Guidance for Skullbase Surgery

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Project Statement

Our Goal:
Improve accuracy using **intra-operative sensing/imaging** so as to **protect critical structures** during drilling, particularly in **children**

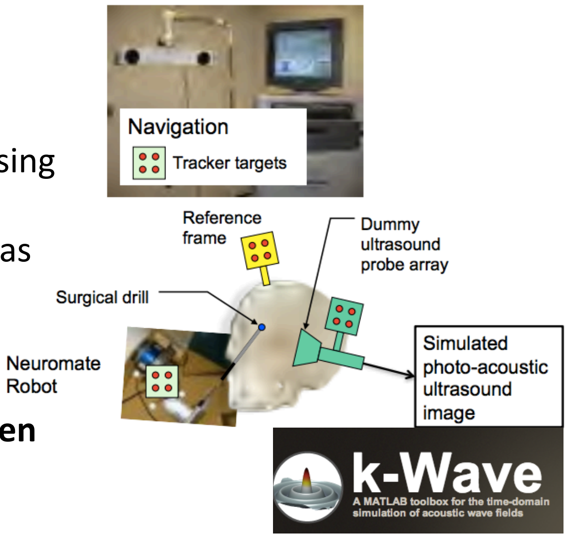

Image source: Dr. Kazanzides

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Paper

Noninvasive reflection mode photoacoustic imaging through infant skull toward imaging of neonatal brains

Xueding Wang, David L. Chamberland, Guohua Xi

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Problem Statement

- It is important to monitor both **morphological and functional information** of infant brains
- With **high sensitivity**, **high spatial resolution**
- In a manner that is **convenient, continuous**, **non-invasive, fast** and **inexpensive**
- Conventional optical imaging is desirable because of its **sensitivity** but limited by its **low spatial resolution**

Goal

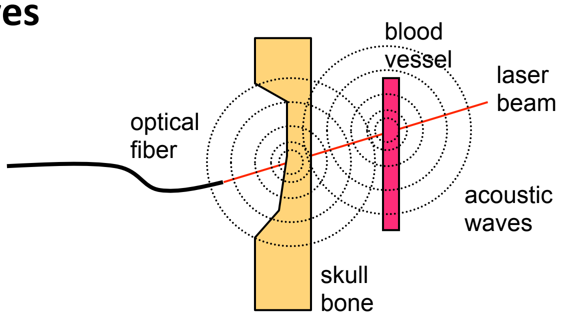
- Study the **feasibility** of morphological and functional imaging of an infant skull using **reflection-mode photoacoustic imaging**
  - Examine the **quality** of the photoacoustic signals and images from imaging an infant skull

Key Results

- Reflection mode photo-acoustic imaging **exhibits great potential** for performing **high quality imaging** of neo-natal brains
- Lateral resolution: 420 μm
- Axial resolution: 50 μm
- Depth: at least 21mm beneath the infant skull

Background: Photoacoustic Imaging

- Non-ionizing **laser** pulses
- **Absorption** of light energy causes **thermoelastic expansion**, generating **ultrasonic waves**
- **Ultrasonic transducers** measure the signal



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Background: Photoacoustic Imaging

Advantages

- **Optical absorption contrast:** PAI intrinsically sensitive to blood vessels
- Non-invasive, non-ionizing, low-cost
- **Spatial resolution not limited** by optical diffusion or photon scattering
- Ultrasound waves travel one way

Drawbacks

- The **skull bone** attenuates **light**
- Also attenuates and distorts **acoustic signals**
- Problem in **adult skulls**
- However, **infant skulls** are very thin (~1.3mm)

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Materials: Phantoms

- **Newborn infant skull**: 7cm by 9cm dimensions, 0.6-0.9mm thickness
- **Simulated vessel** embedded in skull: 50μm transparent tubing with fresh whole dog blood
- **Fresh canine brain** 6cm by 6cm by 4cm OR **gel phantom**: 10% porcine gel with whole milk

