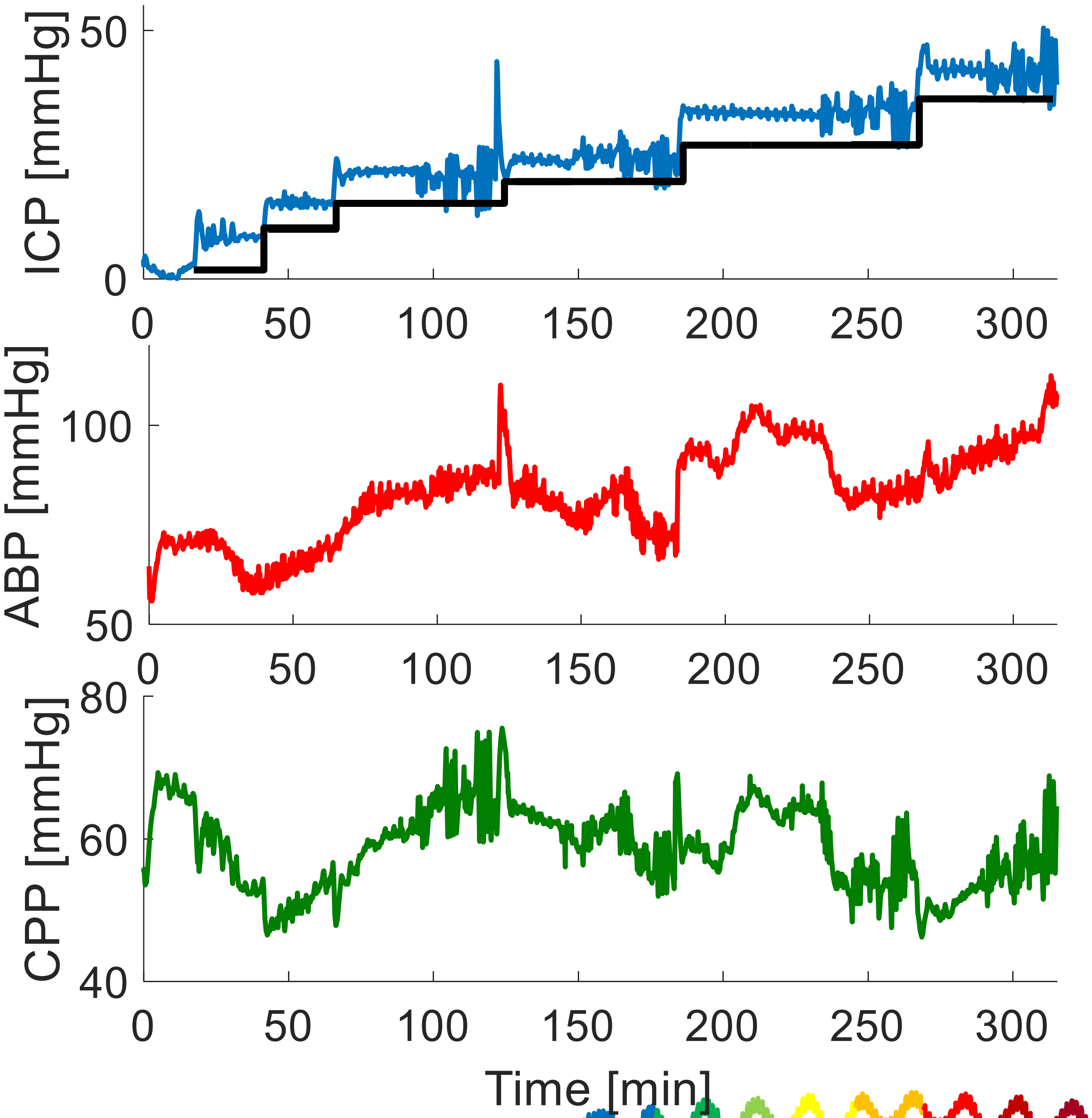
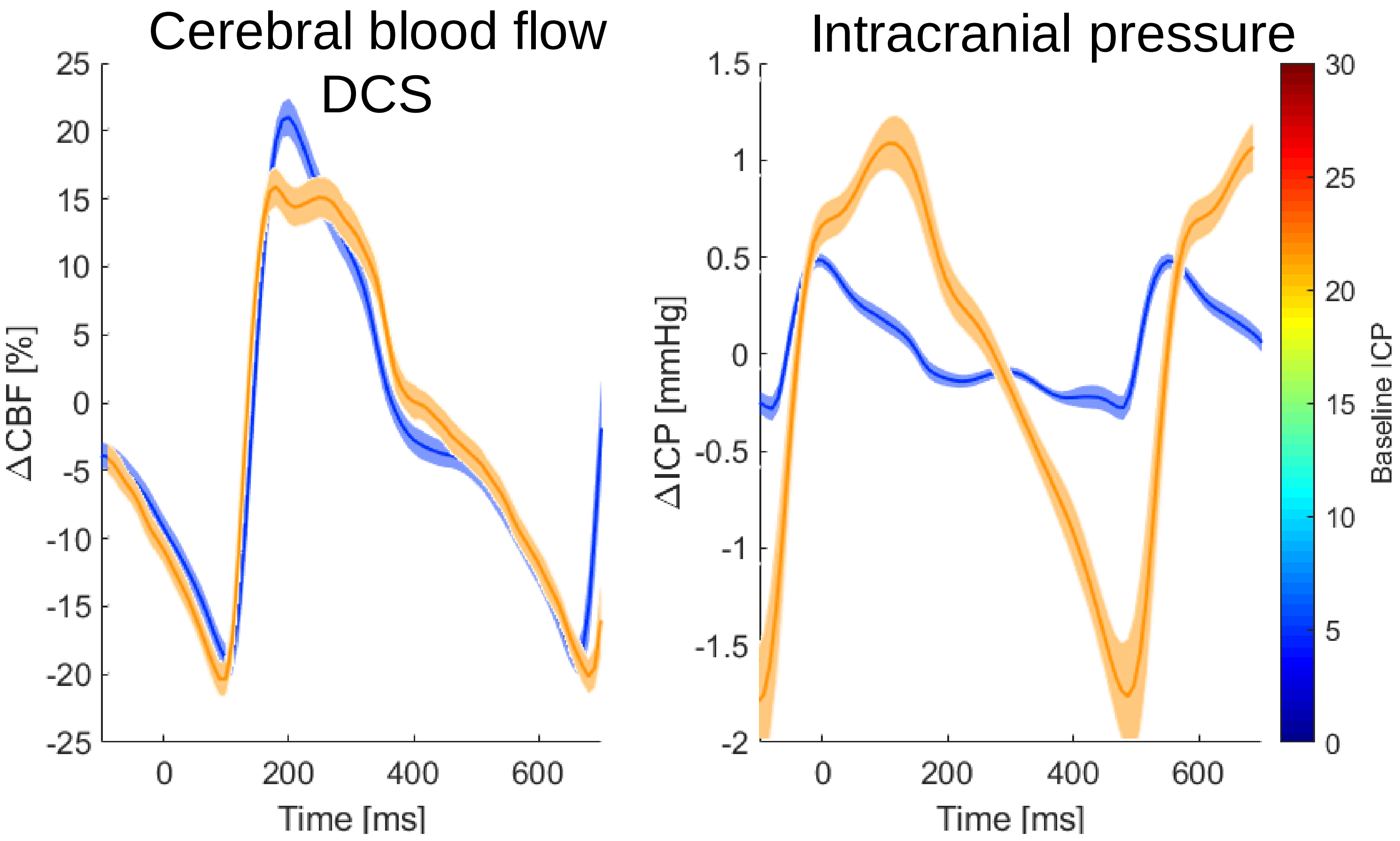


