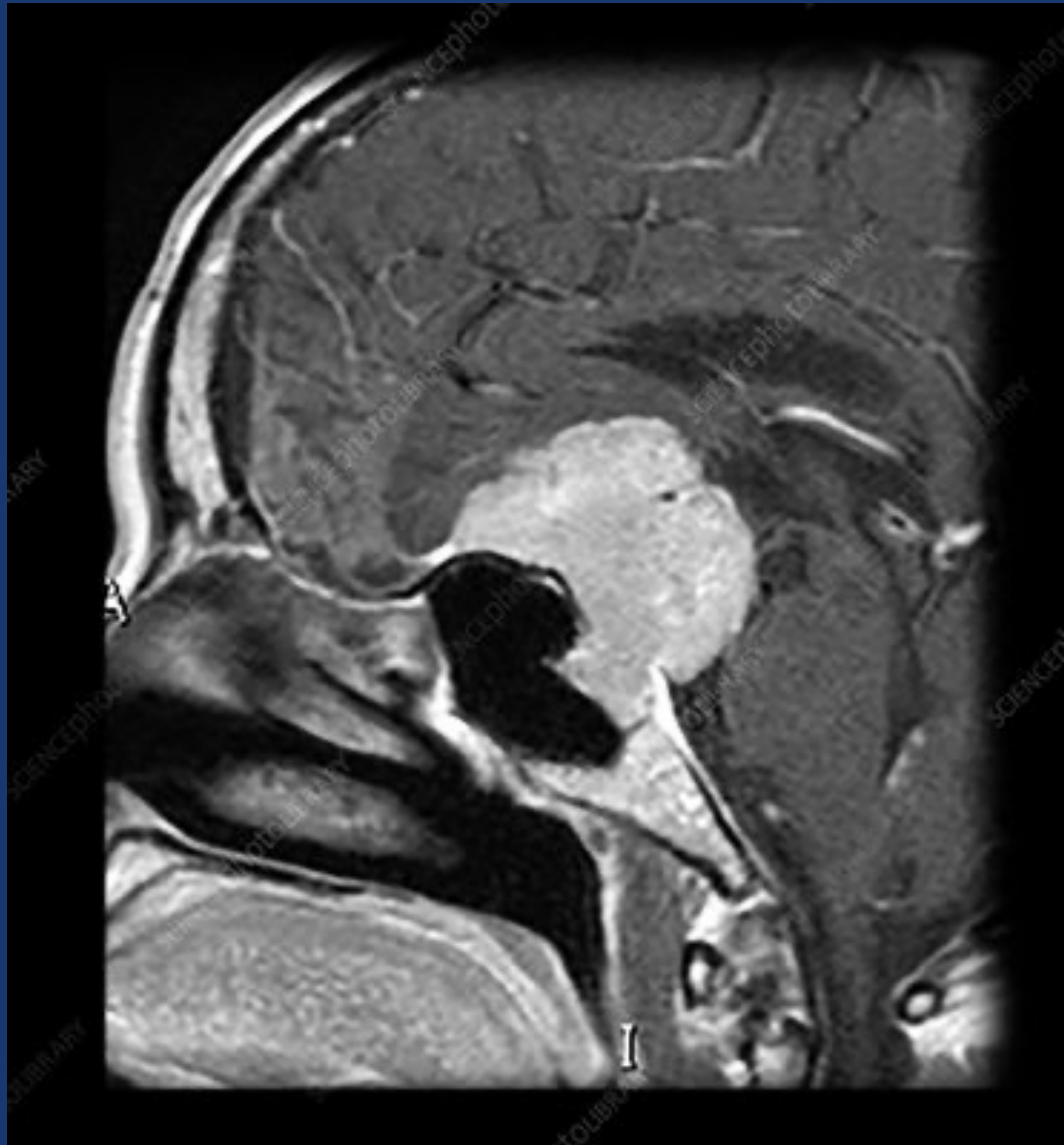
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Computer-Integrated Surgery: Applications in Neurosurgery

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Disclosures

There are no financial or other conflicts of interest in relation to this presentation.

Outline

- Neurosurgery: An Overview
- History of Neurosurgery at Johns Hopkins
- Computer Integration to Modernize Neurosurgery
- Computer Integration to Improve Surgical Training

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What is neurosurgery?

Medical specialty concerned with the **surgical treatment** of disorders which affect **any portion of the nervous system** including the brain, spinal cord, and peripheral nervous system.