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Materials: Imaging System

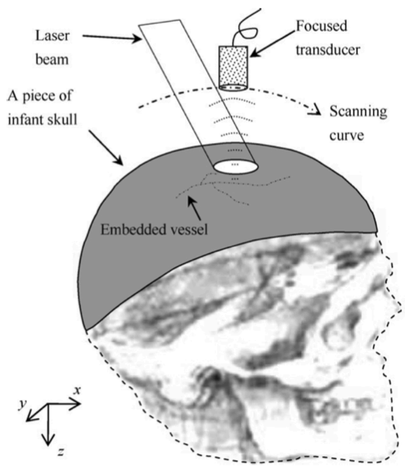

Fig. 1. Geometry of reflection mode transcranial photoacoustic imaging of brain.

Pulsed Laser
Tunable wavelength: 680nm to 950nm,
Repetition rate: 10Hz,
Pulse width: 5.5ns,
Incident energy density: 15mJ/cm^2,
Incident diameter: 13mm

↓ Wideband focused ultrasonic transducer

↓ Pre-amplifier

↓ Oscilloscope

↓ Computer

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Materials: Imaging System

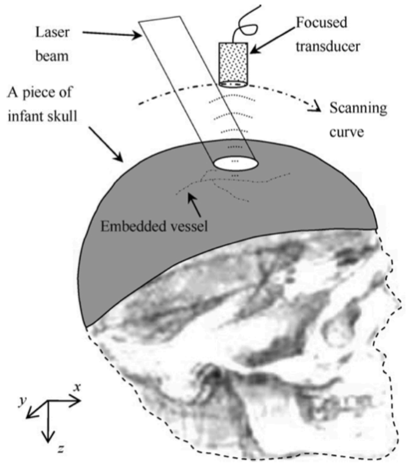

Fig. 1. Geometry of reflection mode transcranial photoacoustic imaging of brain.

- Reflection mode transcranial photoacoustic imaging

A-line
↓ Arc along curvature of skull
2D B-scan
↓ Along surface of skull
3D Volumetric Image

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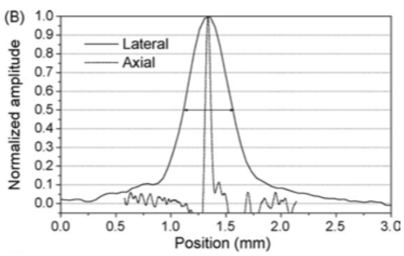
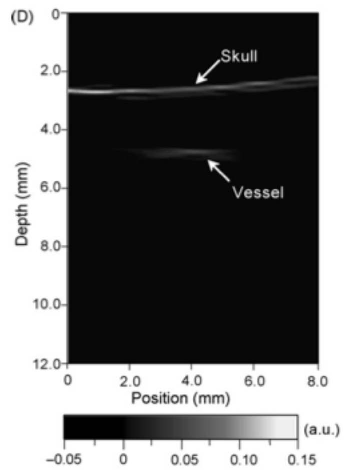
Results: Spatial Resolution

Good contrast-to-noise ratio

For the V311 transducer

- **Lateral resolution**: 420 µm
- **Axial resolution:** 50 µm





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Results: Ultrasound and light attenuation by the skull

Applicable to infant skulls

- **Low ultrasound attenuation** of infant skull
- **60-70%** of light transmitted through infant skull

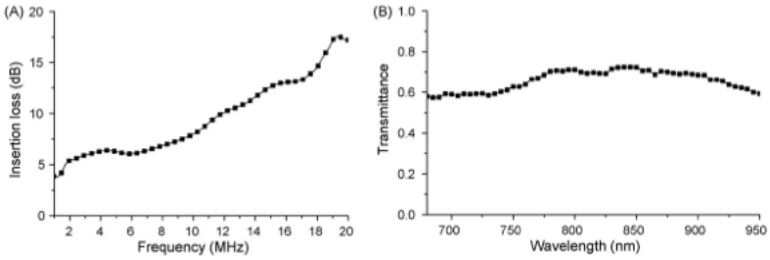

Fig. 3. (A) Frequency-dependent ultrasound insertion loss of the infant skull. (B) Wavelength-dependent light transmittance through the infant skull.