Cardiac Pulse Waveform as a Function of ICP

- ICP cardiac pulse waveform changes with baseline



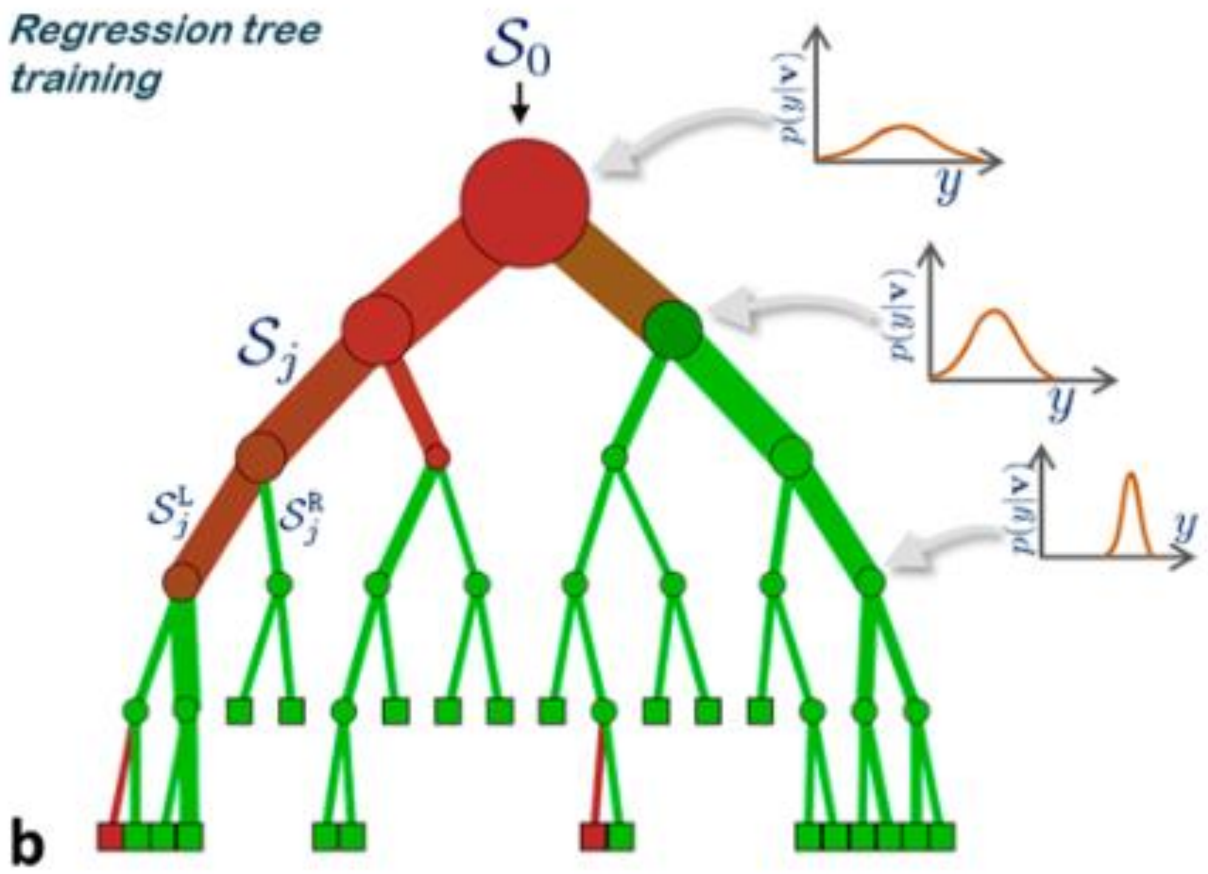
Hypothesis:

