Guidance for Skullbase Surgery

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Team 10: Grace Yeo and Allen Zhu
Checkpoint Presentation
Mentors: Peter Kazanzides, Muyinatu Bell

Outline of Presentation

- Project Summary
- Project Plan: Updates and Changes
- Progress
  - Phantom Design
  - k-Wave Simulations
  - Experimental Design and Set-Up
  - Software Design
- Deliverables
- Dependencies

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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**

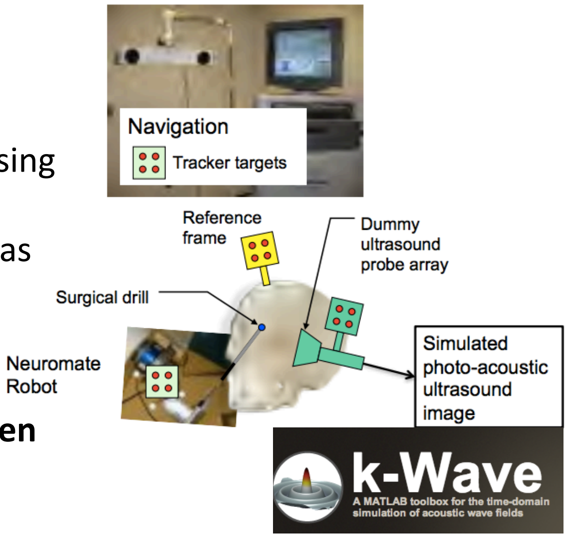

Image source: Dr. Kazanzides

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Approach

Sensing and control to reduce model registration uncertainty

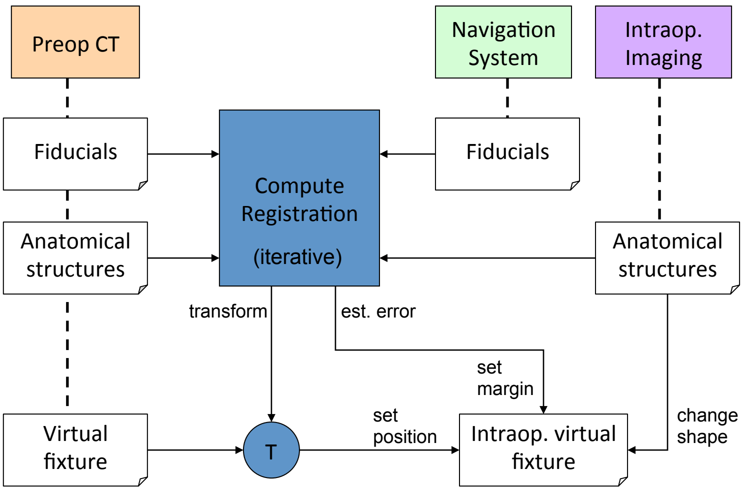

Image source: Dr. Kazanzides

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Project Plan: Updates

		February			March				April				May		
		2	3	4	1	2	3	4	1	2	3	4	1	2	3
PHASE 1: PLANNING AND BACKGROUND															
Literature Review	✔														
Project Planning	✔														
Photoacoustic Imaging Tutorial	✔														
K-wave Tutorial	✔														
PHASE 2: DESIGN, SET-UP, SIMULATIONS															
Experimental Design	✔														
Phantom Design	✔														
Experimental Set-Up	✔														
Build Phantom/CT Scan of Phantom	In Progress														
K-wave Simulations	In Progress														
Registration Software Design **(March 31)**	✔														
PHASE 3: SOFTWARE, EXPERIMENTATION, DATA ANALYSIS															
Registration Software Implementation	In Progress														
Registration Software Debugging	In Progress														
Experiments on Simple Phantom (I)	Allen														
Data Analysis (I) **(April 14)**	Both														
PHASE 4: EXTENSION, FINAL REPORT AND PRESENTATION															
Integration of Neuromate	Allen														
Experimental Set-Up	Grace														
Experiments on Simple Phantom (II)	Both														
Data Analysis (II)	Both														
Final Report	Both														
Final Presentation **(May 13)**	Both														
Documentation	Both														

