



# Optical Neuroimaging

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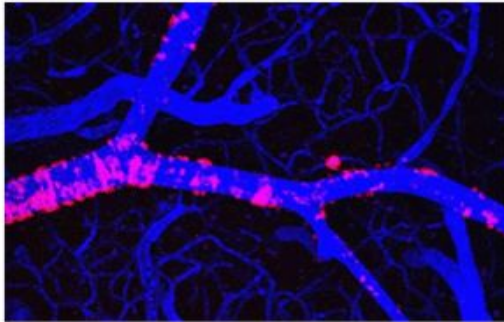
*NEUR 4330*

*Dr. Dhamala*

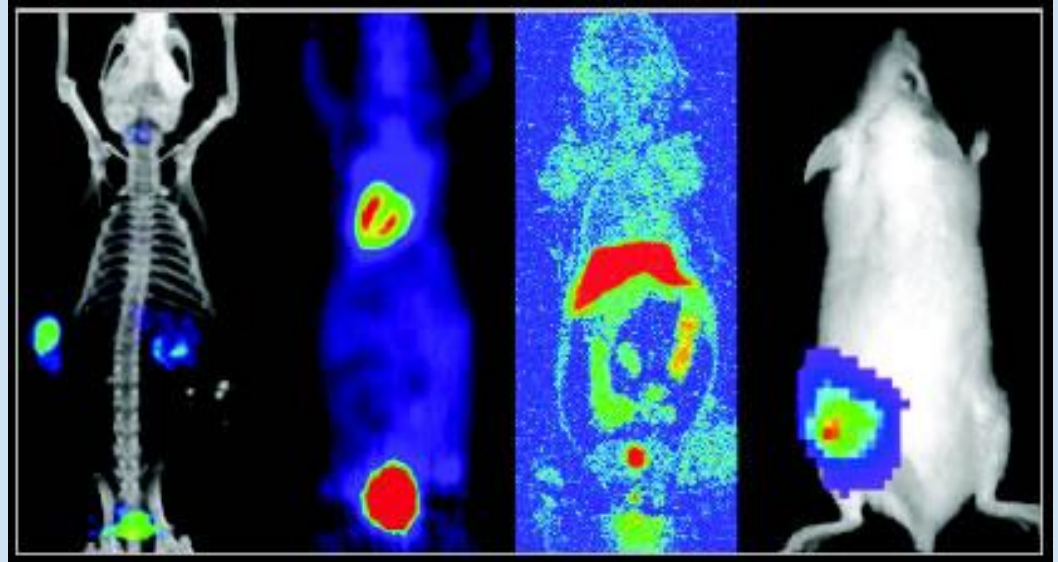
*7 December 2016*

# What is Optical Neuroimaging?

- Uses different techniques that implement light to retrieve images from the body.
- Inside and outside the body
- Tissues and organs

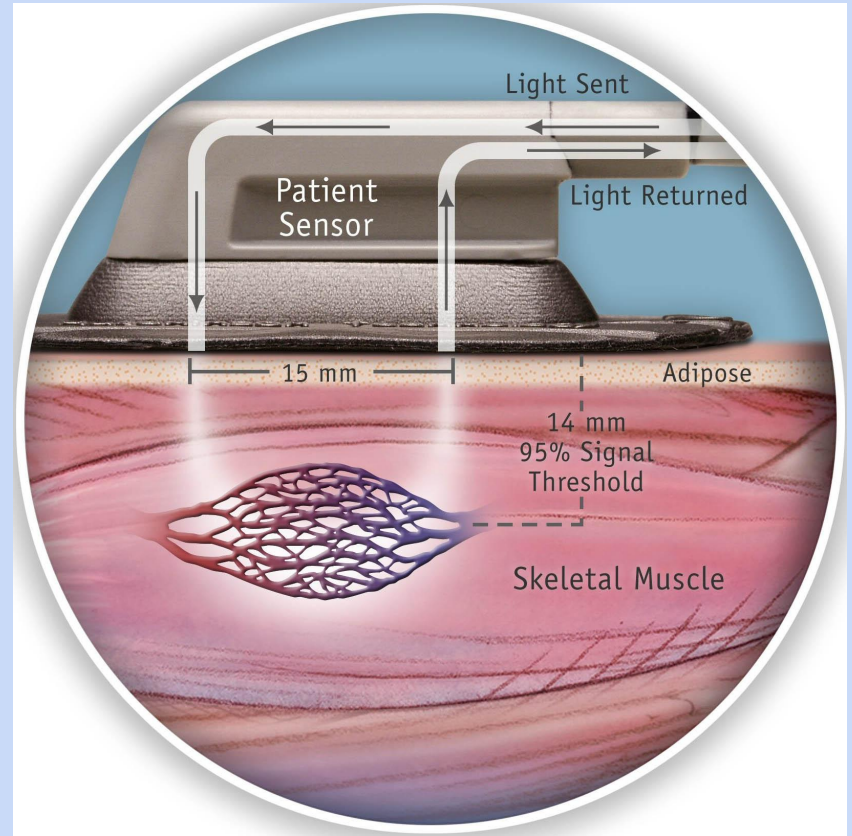


Optical imaging of amyloid deposits (red) in living mouse brain blood vessels in a mouse model of Alzheimer's Disease. *Garcia-Alloza et al., J. Neurochem., 2007.*