Path to becoming a neurosurgeon

YOU ARE HERE

College
- 4-5 years
- MCAT

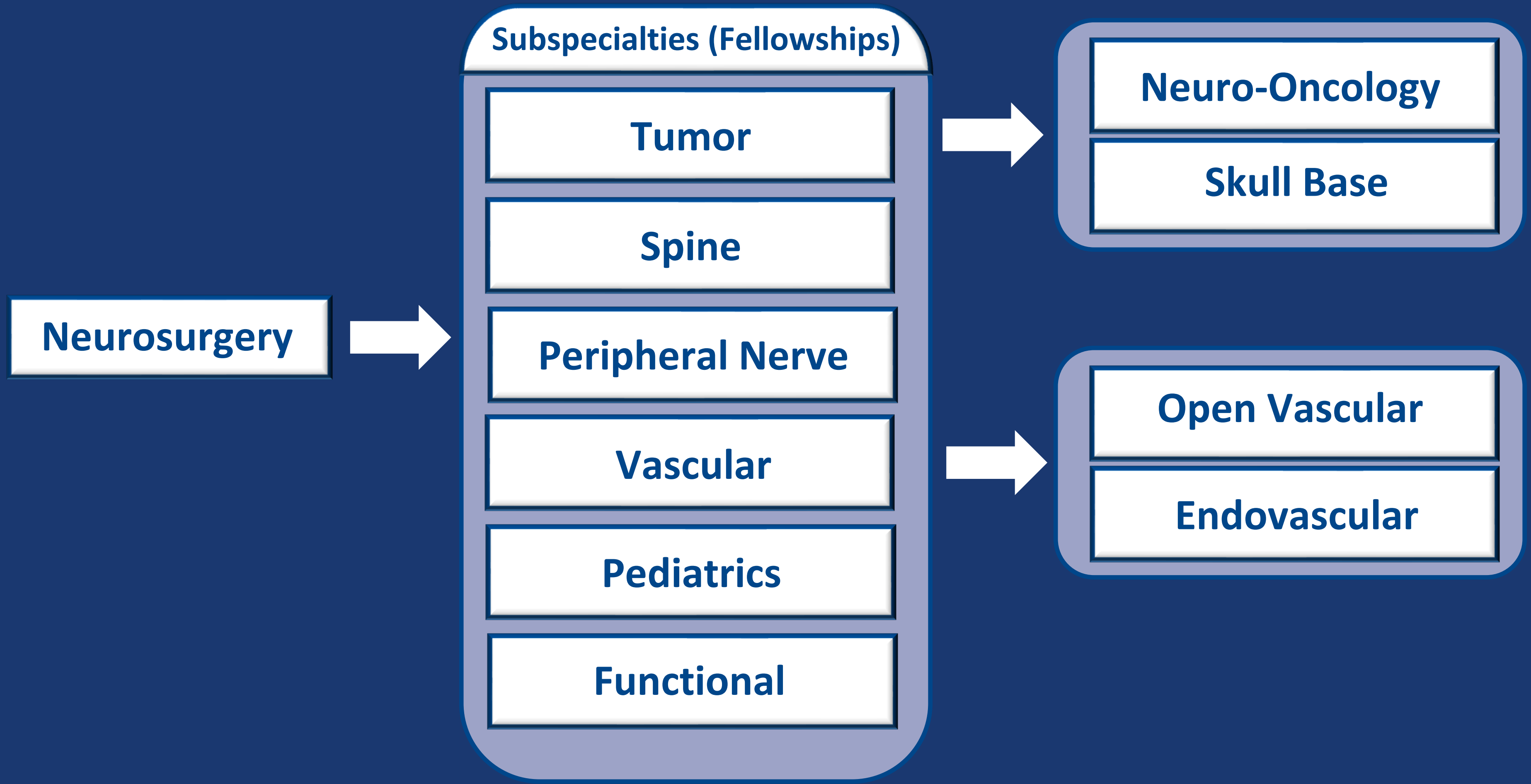
→

Medical School
- 4-5 years
- USMLE Step 1, 2

→

Neurosurgery Residency
- 7 years
- Written Boards
- +/- Fellowship

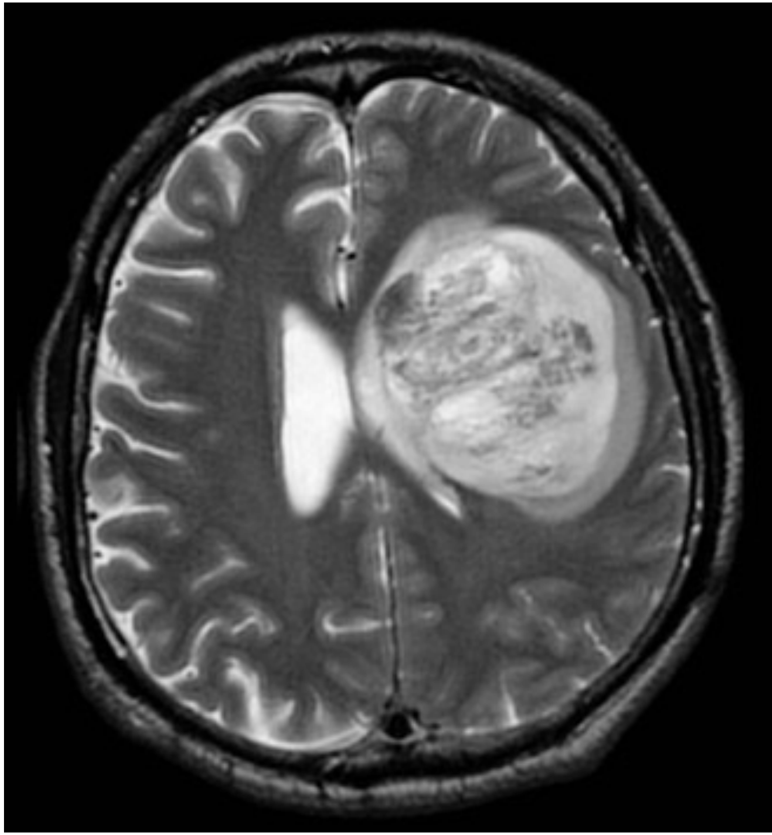
Neurosurgical Subspecialties



Tumor – Neuro-Oncology

Comprehensive management of brain tumors.

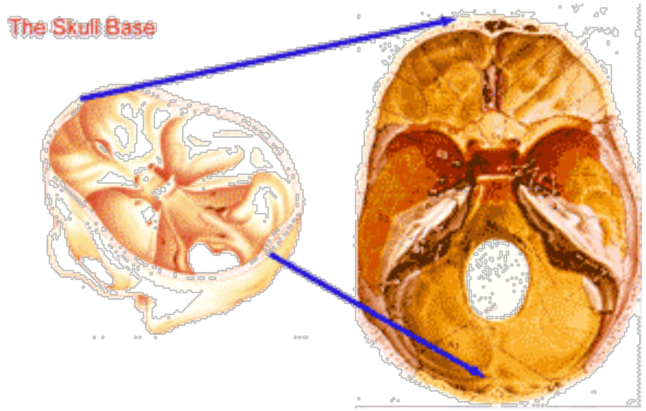
- Awake surgery
- Electrophysiological mapping
- Laser-induced thermal therapy
- Gamma Knife radiosurgery



Tumor – Skull Base

Emphasis on tumors arising along base or floor of skull

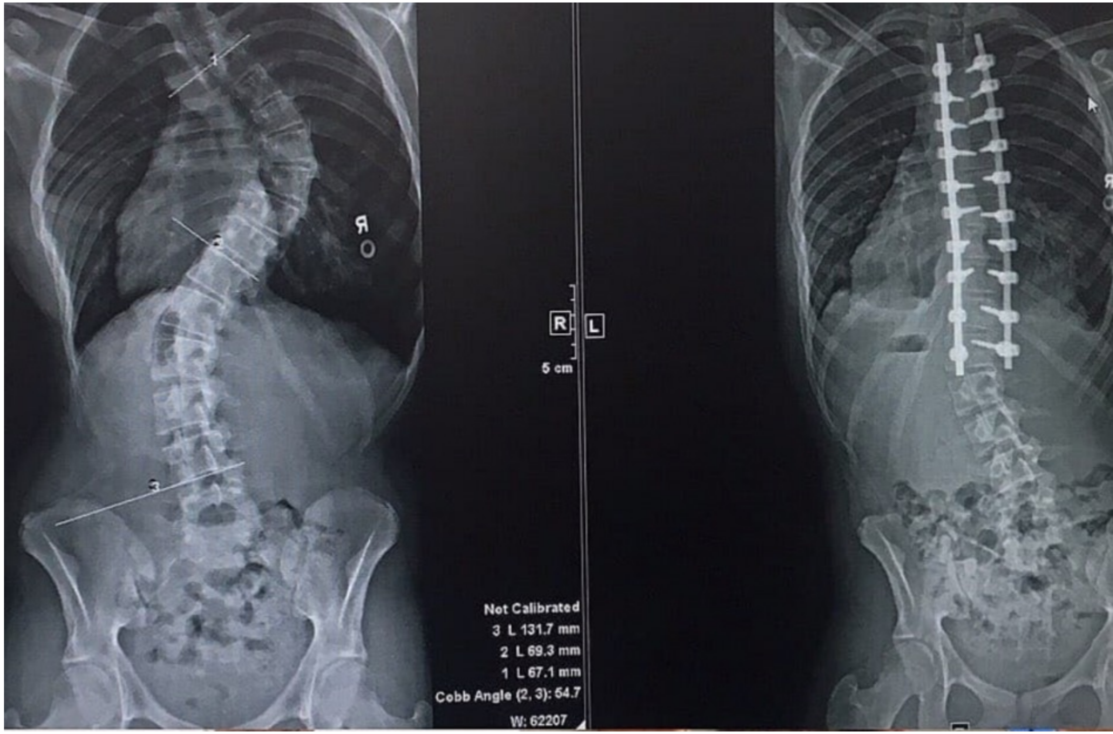
- Transcranial microsurgical approaches
- Endoscopic endonasal surgery
- Transorbital surgery
- Endoscopic/exoscopic port surgery



Spine

Craniocervical, cervical, thoracic, lumbar, sacral spine

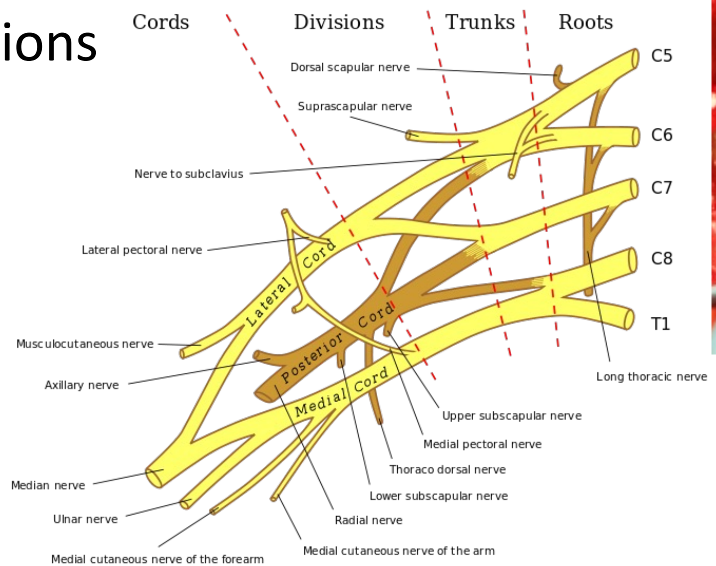
- Degenerative
- Trauma
- Congenital
- Tumor
- Infection/Inflammatory