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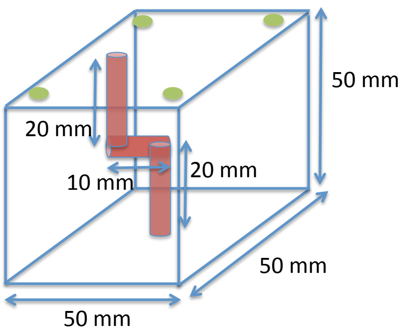
Progress: Phase 2 – Phantom Design



- Simple phantom to demonstrate proof of concept
- Materials: cardboard and plastic/rubber tubing
- Front face of cardboard box is open
- Diameter of plastic/ rubber tubing is 5 mm
- Four fiducials at each corner of the box
- Budget: negligible

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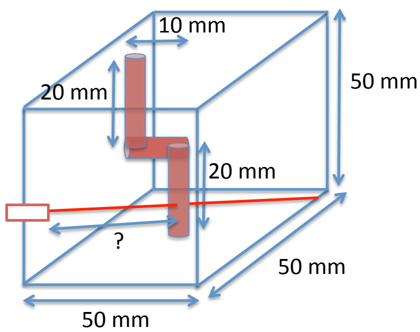
Progress: Phase 2 – k-Wave Simulations

Part 1: Segmentation and Intersection

- **Manual segmentation** of carotid artery in 3D Slicer
  - Thresholding
  - Output .vtk
- **Model path of laser and surface of segmented artery** to find intersection using VTK
  - Did the path of the laser intersect with the artery?
  - If yes, what is the distance from the laser to the artery?



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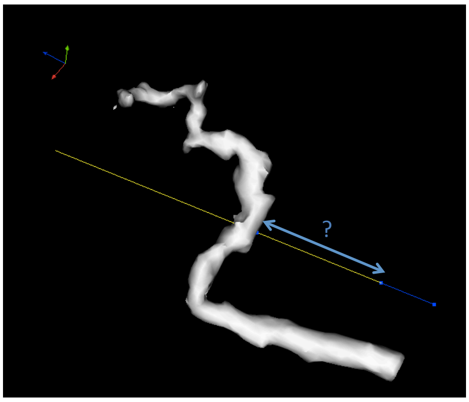
Progress: Phase 2 – k-Wave Simulations

Part 1: Segmentation and Intersection

- Position of carotid artery and laser in CT coordinates
- Simple model of **laser path as a ray** parallel to the line that is formed by the tool tip and the tool hind
- Surface of carotid artery represented in BBox tree for fast intersection computation
- **Calculate distance** between tool tip and **first point** of intersection with segmented surface



Source: Manual segmentation of ICA using example data in 3D slicer

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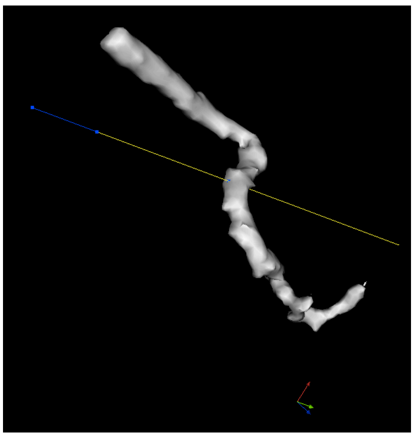
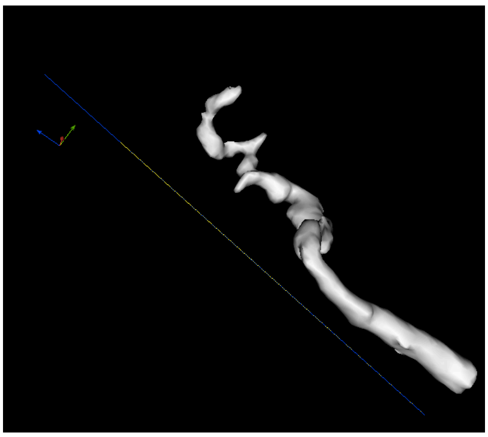
Progress: Phase 2 – k-Wave Simulations





Source: Manual segmentation of ICA using example data in 3D slicer

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Progress: Phase 2 – k-Wave Simulations