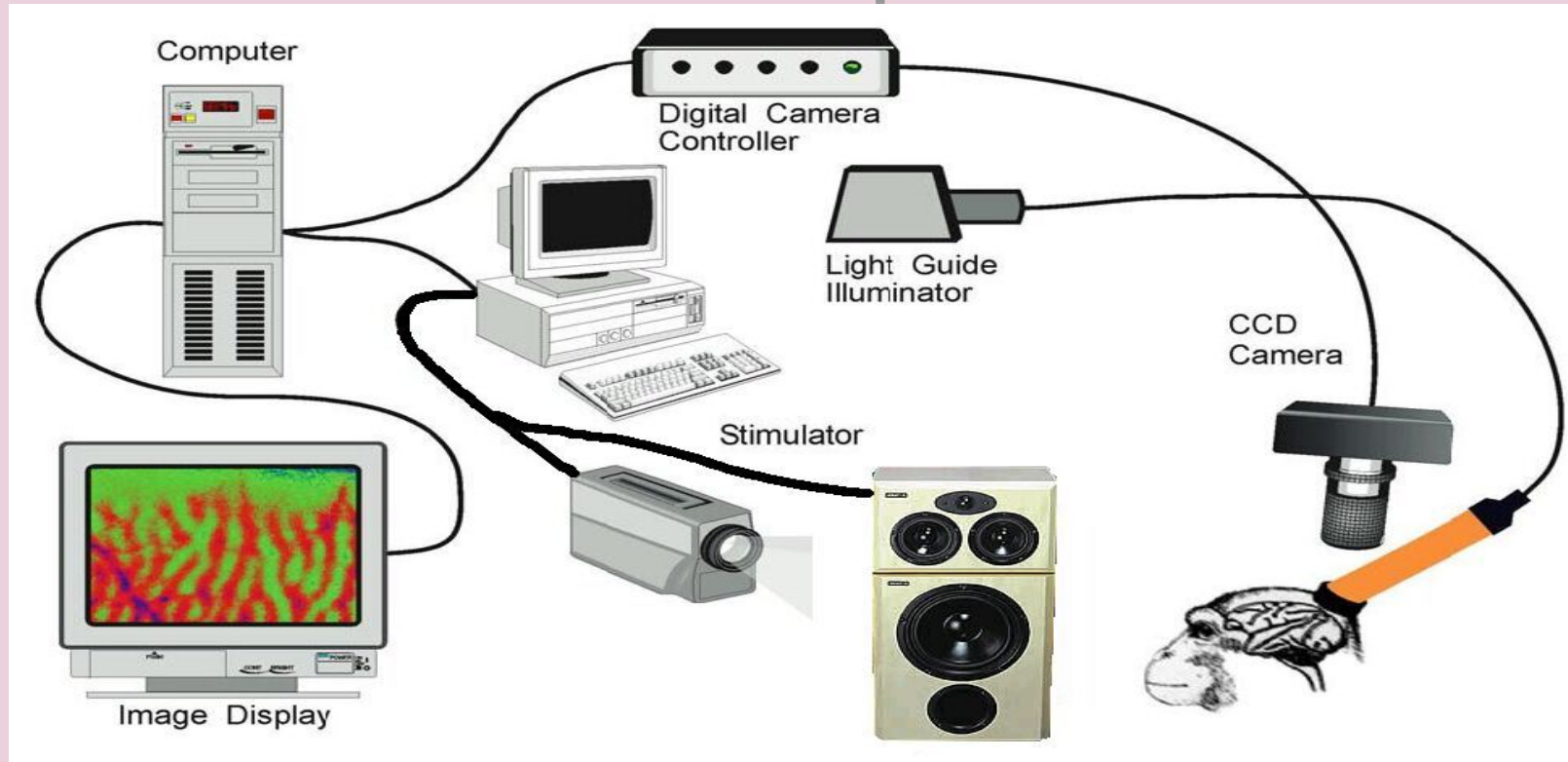


# How does this work?

- ❖ Fiber optic cables shine IR light onto scalp.
- ❖ Light only goes down about 1 cm into brain.
  - Goes deeper when cells are active
- ❖ Light is reflected back.
- ❖ Measures activity on outside of brain.
- ❖ Time for light to travel from source to light detector depends on level of brain activity.
- ❖ Can determine where and when activity is happening.