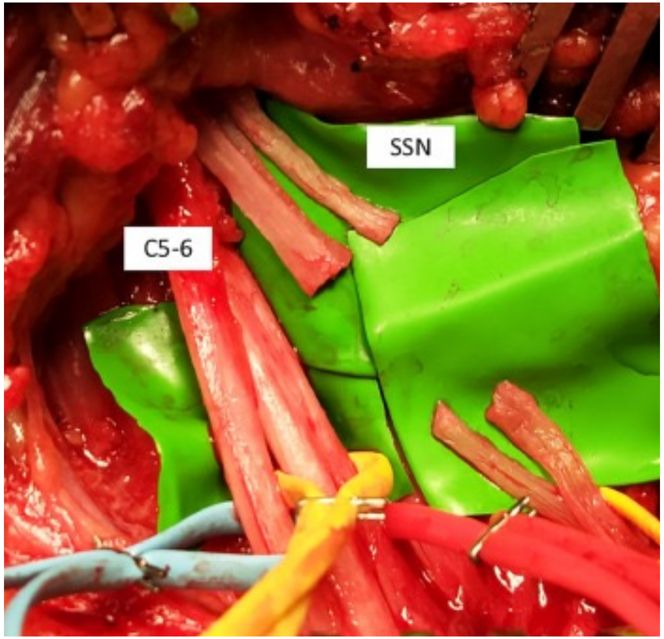


Peripheral Nerve

Nerves outside the brain/spinal cord including brachial plexus

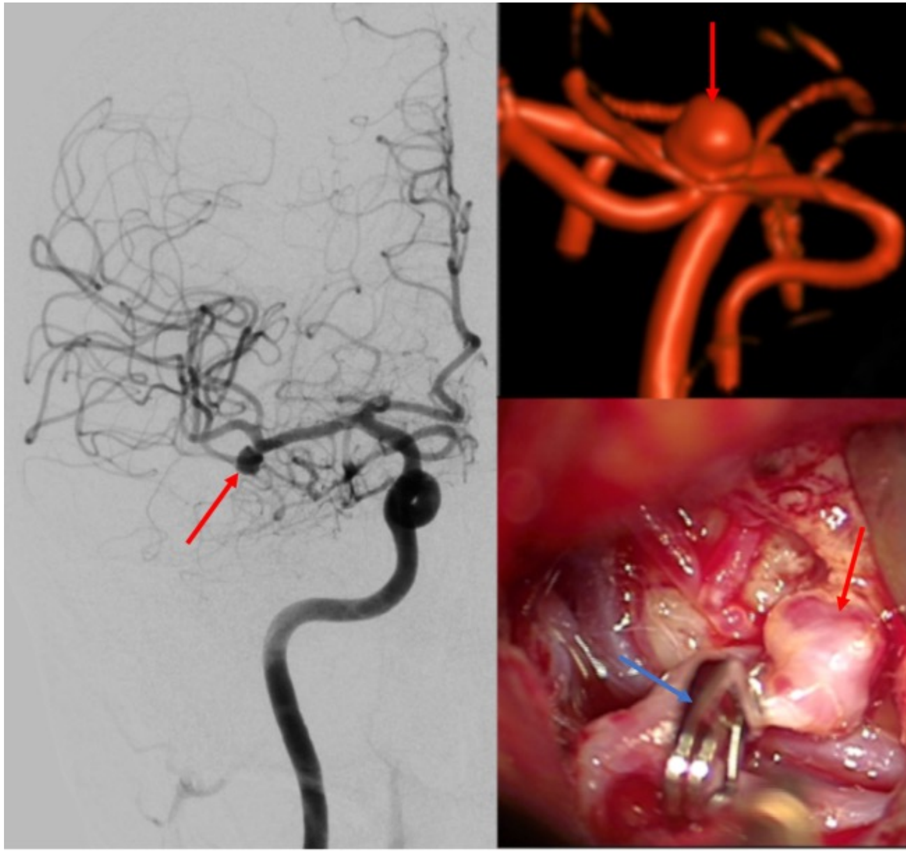
- Brachial plexus injuries
- Metabolic and other neuropathies
- Compression syndromes
- Inflammatory lesions
- Tumors
- Pain





Vascular - Open

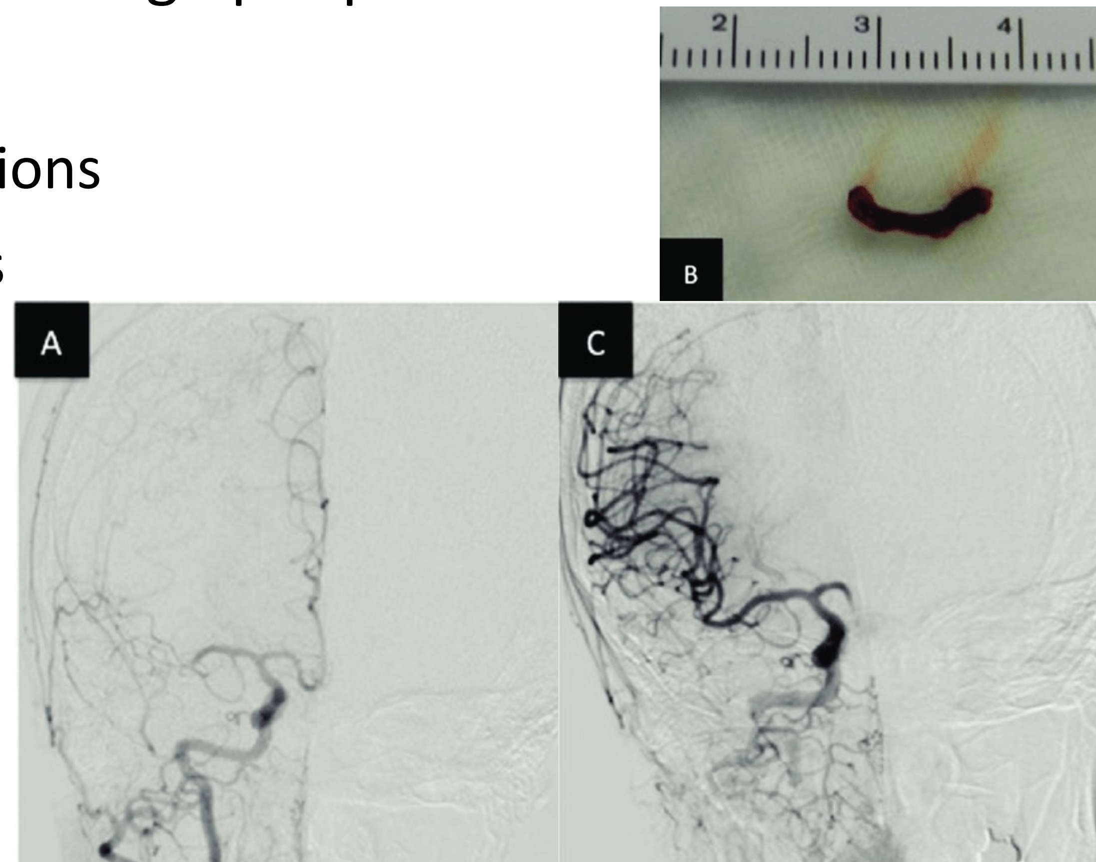
- Aneurysms
- Arteriovenous malformations
- Cavernous malformations
- Fistulas
- Carotid stenosis
- Developmental



Vascular - Endovascular

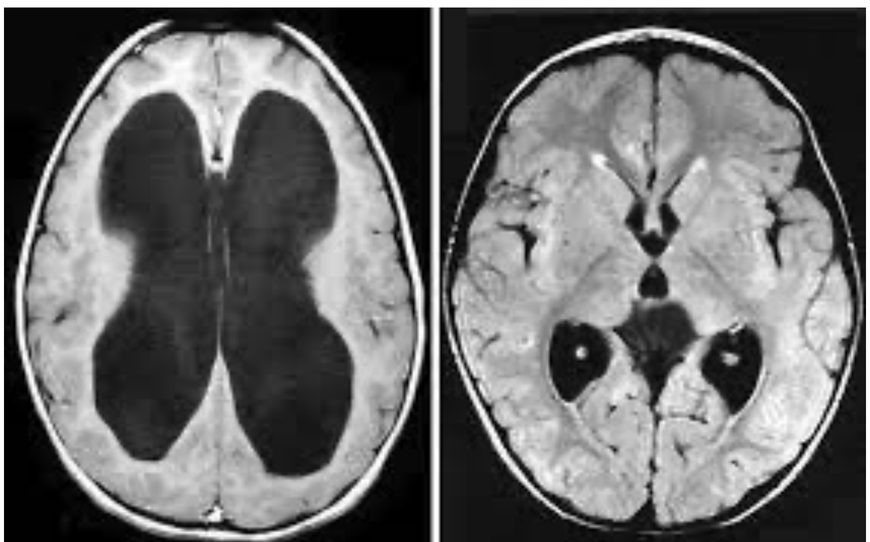
Minimally invasive, access through peripheral arteries

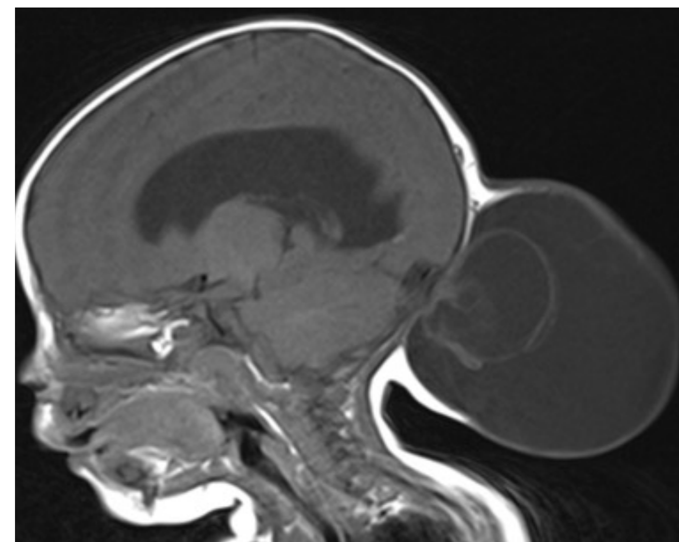
- Aneurysms
- Arteriovenous malformations
- Cavernous malformations
- Fistulas
- Carotid stenosis
- Developmental
- **Stroke**



Pediatrics

- Congenital/Developmental
- Tumor
- Trauma
- Vascular
- Spine
- Functional
- Hydrocephalus
- **Everything**