Similar changes are observable in the cerebral blood flow pulse wave

A. Ruesch et al., JCBFM, 2019
A. Ruesch et al., BOEx, 2020

The Decision Forest as a Machine Learning Tool

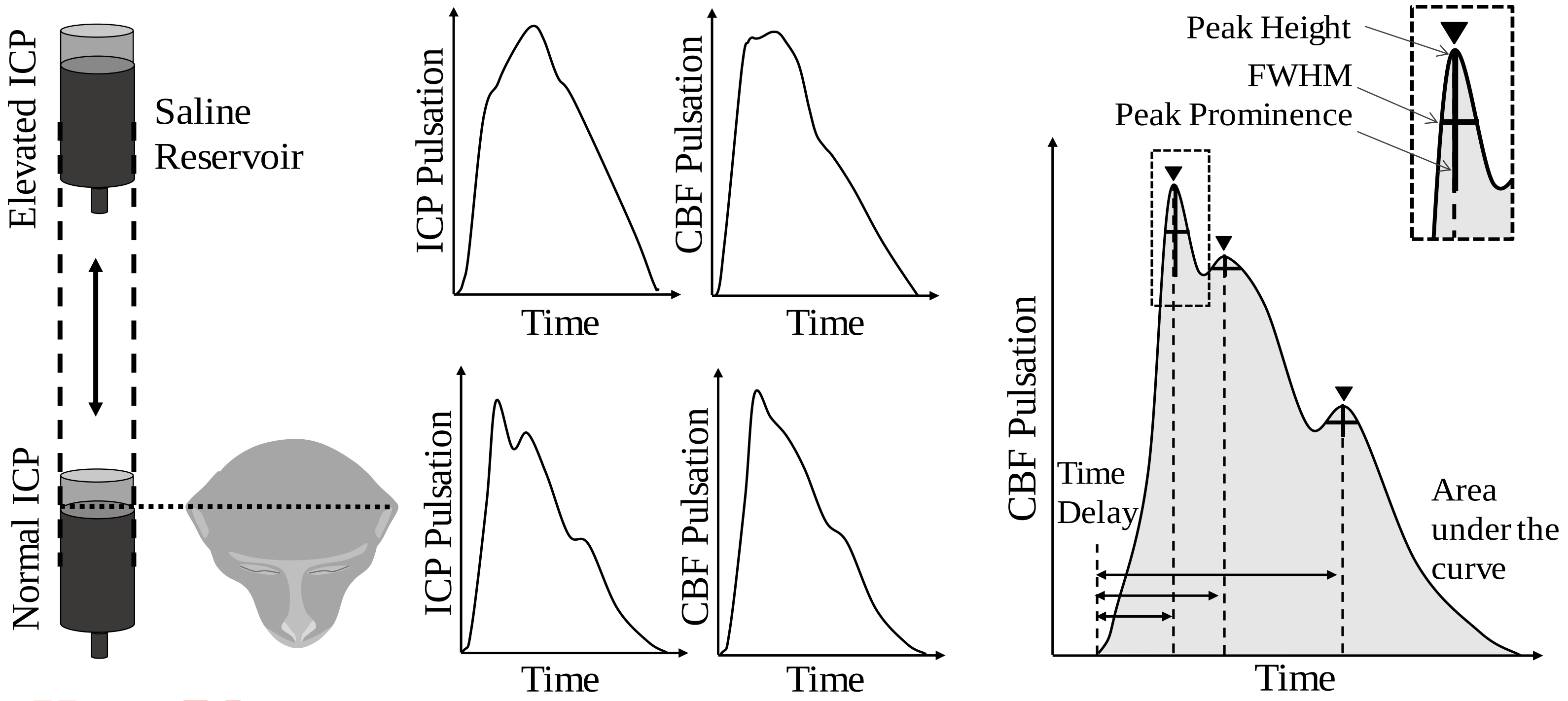
- Regression Forest
- Continuous values opposed to discrete classes
- Value given by distribution of ground truth values in every terminal node



Criminisi A., et al., Springer. E-pub, February 2013.