# Conventional Optical Imaging Device Setup



# Advantages and Limitations of Optical Imaging



## Advantages

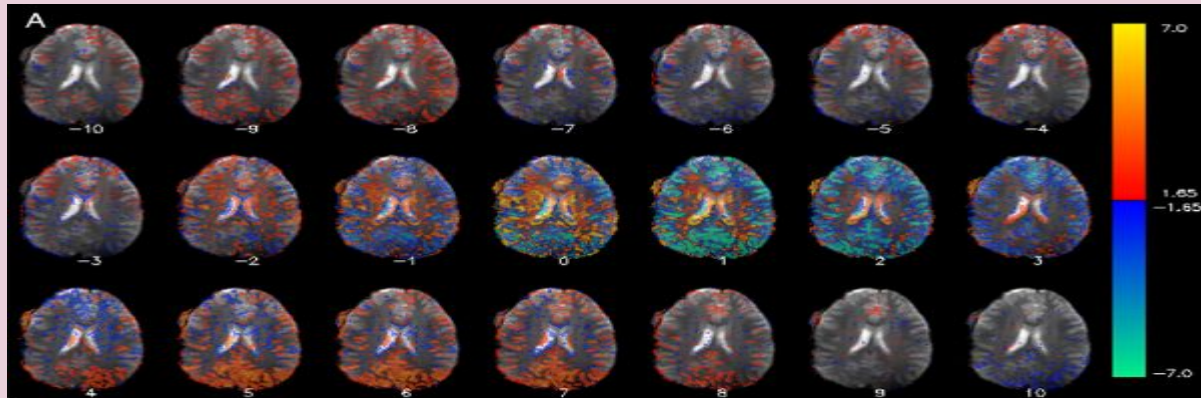
- ❖ No harmful radiation
- ❖ Significantly faster than other techniques
- ❖ Can be used for extensive periods of time in the monitoring of diseases and/or their treatments
- ❖ Non-invasive
- ❖ Soft tissue visualization
- ❖ Can be combined with MRI and X-rays
- ❖ Can measure many different properties of an organ or tissue at the same time
- ❖ Subject can move in comparison of fMRI
- ❖ Not much noise compared to fMRI
- ❖ Cheaper than fMRI

## Disadvantages

- ❖ Can only see cortical region of the brain (~4 cm)
- ❖ Low spatial resolution (~1cm)
- ❖ Needs EEG in order to diagnose

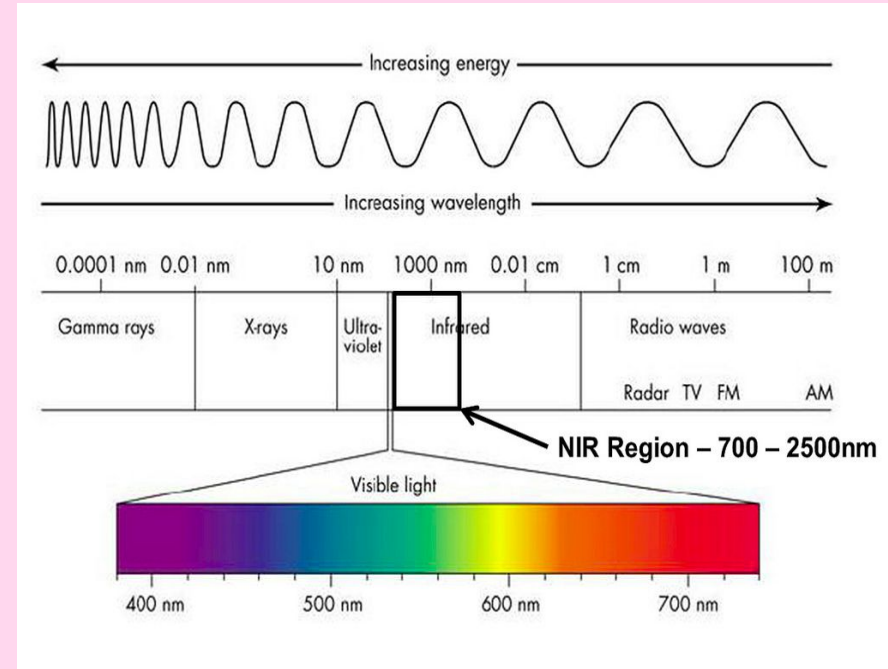
# Limitations of fMRI

- ❖ Extremely rigid stabilization of the head.
- ❖ High magnetic fields and rapid RF gradients. Hence need more precaution.
- ❖ High intensity acoustic environment.
- ❖ Highly propensity for movement artifacts.
- ❖ Very difficult for infant to stabilize and have successful fMRI.



# Near Infrared Spectroscopy (NIRS)

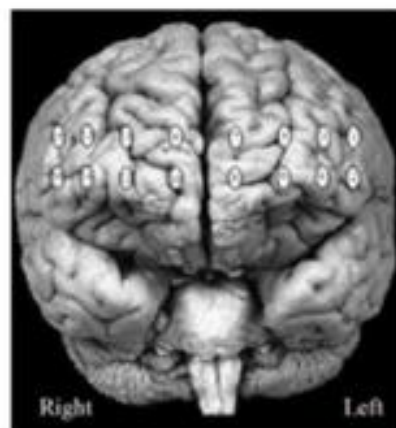
- ❖ Spectroscopy
  - study of measurement and investigation of spectra produced when electromagnetic radiation interact with matter.
- ❖ Near infrared spectroscopy
  - studies the interaction of near infrared radiation with matter.
- ❖ Where is the near infrared region in electromagnetic spectrum?