Part 2: k-Wave simulation photo-acoustic wave fields

Inputs to kspaceFirstOrder3D

- **Computational grid**
  - 5 x 5 x 5 cm
  - dx = 0.1mm
  - 500 x 500 x 500 grid points
- **Medium properties**
  - Speed of sound in tissue = 1550m/s
- **Initial pressure source**
  - From simulation in Part 1 in CT space convert to grid coordinates
- **Position of sensor**
  - In CT space convert to grid coordinates

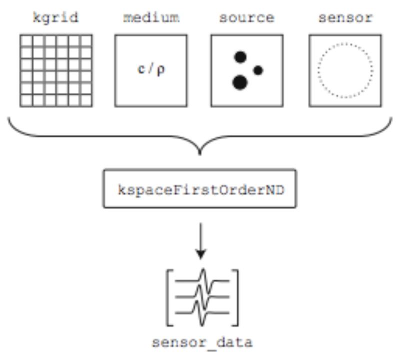

Fig. 2 Schematic of the architecture of the simulation functions within the k-Wave toolbox that are based on coupled first-order acoustic equations for heterogeneous media.

Source: Treeby et al. k-Wave: MATLAB toolbox for the simulation and reconstruction of photoacoustic wave fields

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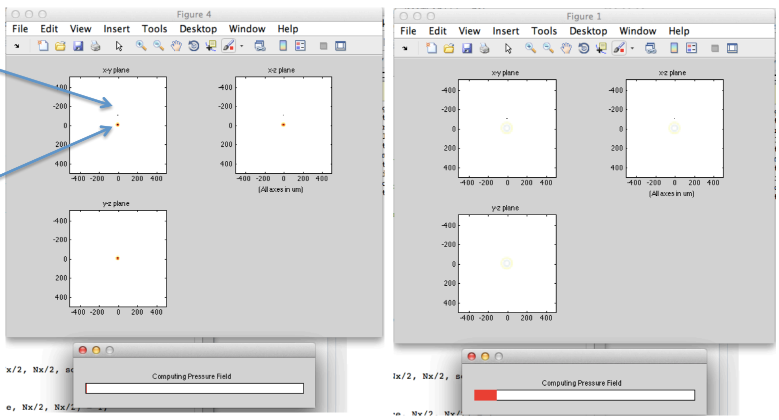
Progress: Phase 2 – k-Wave Simulations

Part 2: k-Wave

Position of sensor

Position of point source



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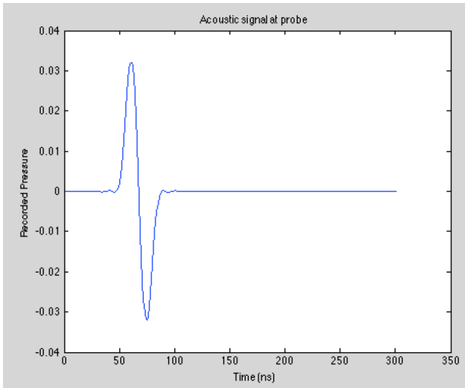
Progress: Phase 2 – k-Wave Simulations

Part 2: k-Wave

- Calculate distance based on peak of acoustic waveform detected at position of probe
- **Takes into account acoustic attenuation but not light scattering**
- **Disadvantage: Computationally intensive** – Cannot do visualization and experiments in real-time
- **Advantage: Possibility of 2D or 3D visualization**

Alternative: Report known distance



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Software and Experimental Setup

- CT scan of phantom
- Manual segmentation of artery to generate surface model
- Fiducials will give paired points with StealthStation
- Register CT Image to StealthStation
- This transformation will be treated as "actual"
- Introduce artificial error in CT to StealthStation transformation (incorrect frame)
- Use "laser" to find distance between tip and artery surface model in the actual frame
- Run ICP algorithm to transform those points to the surface model in incorrect frame (fixed transformation)
- **Compare error values from fixed transformation with actual transformation**