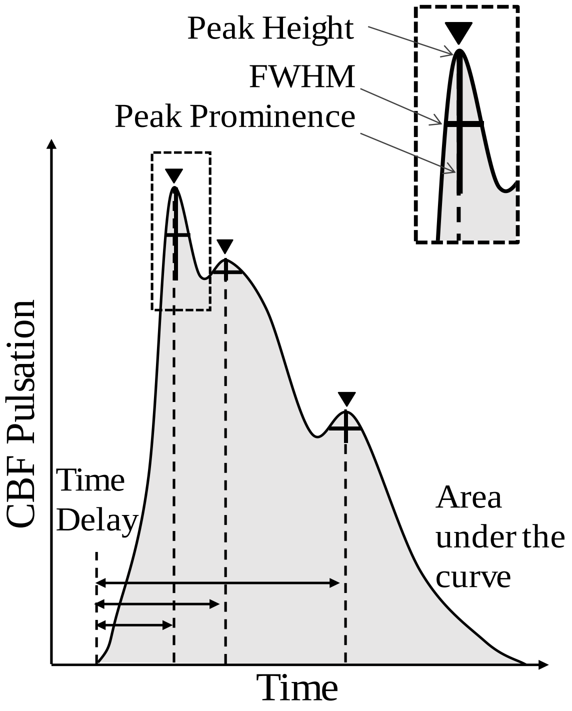
Feature extraction

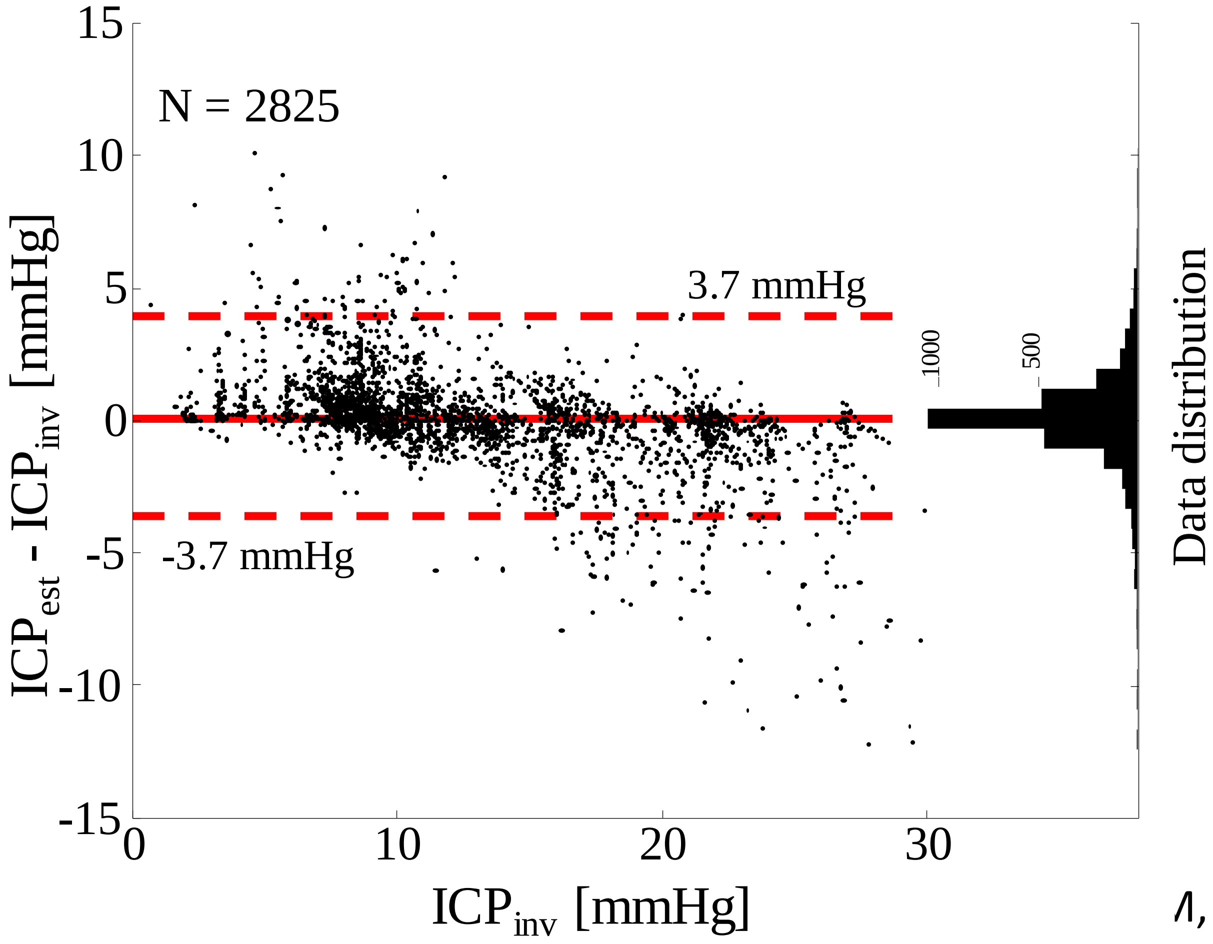
- Single pulses are determined by peak finding algorithm
- Averaging of 60 pulses for increased SNR
- Calculate average ICP in the given time window as ground truth
- Use features in regression forest



Machine Learning for ICP Calculation

- Using feature based machine learning (regression forest)