# fNIR



- ❖ Measures neural activity and hemodynamic response in **prefrontal cortex**.
- ❖ IR sensor is worn on forehead that includes four IR light sources and ten detectors mounted in a flexible band.
- ❖ fNIR sensor detects oxygen level changes in the prefrontal cortex
- ❖ Provides real time values for oxy-hemoglobin and deoxygenated haemoglobin blood.
- ❖ Provides a continuous and real time display of oxygen changes as the subject performs different tasks.
- ❖ These data are combined with other physiological variables such as EEG, respiration, cardiac output, blood pressure, electrodermal activity and stimulus marker. Hence detailed assessment of subject is possible



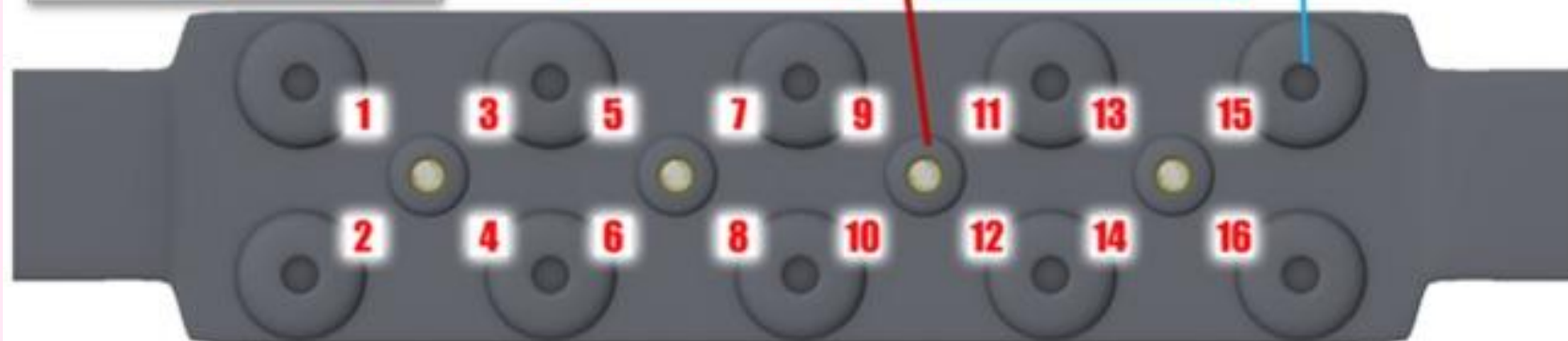
Computer running  
COBI Studio  
(Data acquisition  
and visualization)



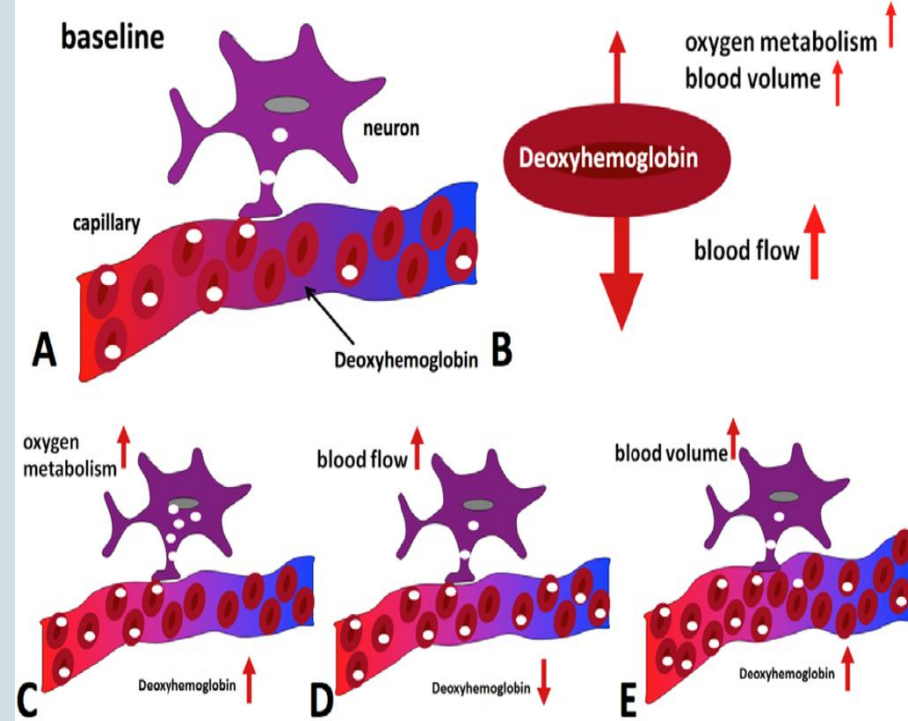
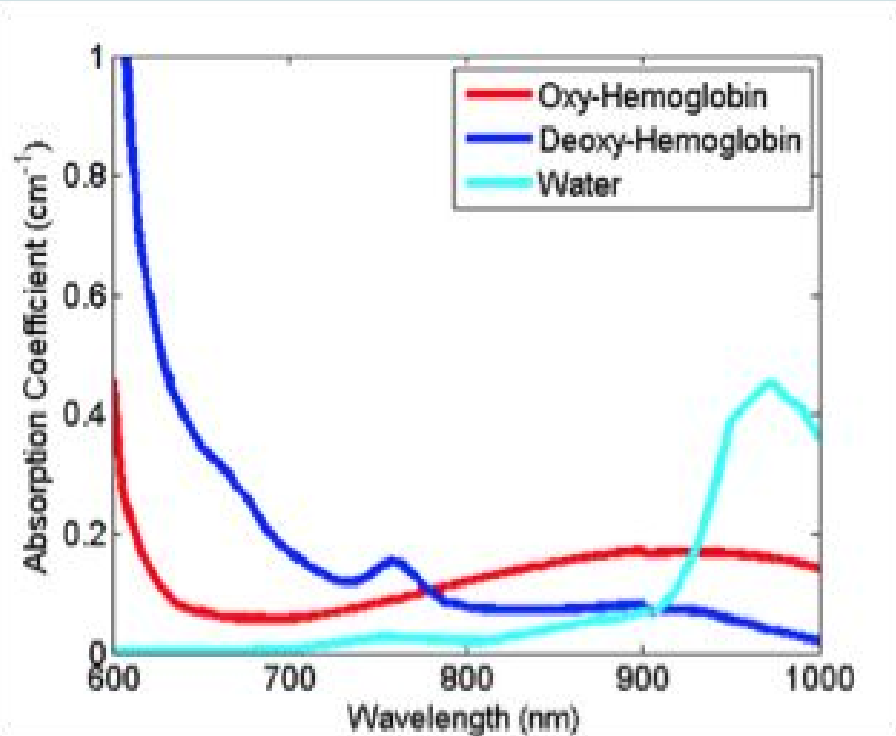
Control Box