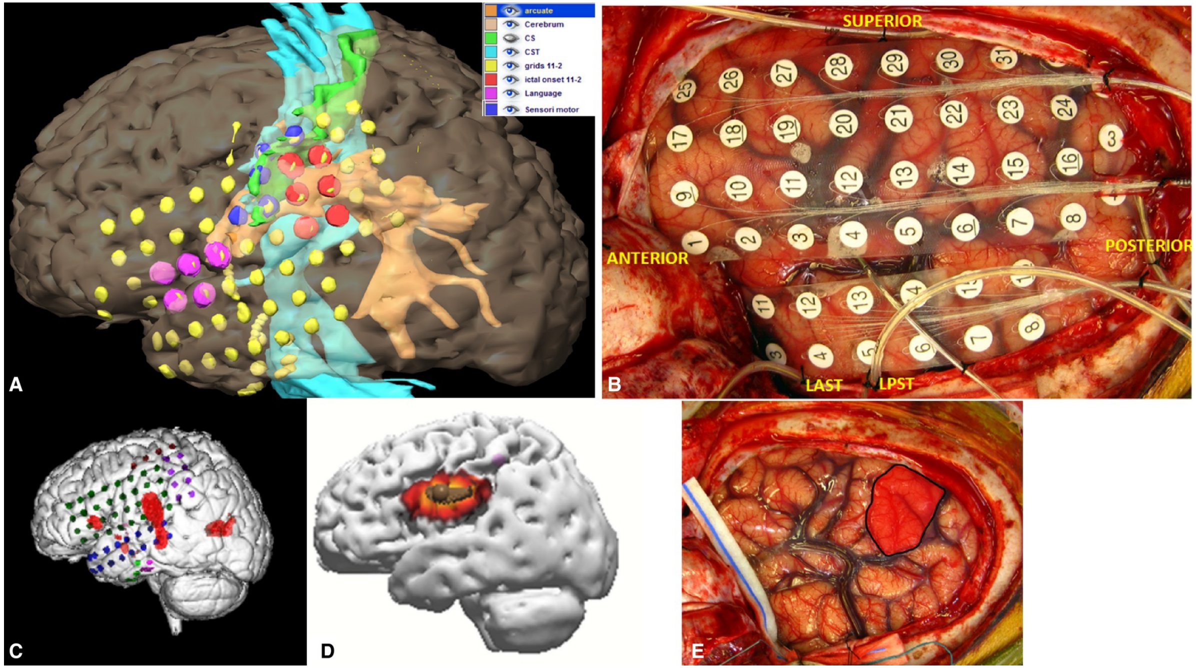




Functional

Emphasis on restoring quality of life/neurological function

- Cognitive & neuropsychiatric
- Epilepsy
- Movement disorders
- Pain



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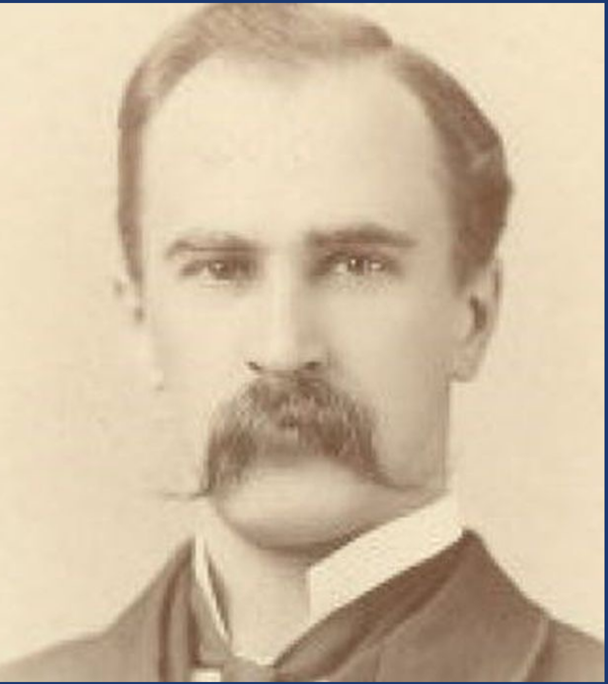
1889 – Johns Hopkins Hospital founded

Harvey Cushing

1896 – Surgical assistant to **William Halsted**

Osler

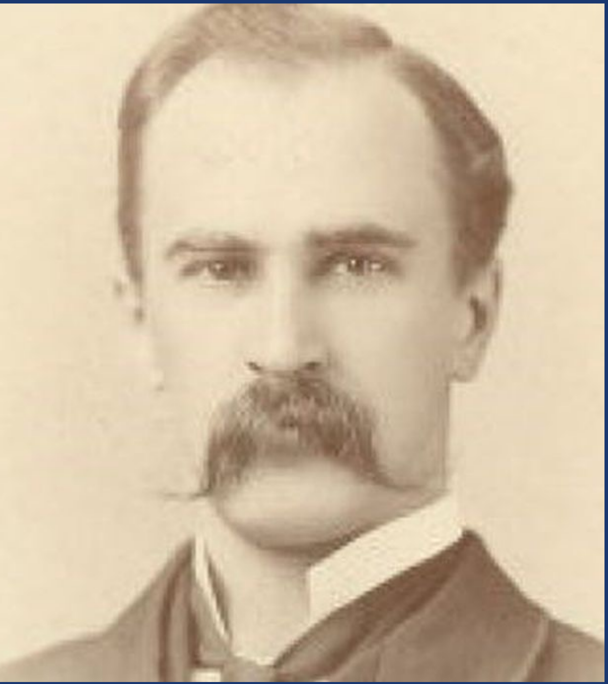


Cushing

Halsted

1900-1901 - **Cushing** spends one year in Europe observing others and studying blood pressure in the context of brain compression.

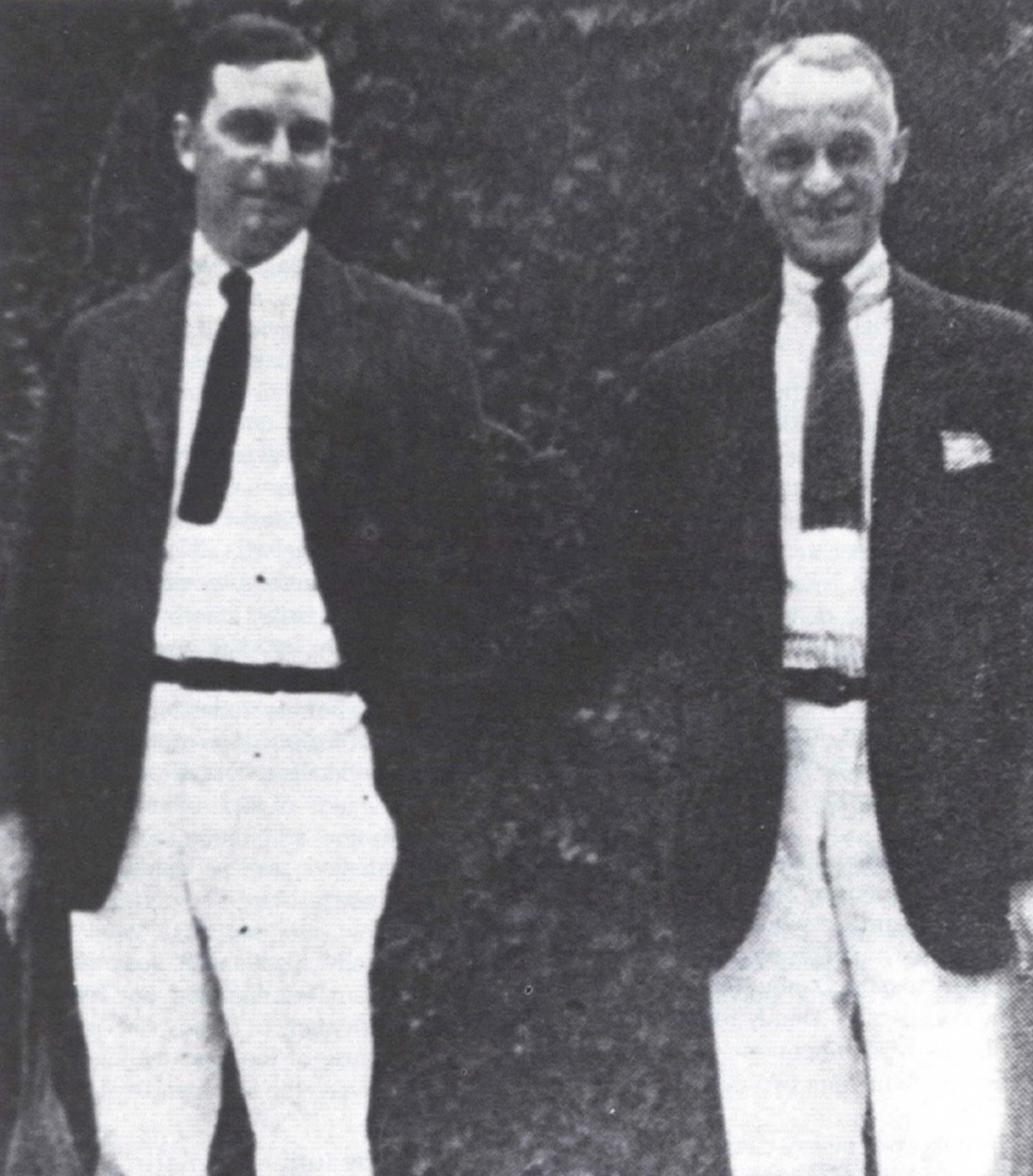
Osler



Cushing

Halsted

1901 - **Halsted** offers **Cushing** a full-time surgical position working in neurology and neurosurgery.