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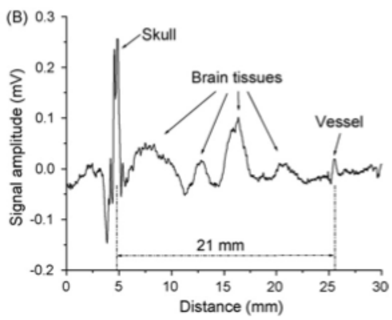
Results: Imaging Depth

Able to image **significant section** of neonatal brain

- Strong signals from **skull bone** as well as **brain tissues**
- Signal from the vessel still clearly recognizable at depth of **21mm**



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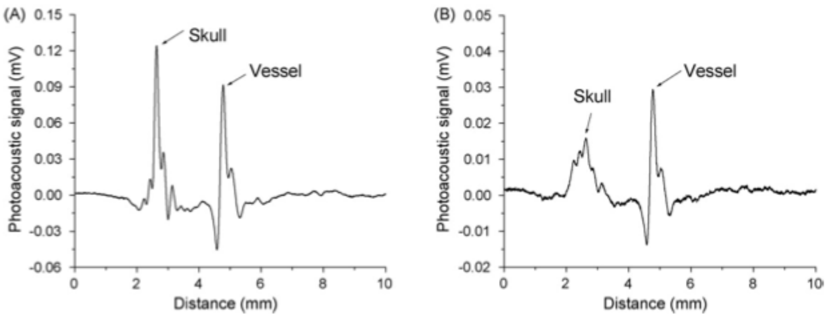
Results: Dark-field Illumination

Dark-field illumination can **improve imaging**

- Light beam in a dark-field is **ring-shaped**
- Photoacoustic signals from the surface of the skull are **suppressed**



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Results: C-scan imaging

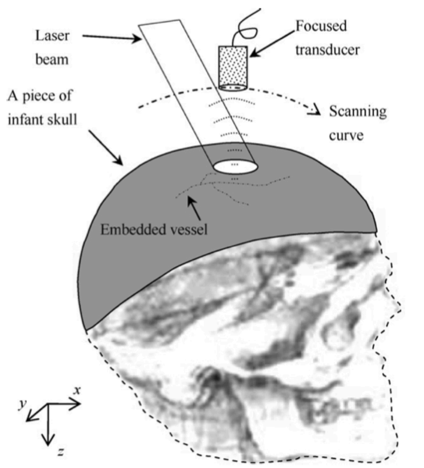

Fig. 1. Geometry of reflection mode transcranial photoacoustic imaging of brain.

- Three vessels embedded along the x-y plane
- 72 48μm steps along x-axis
- 43 50μm steps along y-axis
- C-scan images can be presented at different depths

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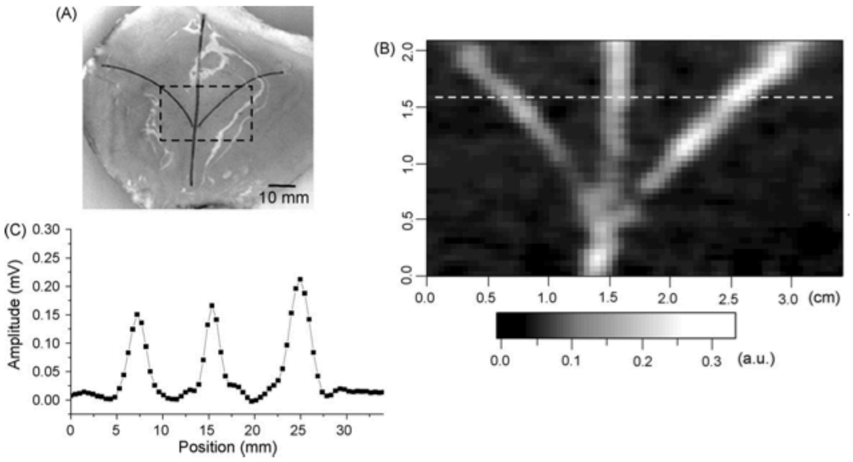
Results: Functional measurement