Light Sources  
(4 LEDs)

Light Detectors  
(10 Photodetectors)



# Role of Oxyhemoglobin & Deoxyhemoglobin



# Modified Beer-Lambert Law

- ❖ This is the basis of continuous wave near infrared tissue spectroscopy(cwNIRS)
- ❖ This law states that the change in light attenuation is proportional to the changes in the concentration of tissue chromophores (responsible for color), mainly oxy- and deoxyhaemoglobin
- ❖ If attenuation changes are measured at two or more wavelengths, concentration changes can be calculated.
- ❖ Modified Beer- Lambert Law for Homogenous and Heterogeneous media

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4242038/>

$$\Delta OD_{DCS}(\tau, \rho) = -\log \left( \frac{g_2(\tau, \rho) - 1}{g_0^2(\tau, \rho) - 1} \right) \\ \approx d_F(\tau, \rho) \Delta F + d_a(\tau, \rho) \Delta \mu_a + d_s(\tau, \rho) \Delta \mu'_s.$$

$$-\log \left( \frac{g_2(\tau, \rho) - 1}{g_0^2(\tau, \rho) - 1} \right) \approx \\ \sum_{k=1}^N \left[ d_{F,k}(\tau, \rho) \Delta F_k + d_{a,k}(\tau, \rho) \Delta \mu_{a,k} \right. \\ \left. + d_{s,k}(\tau, \rho) \Delta \mu'_{s,k} \right],$$

# Properties and Resolution

- ❖ Temporal resolution of 500 ms (EEG- 1ms/ fMRI- 1s) with 2.5cm source detector separation with 1.25cm penetration depth and 16 measurement locations
- ❖ Usually monitor dorsal and inferior frontal cortical areas
- ❖ Light emitting diode (LEDs) are activated one light source at a time and four photodetectors around the active source are sampled.
- ❖ Usually data acquisition and visualization are done using COBI (Cognitive Optical Brain Imaging) studio software ( Ayaz et. al 2011).
  - Allows for calculations to be done
  - Raw vs processed data options
  - ACOBI (analysis for cognitive optical brain imaging studio)
    - - allows for post-processing interaction with fNIR data