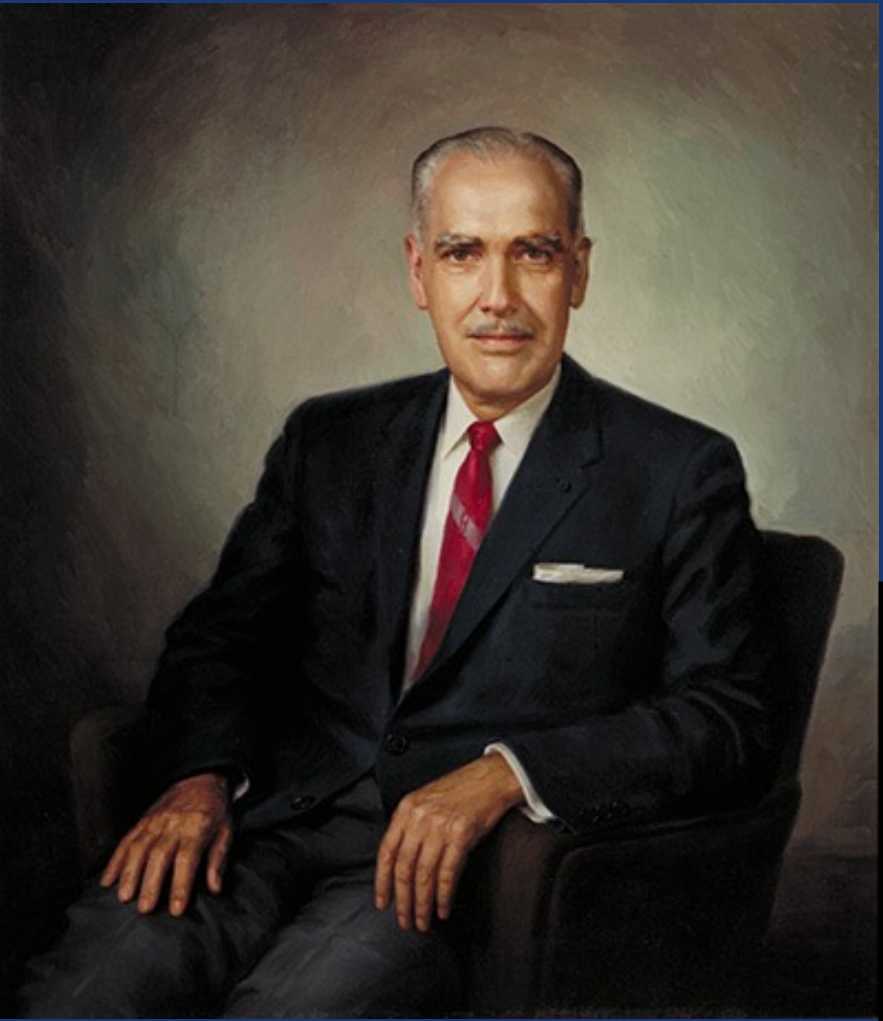
1911 – 1912:
87 neurosurgical cases completed by **Harvey Cushing** and his medical student assistant, **Walter Dandy**.

Walter Dandy

By **1919**, **Dandy** is established as Chief of Neurosurgery at Johns Hopkins.

Walter Dandy

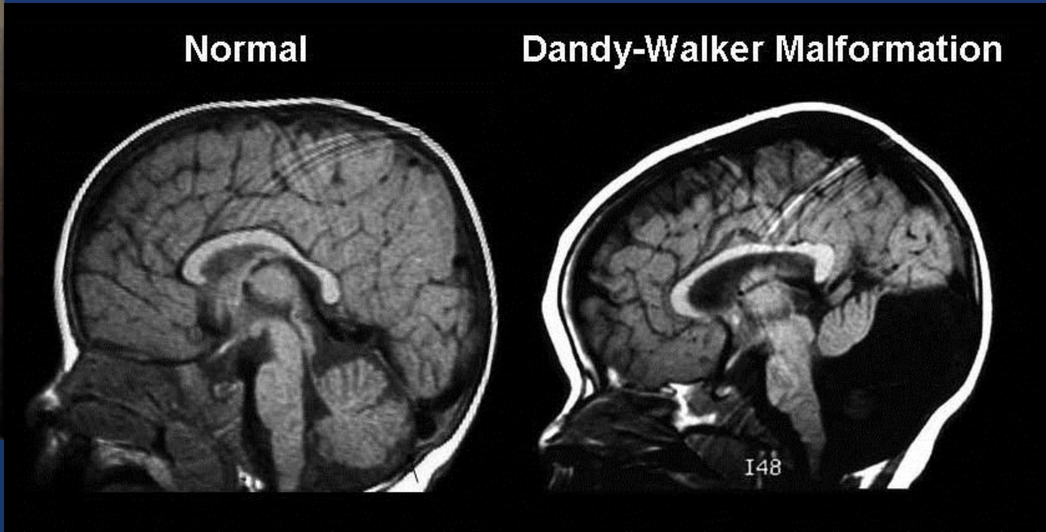
Described treatment of hydrocephalus, pneumoencephalography, first aneurysm clipping



Earl Walker

1947 - succeeds **Dandy** as Chief of Neurosurgery

Credited with describing Dandy-Walker syndrome

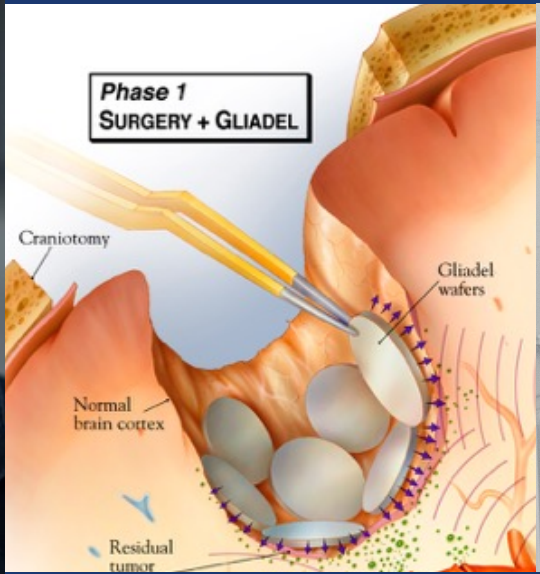


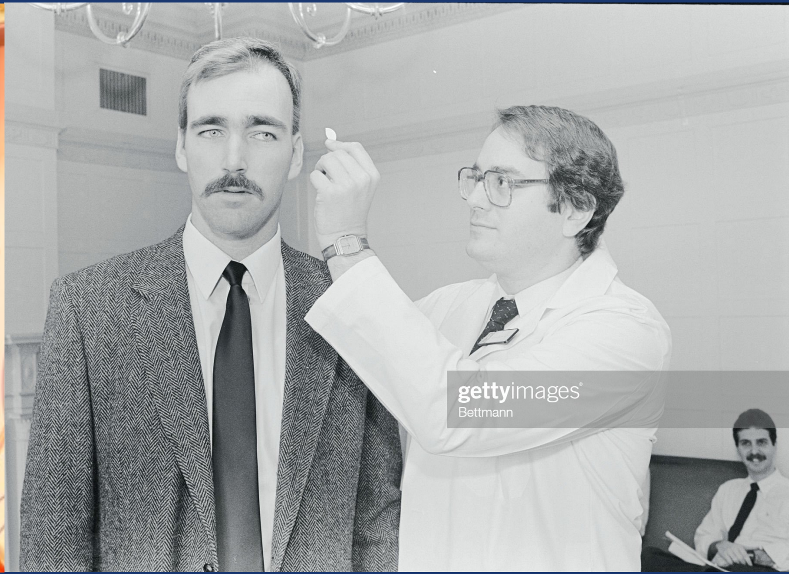
1973 – **Donlin Long** becomes first director of the Department of Neurosurgery.

Pioneer in electrostimulation for treatment of back pain.

Founded the Johns Hopkins Blaustein Chronic Pain Clinic.

2000 – Dr. Henry Brem succeeds **Dr. Long** as chair of the Department of Neurosurgery



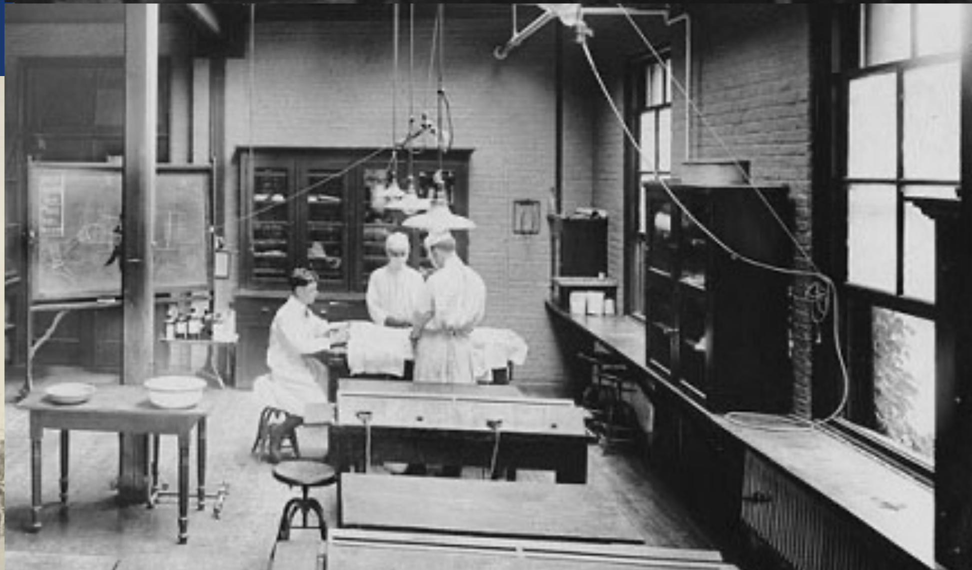


Developed carmustine wafers (Gliadel) leading to significant increases in the median survival of patients with glioblastoma.