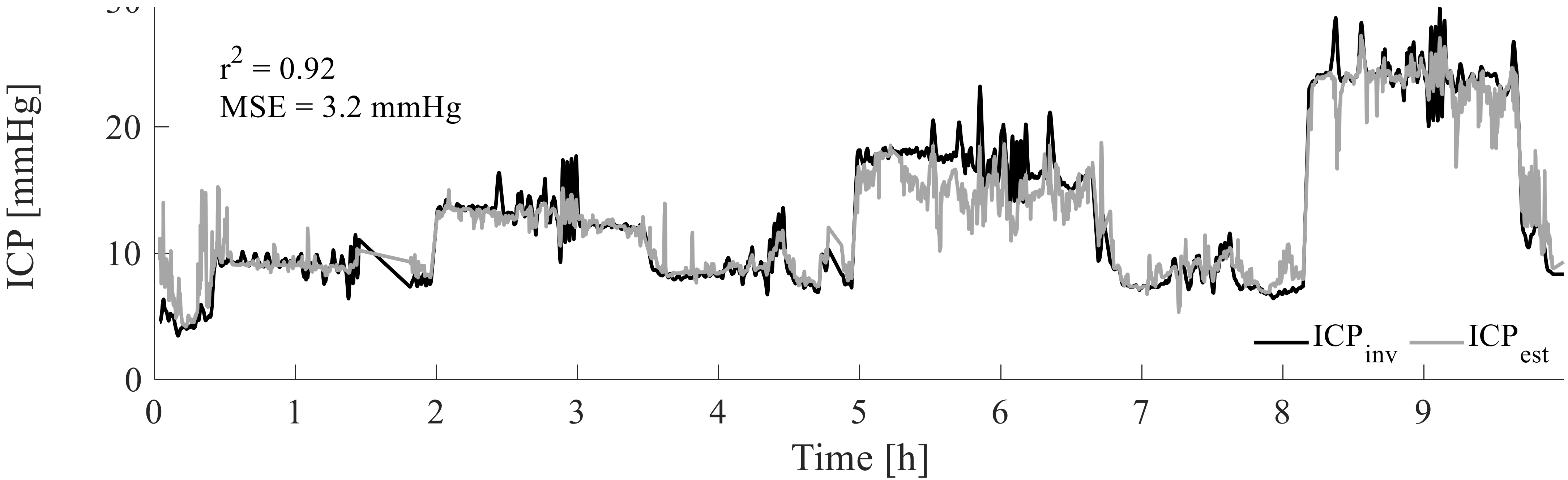


/I, 2019

A. Ruesch et al., BOEx, 2020

Absolute ICP can be extracted

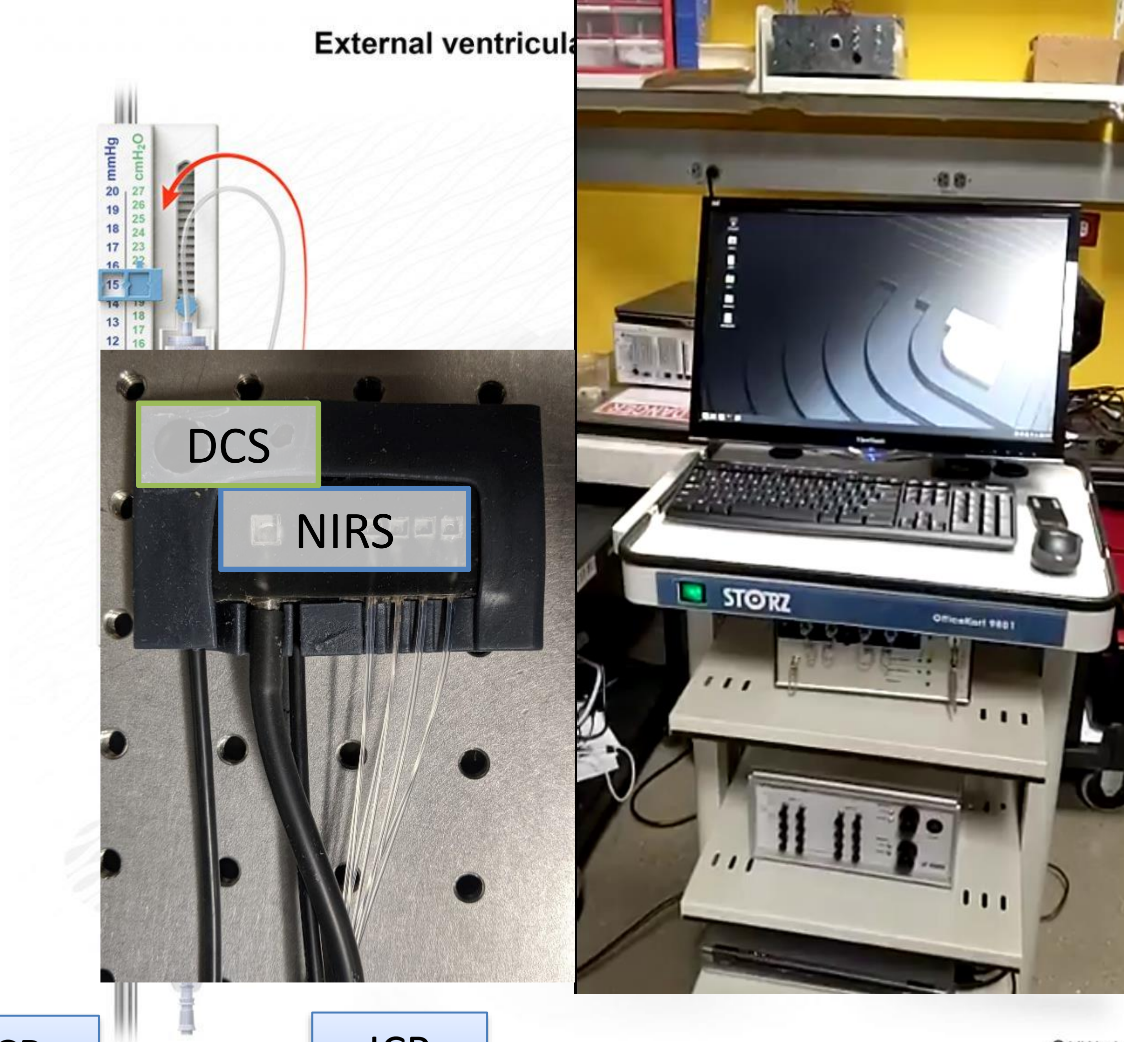
- Changed over time can also be extracted
- One example animal shown