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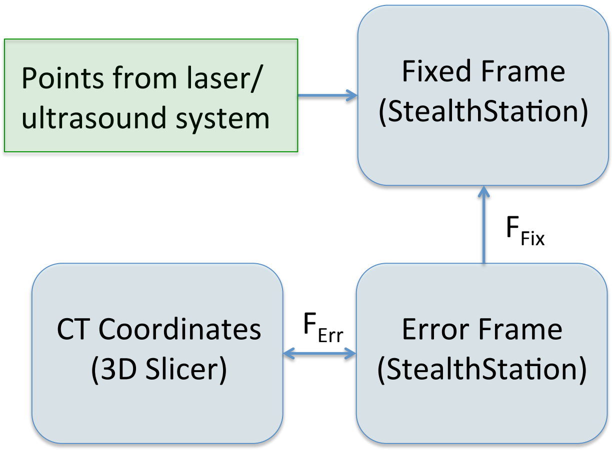
Progress: Phase 2 – Experimental Design

- Registration of image to StealthStation
- Use pointer tool to determine laser tip and line
- Find intersection of laser with surface model in actual frame
- Use points to find F_{Fix}



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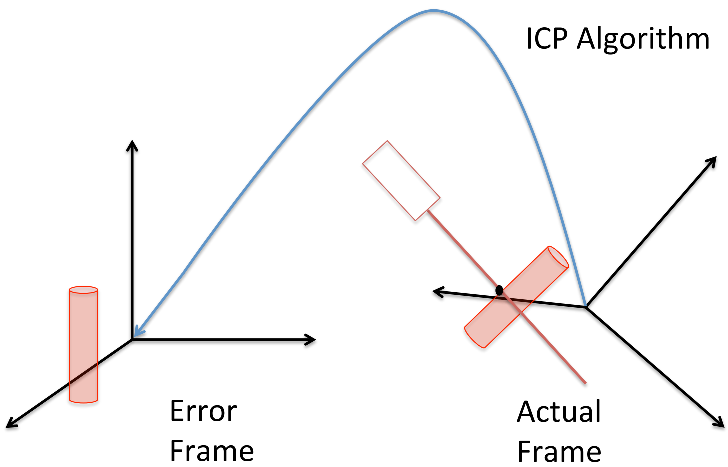
Progress: Phase 2 – Experimental Design



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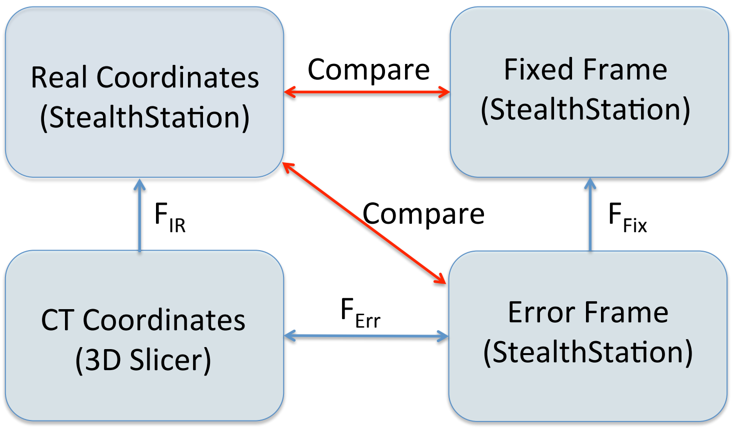
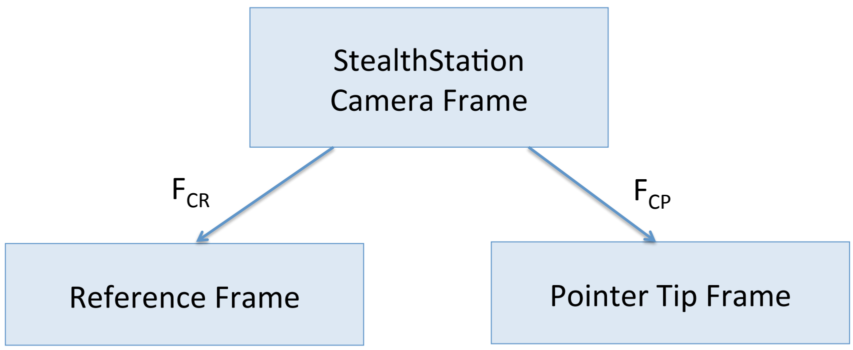
Progress: Phase 2 – Experimental Design