The Hunterian Laboratory

Established in **1895** by **Welch** and **Halsted**

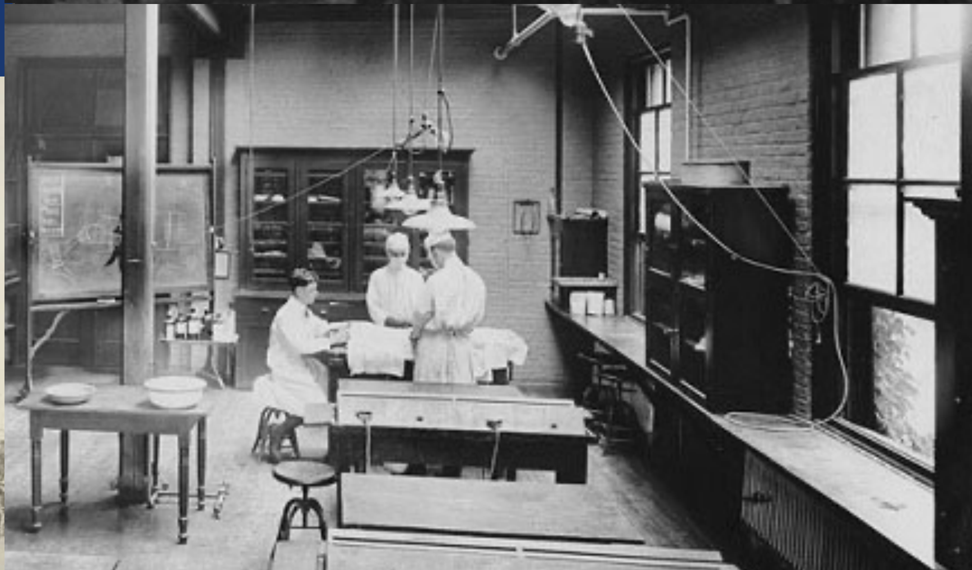
Cushing appointed as laboratory head in **1904**