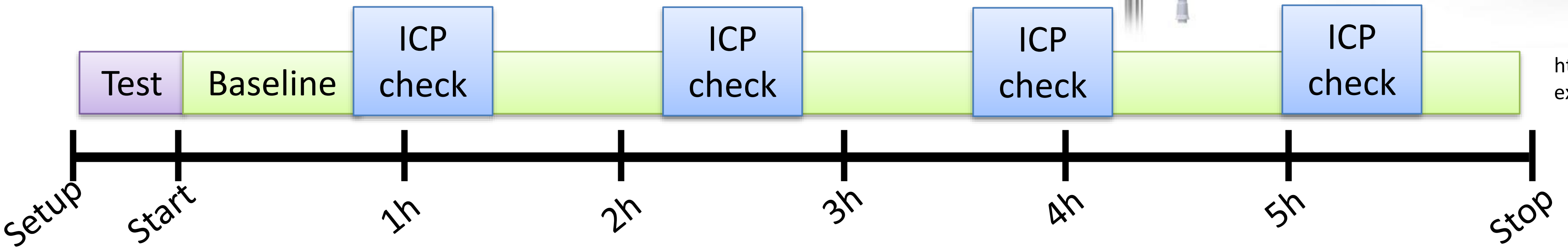
A. Ruesch et al., JCBFM, 2019
A. Ruesch et al., BOEx, 2020

Clinical Translation

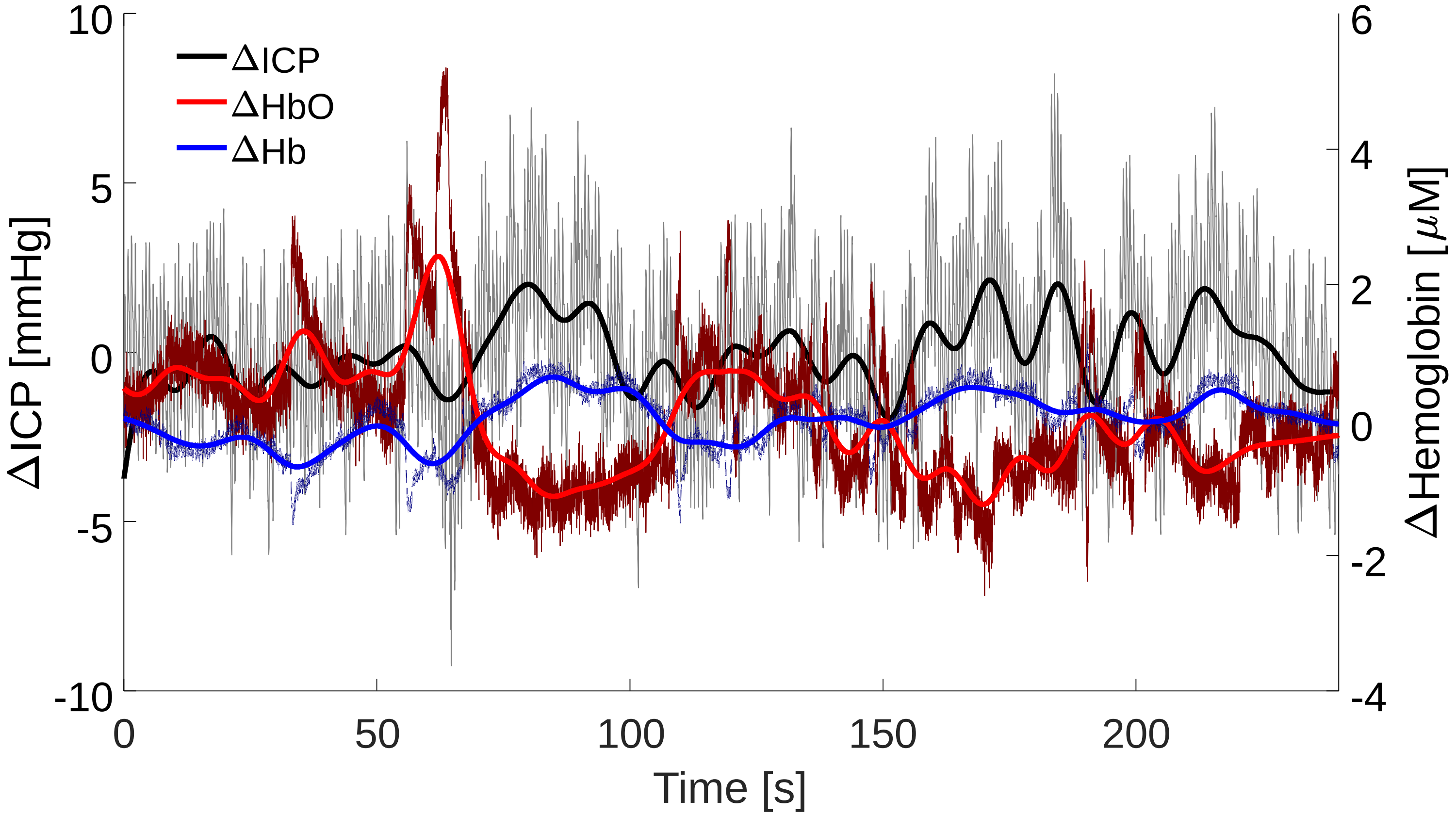
- Collaboration with the Children's Hospital of UPMC of Pittsburgh
  - Pediatric Intensive Care Unit
- Measure hemodynamics on pediatric TBI and Hydrocephalus patients
  - Co-Localized DCS and NIRS
  - With ICP monitor or ventricular drain
- Until today: 4 subjects with a total of 12 hours of data