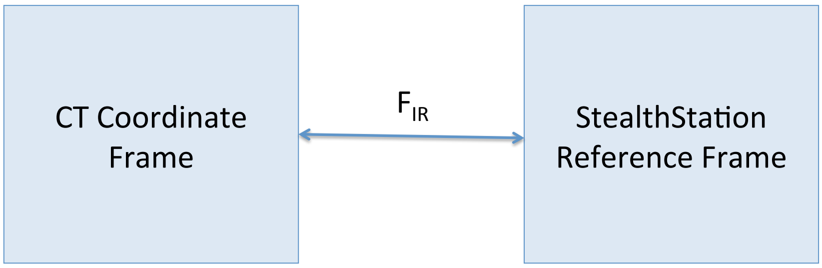


Progress: Phase 2 – Software



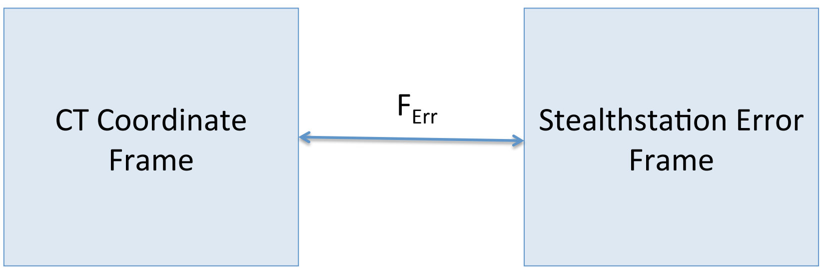
- Use reference frame coordinates (not camera)
- Input: F_{CR} and F_{CT} (given by StealthStation)
- Output: $F_{CR}^{-1} * F_{CT}$ to register tip to frame

Progress: Phase 2 – Software



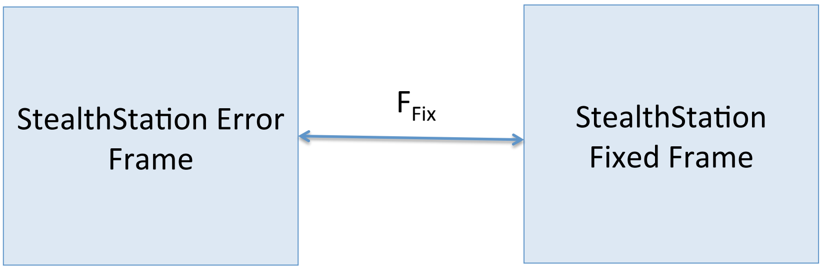
- Register CT frame to Stealthstation frame
- Input: fiducials will give paired points
- Output: F_{IR} using Arun's Method

Progress: Phase 2 – Software



- Introduce artificial error in the transformation
- Input: N/A
- Output: Random rotation and translation

Progress: Phase 2 – Software



- Use an ICP algorithm to transform points from PAI onto the surface model (segmented in 3D slicer)
- Input: surface model of artery (CT coordinate frame) and actual points on artery (actual frame)
- Output: transformation that fixes introduced error

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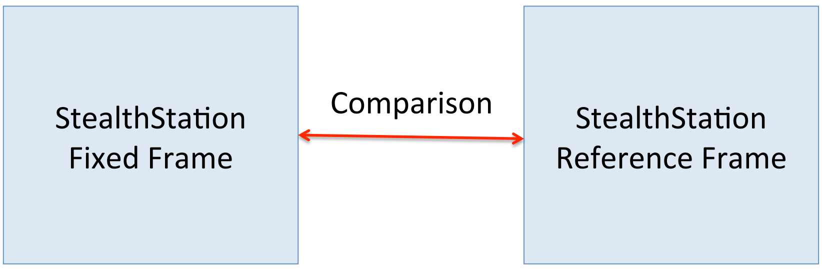
Progress: Phase 2 – Software



- Calculate error with respect to reference frame
- Input: $F_{Err} * F_{Fix}$ and F_{IR}
- Output: Error values
- Conclude if PAI system is feasible in reducing error