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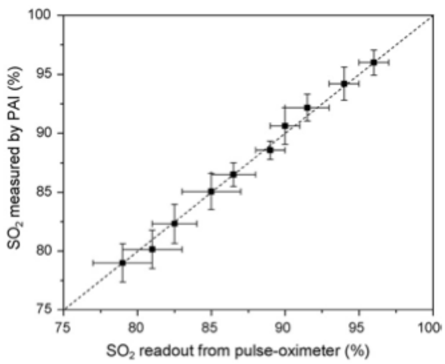
Results: Functional imaging



- Accurate measurement of **blood oxygenation level** through infant skull
- **Soft tissues** significantly influence wavelength

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Good points

- Developed a system that demonstrates why PAI could be a **powerful tool for noninvasive diagnosis**
  - Results from spatial resolution: Proof of **high-quality, high-resolution** images
  - Results from ultrasound/light attenuation and distortion: Particularly for **neonatal skulls**
  - Results from functional imaging: Possible to **determine and localize changes** in blood volume and oxygen

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Relevance to our Project

- Provides **motivation** to our project: Why use PAI in skull base surgery?
  - **High optical contrast:** Clearly discriminates between skull, brain tissue, blood vessel
  - **2D, 3D visualization** of vasculature
- Description of imaging system and phantom design that could be adapted for both **experimental and simulation design**

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Relevance to our Project

- Highlights possible **challenges** for our project
  - **Attenuation of acoustic signals** by skull and brain tissues
  - **Low temporal resolution** for 2D and 3D scans
- Differences from our project:
  - Skull of a **child**, not necessarily neo-natal
  - **Negligible light attenuation**
  - Carotid artery is embedded further into skull

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Limitations of the Study

- Measurements of resolution are in **optimal conditions** – how about in **actual use**?
  - Vessel placed at focal distance of transducer
  - Acoustic beam for signal detection through the center of the light beam
  - **Possible variance** in resolution?

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Limitations of the Study

- Effect of **skull thickness** on attenuation of acoustic signal
  - What is the maximum skull thickness?
  - How much is the acoustic signal attenuated with growing thickness?
- Single vessel, or vessel along plane

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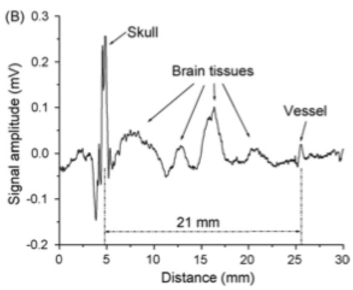
Limitations of the Study

Results: **Imaging Depth**



Results: **Functional Imaging**

- How to **confidently identify signal of vessel** with noise from brain tissues present?
- Particularly at greater depth than 21mm?
- Max imaging depth?

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Future Work

- Use in a **non-optimal setting**
- Determine **maximum depth**
- Determine **maximum skull thickness**
- Modify system to improve **temporal resolution**
- **Incorporation of other conventional imaging modalities** for e.g. functional imaging

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Future Work

- Demonstrate **high sensitivity** to morphological and functional changes with respect to presentation of a disease for e.g. hypoxic-ischemia
- Use in a **clinical setting**

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Conclusion

- PAI is a promising new technology for **non-invasive diagnosis and monitoring of neonatal brain disorders**
- PAI is a **relevant tool for our project** and could potentially be used to improve the accuracy of skull base surgery in children

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Questions?

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