The Hunterian Laboratory

Thrived until **Walter Dandy's** death in **1946**

Resurrected in **1984** by **Dr. Brem**



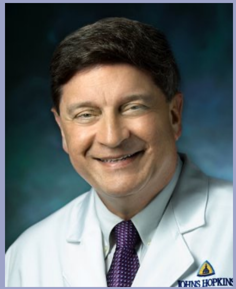
The Hunterian Laboratory: Now

Tumor

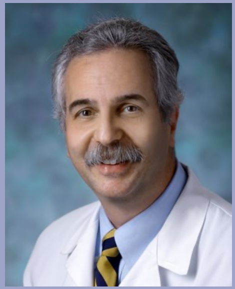



Spine


Pediatrics




Vascular



Hydrocephalus

The Department of Neurosurgery: Now

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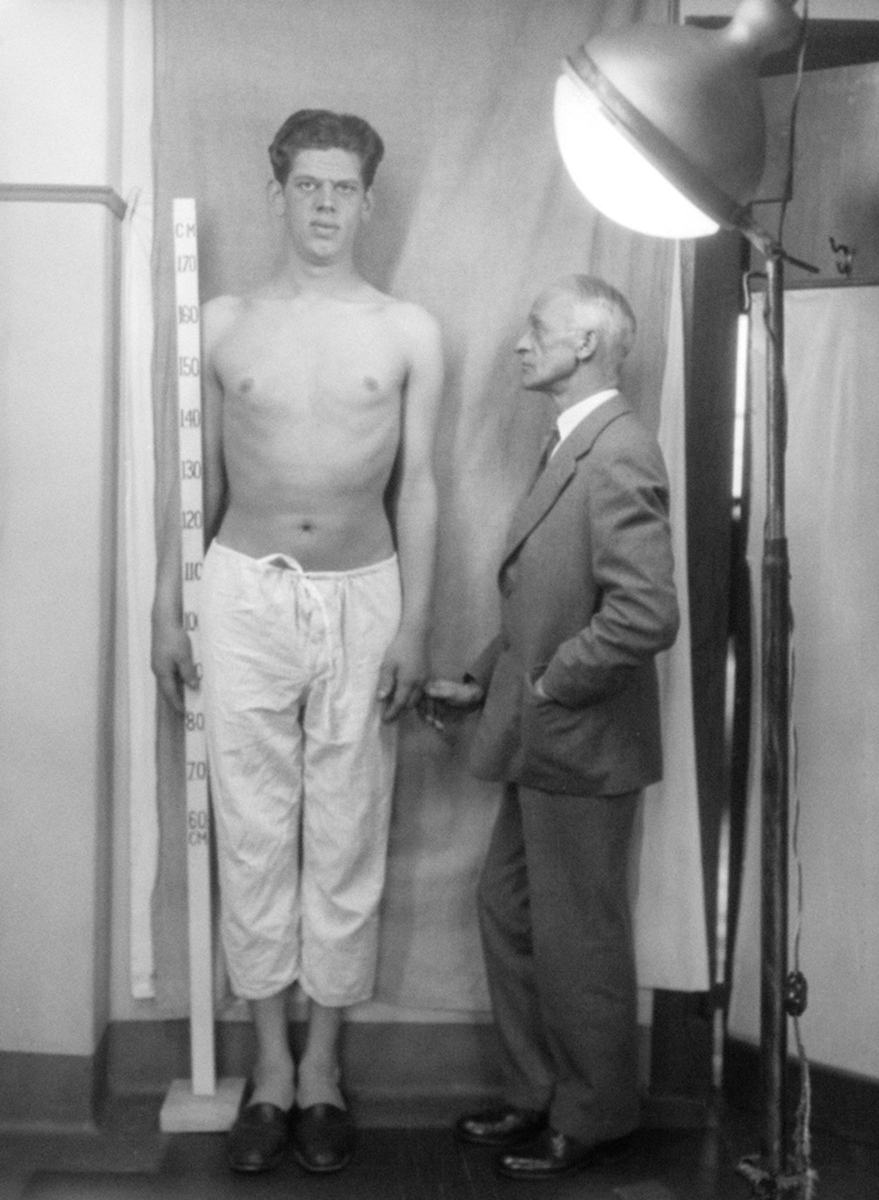
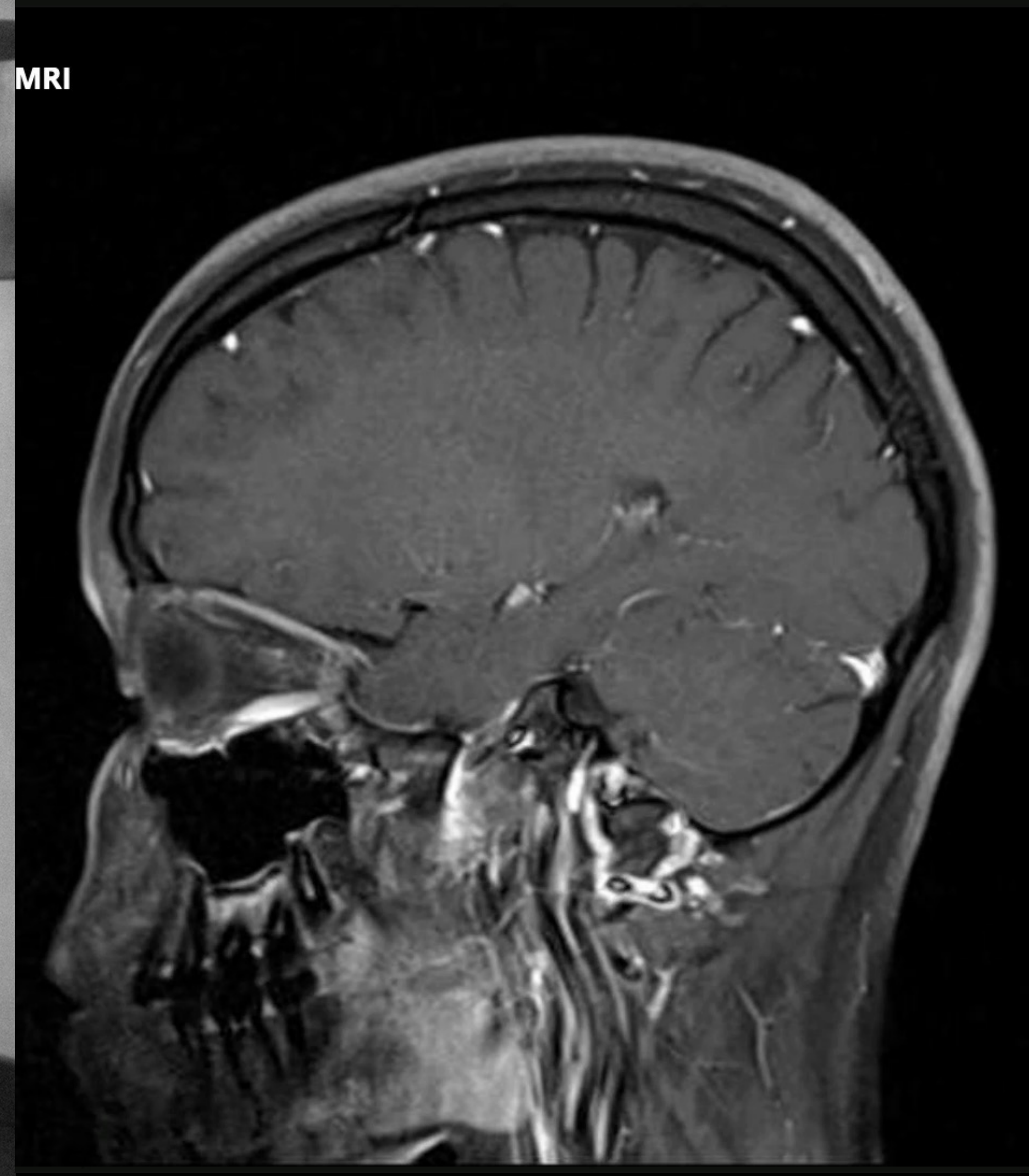
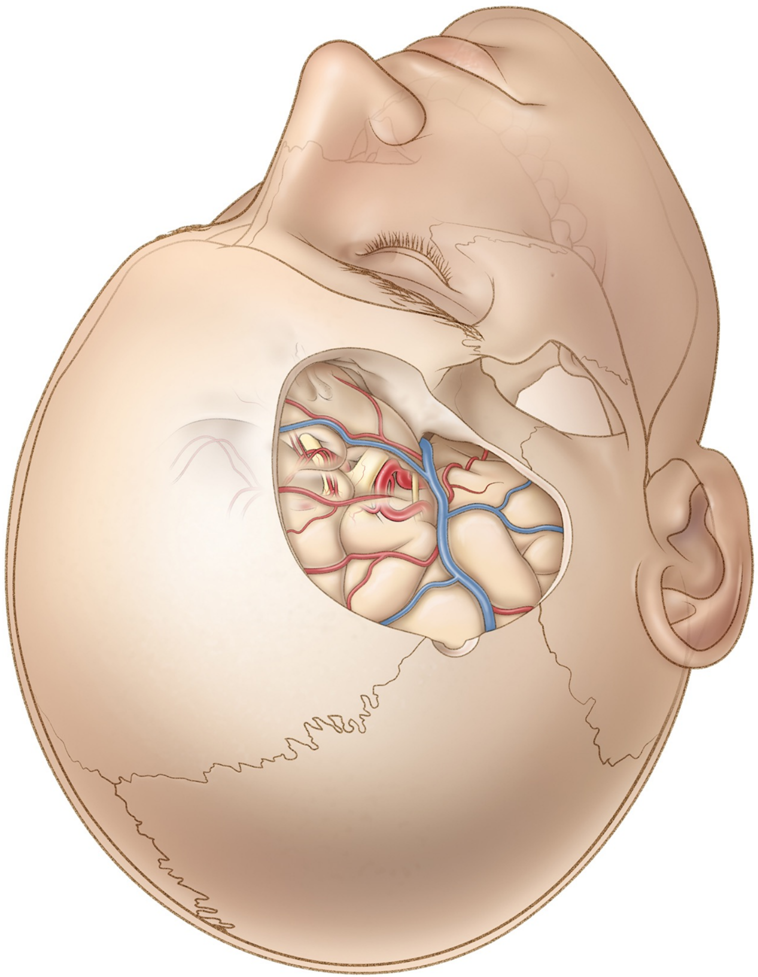
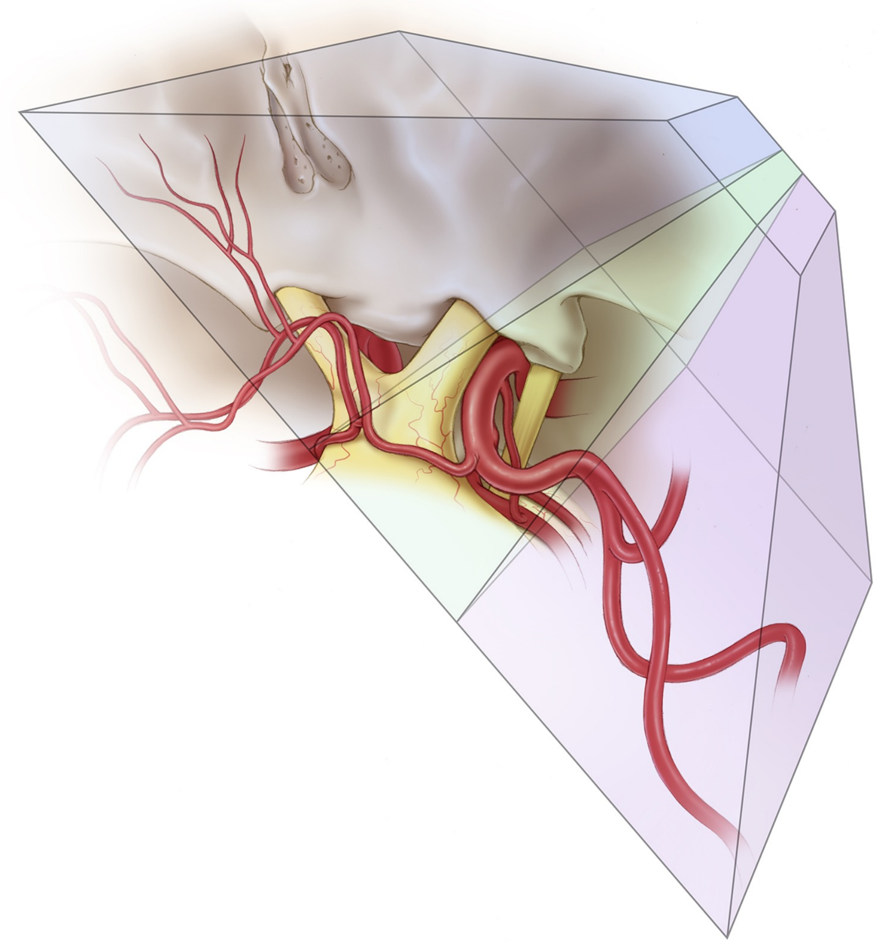
If you needed to get to **center** of head for an operation, how would you get there?