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Status of Deliverables (Minimum)

Deliverable	Status
Simple simulation of photo-acoustic imaging based on tracked location of hand-held tool and probe with respect to anatomy (Without Neuromate® robot)	Complete
Registration using intraoperative imaging	On track
Experiments with simple foam block and rubber tubing	On track

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Status of Deliverables (Expected)

Deliverable	Status
Or: Simple simulation of photo-acoustic imaging based on tracked location of tool (with Neuromate® robot) and probe with respect to anatomy	Preferred expected deliverable

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Status of Deliverables (Maximum)

Deliverable	Status
More realistic simulation of photo-acoustic imaging based on tracked location of hand-held tool with respect to anatomy using the Matlab package kwave	Shifted from expected
Real-time visualization in 3D slicer	New
Implementation of virtual fixture in our framework	New

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Resolved Dependencies

Dependency	Date	Resolution/Plan	Consequences
1) Access to labs in Hackerman	02/23	Waiting for approval	Resolved
2) Access to robotorium svn repository	02/23	Already obtained access Dr. Kazanzides will be introducing us to the repository early next week.	Resolved
3) Tutorials for ultrasound/K-wave	03/01	First tutorial on Go through examples on K-wave website	Resolved
4) Learn to use navigation system, CISST Library, 3D slicer	03/01	Go through tutorials	Resolved
6) Access to a computational platform	03/01	Two alternatives: 1) Shared computer in lab (Nishikant), 2) Server (Anton)	Resolved

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Anticipated Dependencies

Dependency	Date	Resolution/Plan	Consequences
5) CT scan of phantom	04/01	Dr. Kazanzides has access to a 20cm by 20cm CT scan and we have spoken to him about using it in the coming week	Cannot perform experiments (expected)
7) Access to NeuroMate ® Robot	04/01	Dr. Kazanzides will be moving it to the Homewood campus in the coming week	Cannot perform experiments (expected)
8) Learn to integrate CISST and 3DSlicer through OpenIGTLink	04/01	Tutorials on www.slicer.org/slicerWiki	Cannot visualize experiments (maximum)

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Next Steps

- Build phantom
- Get CT Scan
- Implement software design
- Test and debug software design
- Set-up and run experiments **(EXPECTED)**
- Incorporate Neuromate® into experiments
- Real time visualization in 3D slicer **(MAX)**

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Completed Reading List

(Endonasal) Skullbase Surgery

- Xia, T., Baird, C., Jallo, G., Hayes, K., Nakajima, N., Hata, N. and Kazanzides, P. (2008), An integrated system for planning, navigation and robotic assistance for skull base surgery. Int. J. Med. Robotics Comput. Assist. Surg., 4: 321–330. doi: 10.1002/rcs.213
- JF Frazier, K Chaichana, GI Jallo, A Quiñones-Hinojosa, "Combined endoscopic and microscopic management of pediatric pituitary region tumors through one nostril: technical note with case illustrations", *Childs Nervous System*, Vol 24, pp 1469–1478, 2008
- Cappabianca P, Cavallo LM, Colao A, et al. Surgical complications associated with the endoscopic endonasal transsphenoidal approach for pituitary adenomas. J Neurosurg 2002;97:293–8.

Photoacoustic Imaging/Modeling Photoacoustic Imaging

- Xueding Wang, David L. Chamberland, Guohua Xi, Noninvasive reflection mode photoacoustic imaging through infant skull toward imaging of neonatal brains, Journal of Neuroscience Methods, Volume 168, Issue 2, 15 March 2008, Pages 412-421, ISSN 0165-0270, 10.1016/j.jneumeth.2007.11.007
- B. E. Treeby and B. T. Cox, "k-Wave: MATLAB toolbox for the simulation and reconstruction of photoacoustic wave-fields," J. Biomed. Opt., vol. 15, no. 2, p. 021314, 2010
- Kolkman, R., Steenbergen, W., and van Leeuwen, T., "In vivo photoacoustic imaging of blood vessels with a pulsed laser diode," Lasers in medical science 21(3), 134–139 (2006).

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