https://meetings.ami.org/2019/project/external-ventricular-drainage-device/



Clinical Translation
– Low Frequency Correlation in Humans



Low-pass f_c= 0.1 Hz

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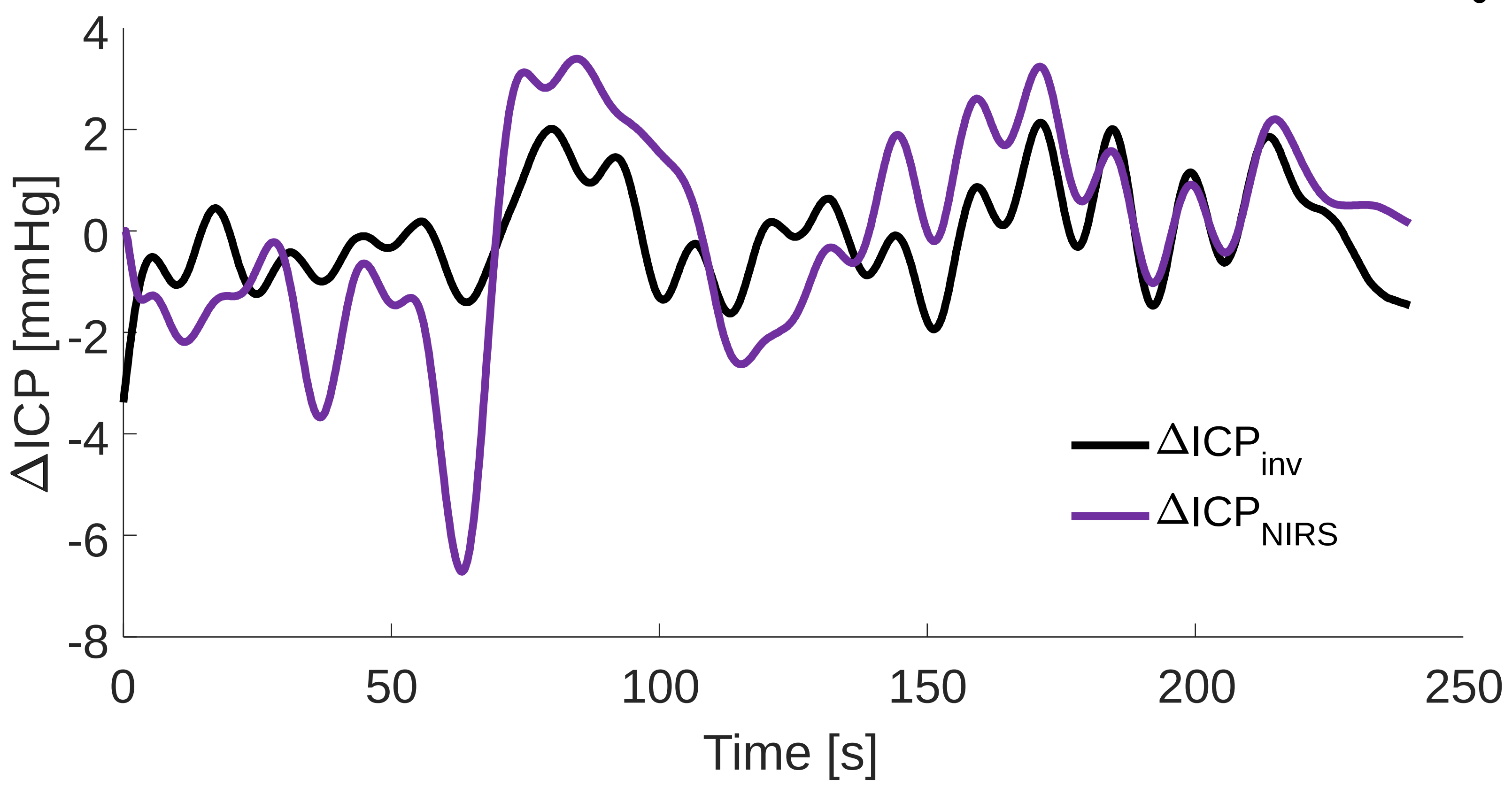
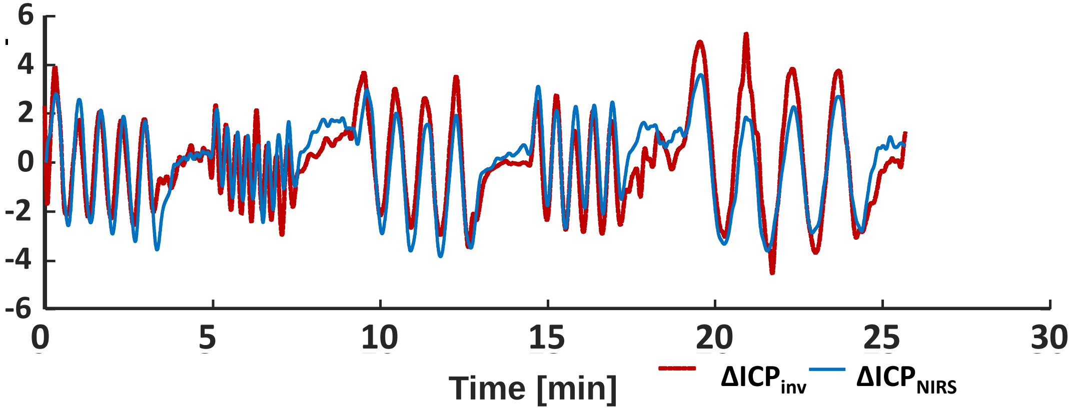
Clinical Translation
– Low Frequency Correlation in Humans