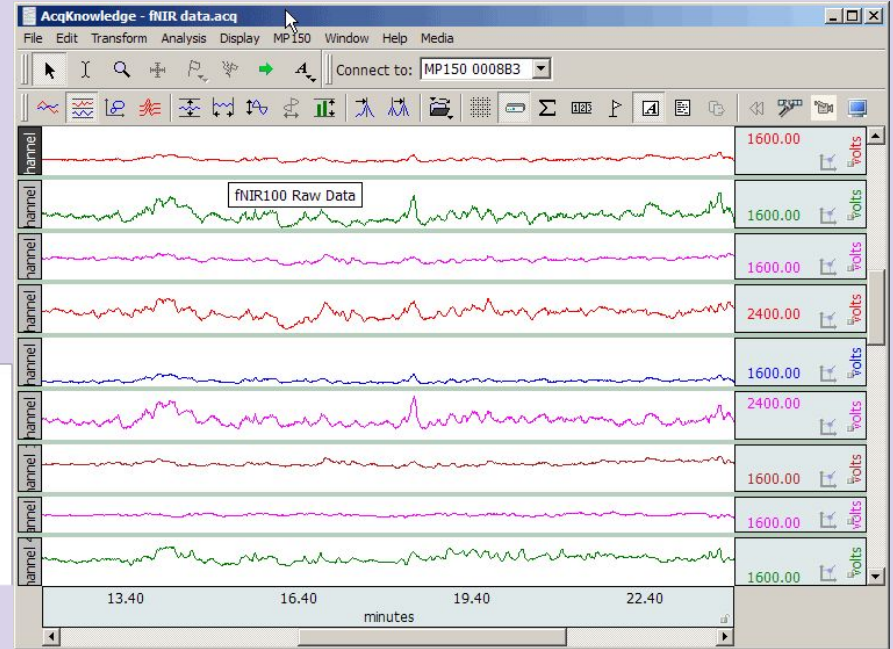
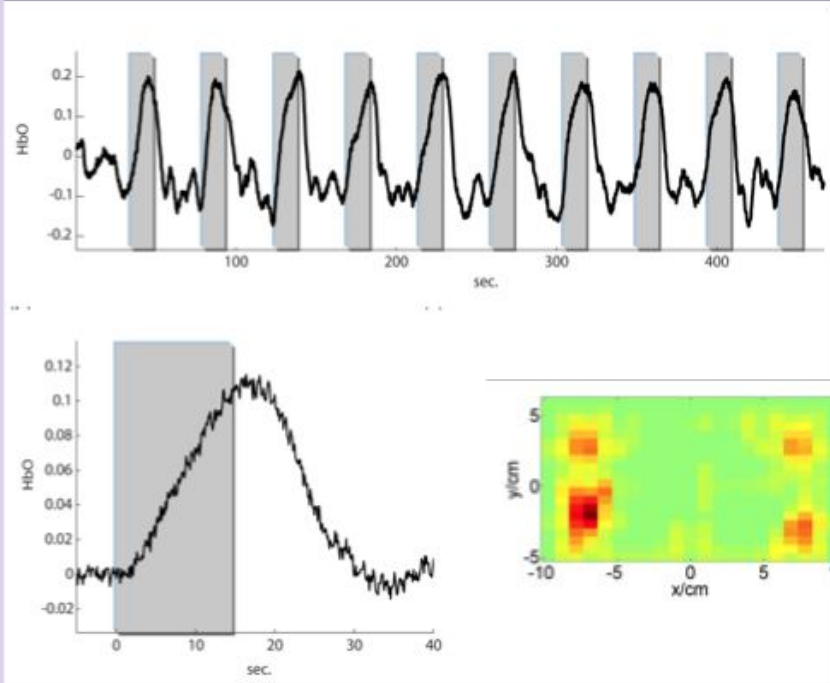
# fNIR Application Area

- ❖ Human performance assessment
- ❖ Depth of Anesthesia Monitoring
- ❖ Pain assessment
- ❖ Brain computer interface
- ❖ Neurorehabilitation
- ❖ Autism
- ❖ Credibility assessment (Lie Detector)

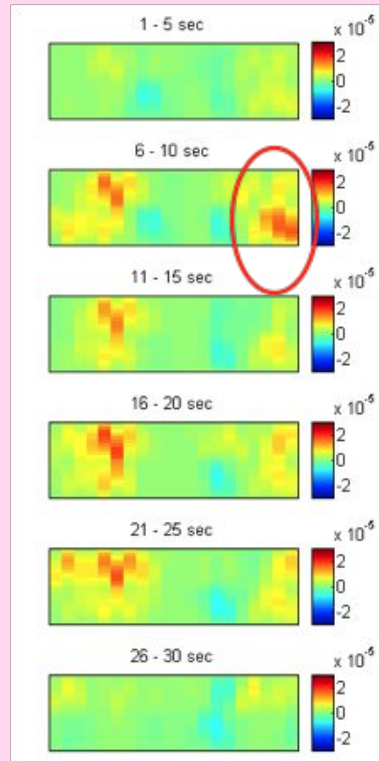
Further applications:

- ❖ Monitoring brain plasticity during rehabilitation in children with cerebral palsy (CP)
- ❖ Brain activation while playing games
- ❖ Continuous bedside monitoring of brain health in traumatic brain injury
- ❖ Real time guidance for treatment optimization in stroke

# How Data Typically Appears in fNIR



# How Data Typically Appears in fNIR cont...



Right finger tapping

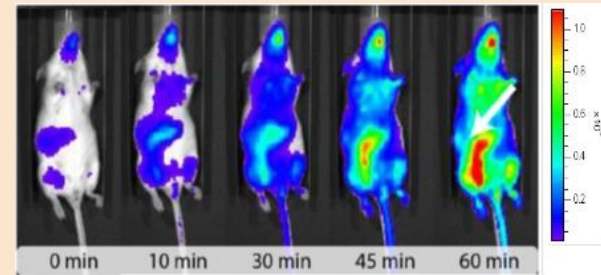
# Optical Imaging Methods

## ❖ Fluorescence Imaging

- Uses endogenous/ exogenous molecules that emits light when activated by an external light source (i.e, laser).
  - Has to be of appropriate wavelength used to excite a target molecule, which then fluoresces by releasing longer-wavelengths (lower energy light).

## ❖ Bioluminescent Imaging (BLI)

- Uses a natural light-emitting protein (i.e luciferase) to trace the movement of certain cells or to identify the location of certain chemicals in the body.
  - Gene Expression
  - Therapeutic monitoring



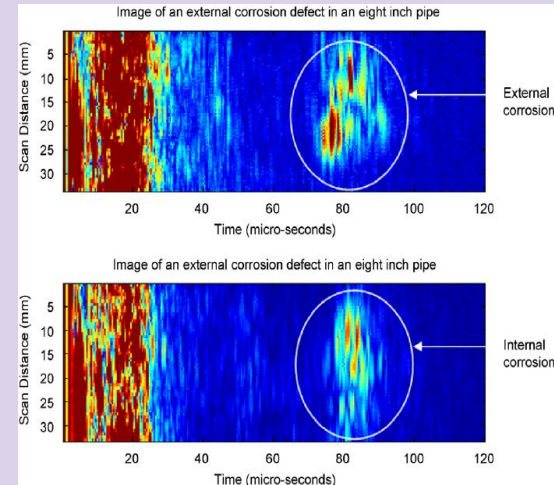
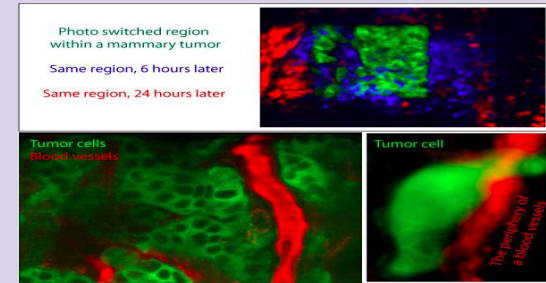
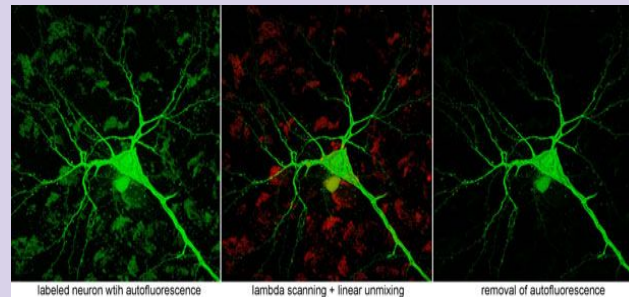
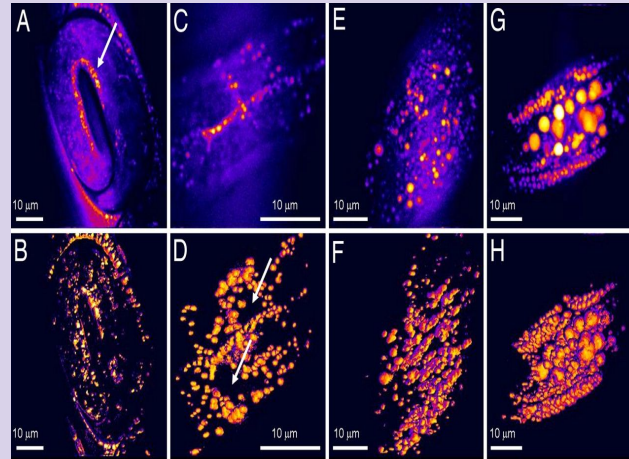
# Other Types of Imaging Techniques & How It Compares to the Conventional Method

- **Diffuse Optical Imaging (DOT):** Based on diffusing light that penetrates certain tissues at multiple projections producing a tomographic image or images. Often uses an array of lasers and detectors in multi-geometric configurations around the image.
- **Diffuse Optical Spectroscopy (DOS):** Combines multi-frequency intensity-modulated and continuous-wave near infrared light to absorb and scatter the spectra of 650 to 1000 nm. It is a useful for quantitative analysis of tissue chromophore, concentrations of oxyhemoglobin, deoxyhemoglobin, methemoglobin, water and lipids.
- **Confocal Microscopy:** Describes a method that has structures in the focal plane as visible and structures on the outside as more hidden. The scanning of the focal plane through the object produced into a collection of 3D microscopic sets. It is also said to be more useful than conventional optical imaging techniques because it easier to control the depth of the field, eliminate image degrading of out-of-focus information and the ability to collect serial optical sections of thick sections.

# Other Types of Optical Imaging Techniques cont...

## Honorable Mentions...

- ❖ Coherent anti-Stokes Raman scattering (CARS)
- ❖ Surface-weighted imaging
- ❖ Phase-array detection
- ❖ Multiphoton imaging
- ❖ Intravital microscopy