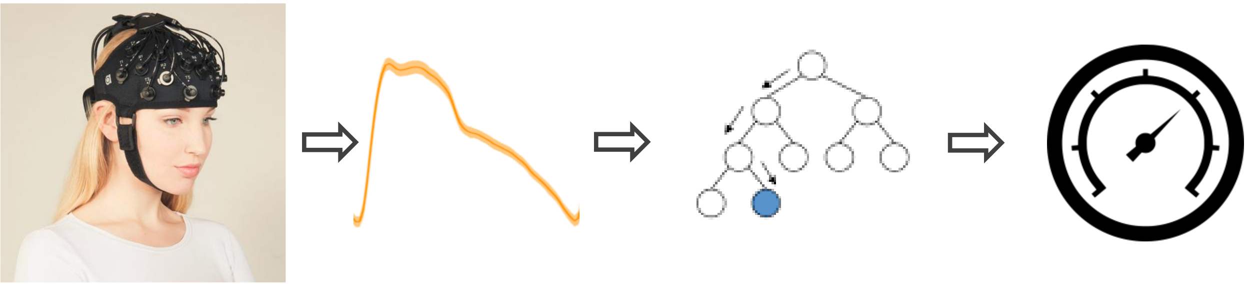
- Predicting changes in ICP using NIRS and non-human primate transfer function shows promising preliminary results

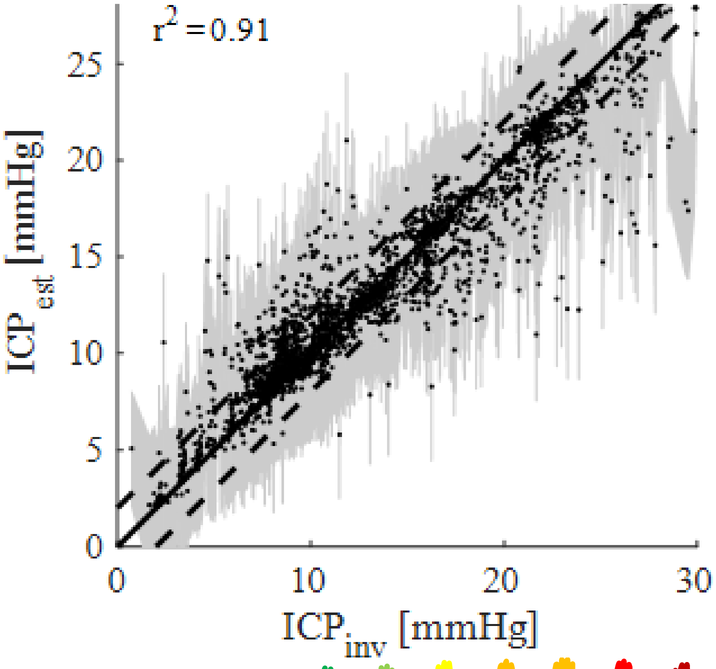
Summary and Conclusions

- Relative changes in intracranial pressure with NIRS and transfer function analysis
- Quantitative estimation based on regression forest tree
- Clinical translation – measure children with hydrocephalus and traumatic brain injury



Use Optical Imaging | Measure Blood Flow | Use Machine Learning | Estimate Pressure





Acknowledgements

BIOMEDICAL ENGINEERING
Carnegie Mellon University

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- Jingyi Wu
- Harsha Sridhar
- Ankita Mukherjea
- Bradley Scammon
- Syeda Tabassum
- Sossena Wood

Neuroscience:

- Barb Shinn-Cunningham

ECE:

- Pulkit Grover
- Maysam Chamanzar

University of Pittsburgh:

- Ted Huppert

Children's Hospital Neurosurgery:

- Elizabeth Tyler-Kabara
- Michael McDowell

Children's Hospital Critical Care:

- Robert Clark; Michael Wolf

Cornell:

- Jim Antaki

Neurology:

- Marcelo Rocha

Psychology:

- Marlene Behrmann
- Anna Fisher, Erik Thiessen

Hematology/Oncology:

- Enrico Novelli

BME/CMU: Adam Feinberg
Matthew Smith

DARPA
NIH
NIBIB
American Heart Association | American Stroke Association
AFOSR AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Pittsburgh Health Data Alliance
Carnegie Mellon University | University of Pittsburgh | UPMC
Center for Machine Learning and Health
Carnegie Mellon University
PA
Office of Naval Research
ONR
Science & Technology
Manufacturing Futures Initiative
The Digital Transformation of Manufacturing