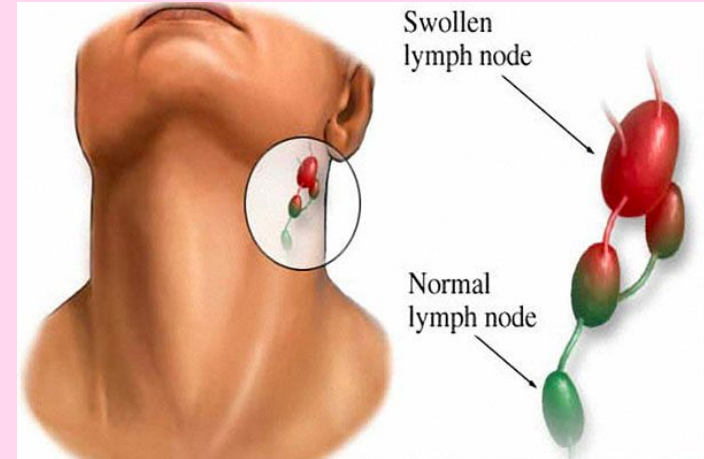
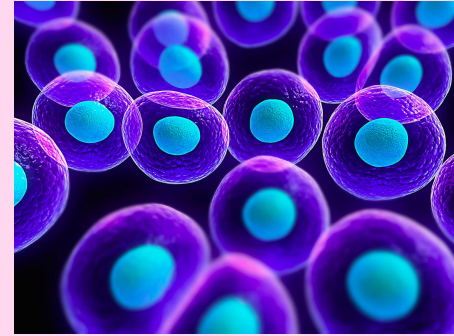
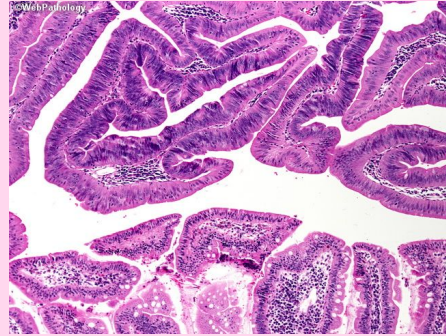


# Overview of the Types of Research Involved

- ❖ Largely used in animal & in vitro models.
- ❖ Clinical uses are also on the rise
  - possibility of endoscopic evaluation
  - study of gynecologic malignancies (i.e. the colon or the heart).
- ❖ Optical molecular imaging techniques are necessary for studying small animal models specifically.

# Clinical Applications

- ❖ fNIRs for Cerebral Palsy
- ❖ Intraoperative scanning
- ❖ Stem cell trafficking
- ❖ Monitoring treatment response
- ❖ For the detection of:
  - Cancer
  - Superficial malignant skin lesions
  - Lymphoma
  - Intestinal adenoma



# A Case Study

- ❖ Infant with distal arthrogryposis and bilateral frontal cortical dysplasia
- ❖ Too much amniotic fluid in womb (polyhydramnios) caused encephalographic seizures
- ❖ fMRI, EEG, and NIRS implemented to diagnose and monitor seizures
- ❖ NIRS showed significant rSO<sub>2</sub> fluctuations (regional saturation of oxygen)
- ❖ Good correlation between seizures and NIRS fluctuations
- ❖ Conclusion: NIRS is effective in monitoring of seizures
  - Effective, easy to interpret, reliable method
- ❖ Limitations:
  - Diagnosis of seizures relies upon EEG
  - Need EEG to localize where to place NIRS pads
  - Not enough published data



# New Optical Imaging Techniques that are Under Development

- ❖ **New molecular probes and nanomaterials including:**
  - Imaging probes based on near-infrared fluorescence that detect lesions a few cm deep into tissue.
  - Contrast agents targeted to specific areas.
  - Tissue-specific multi-modal imaging molecules (typically used in hybrid imaging systems)
  - Quantum dots or fluorescent nanoparticles that emit light when exposed to UV light.
    - Used in treating cancer and other cancers.
- ❖ **Dynamic mapping of cellular transformations at the molecular level**
  - Provides a visual image of the dynamics of proteins, DNA, RNA & lipids during cell disintegration.
- ❖ **Photoablation therapy**
  - Gold nanospheres are heated with near- infrared light to treat melanoma.
- ❖ **Use of diffuse optical tomography to distinguish malignant from benign breast lesions**
  - Photodynamic therapy
  - Photoacoustic tomography or laser-induced ultrasound

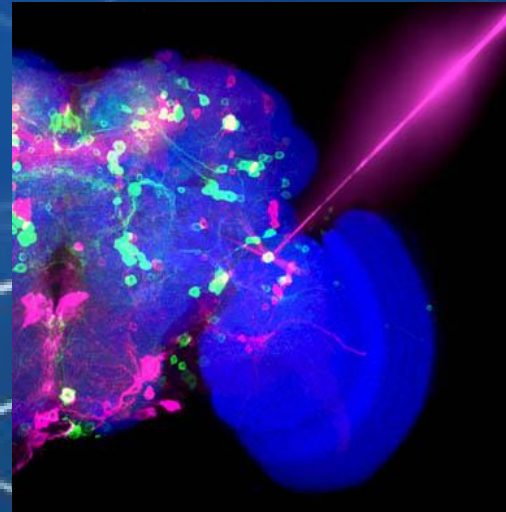


# Future Directions

- ❖ Optogenetics- A new field of neuroscience with possibilities of altering memories using light
  - Creating false memories
  - Deleting memories

- ❖ Using optical imaging

<http://jn.physiology.org/content/110/6/1455.long>



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Questions? Comments?