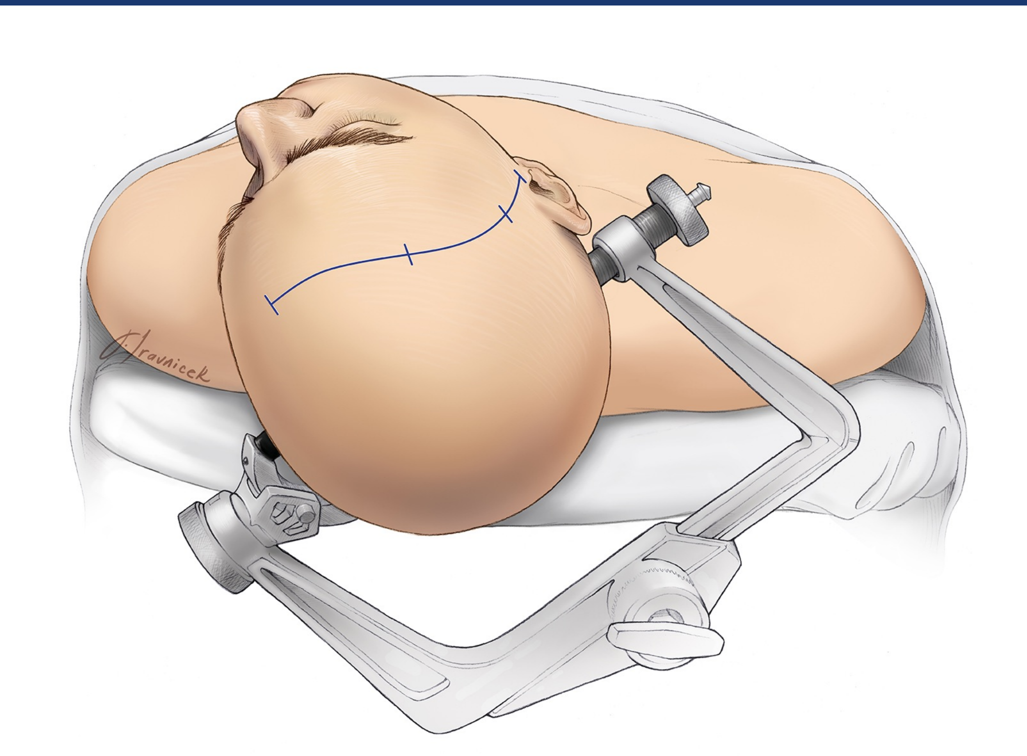

MRI

Open Approach: Pterional Craniotomy

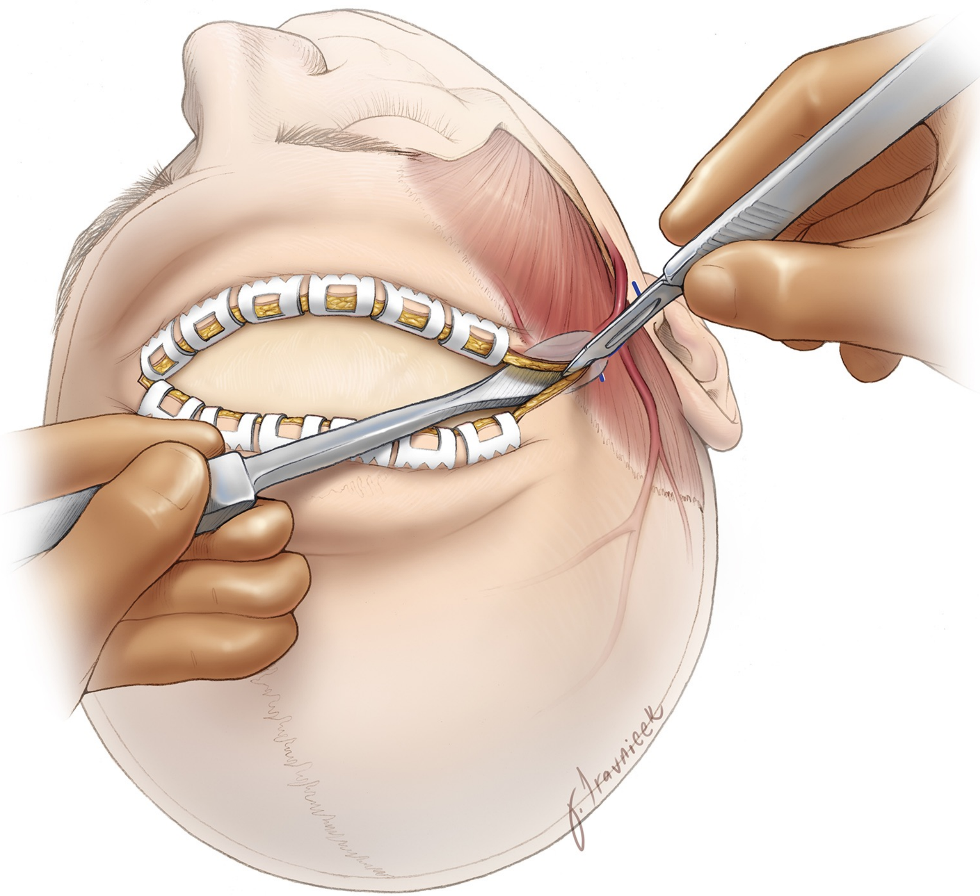


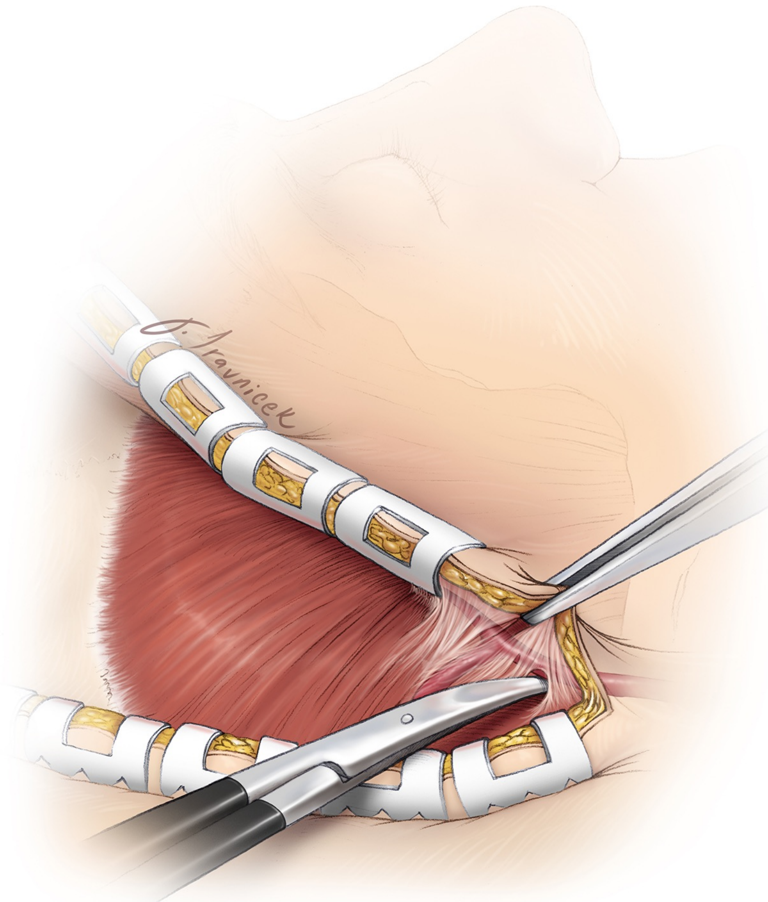


Open Approach: Pterional Craniotomy

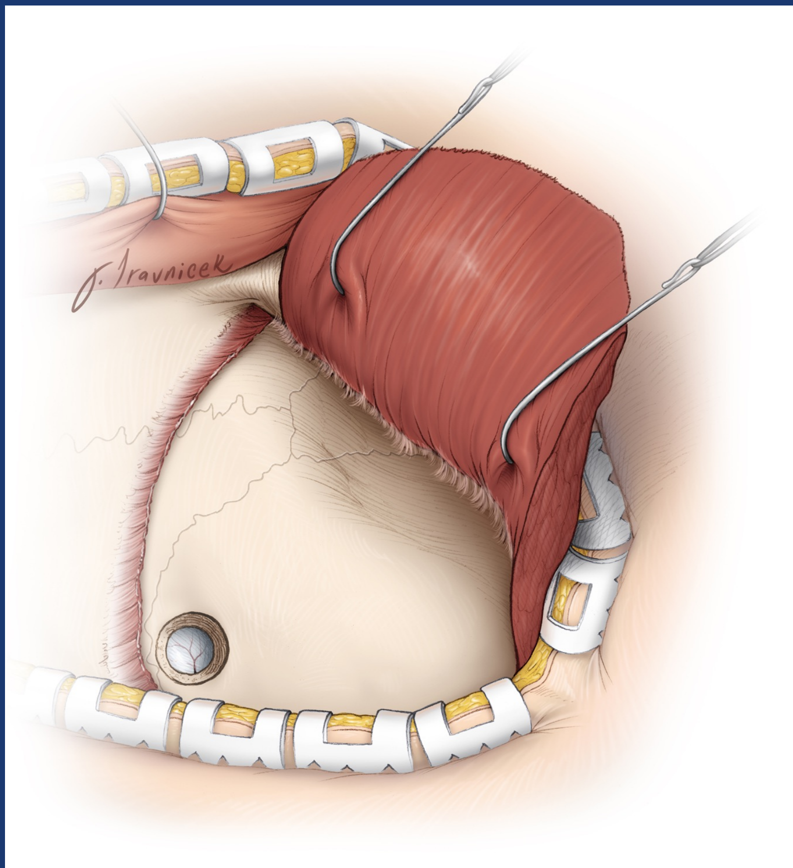


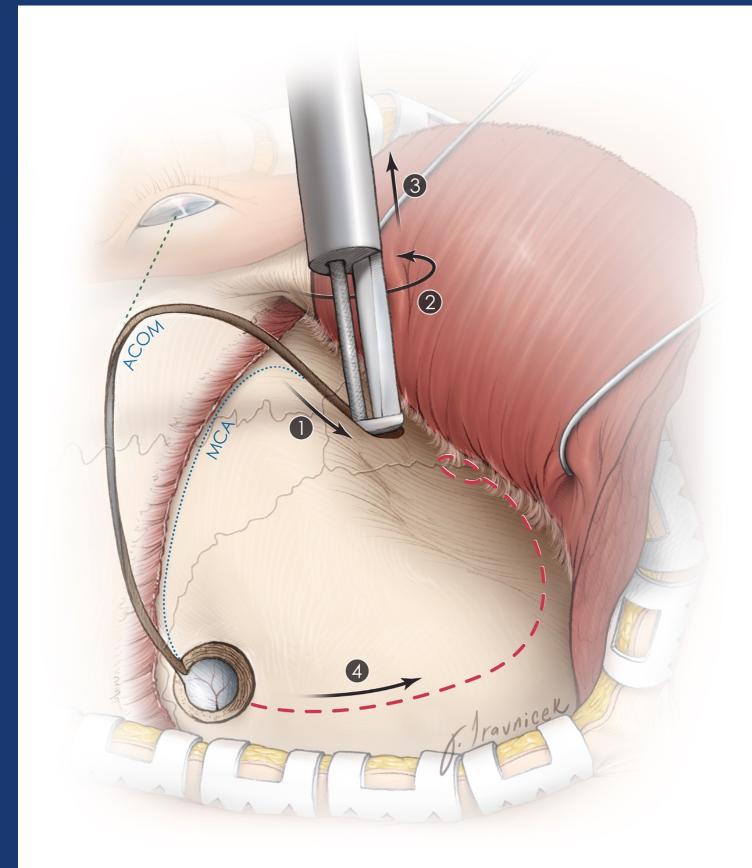
Open Approach: Pterional Craniotomy



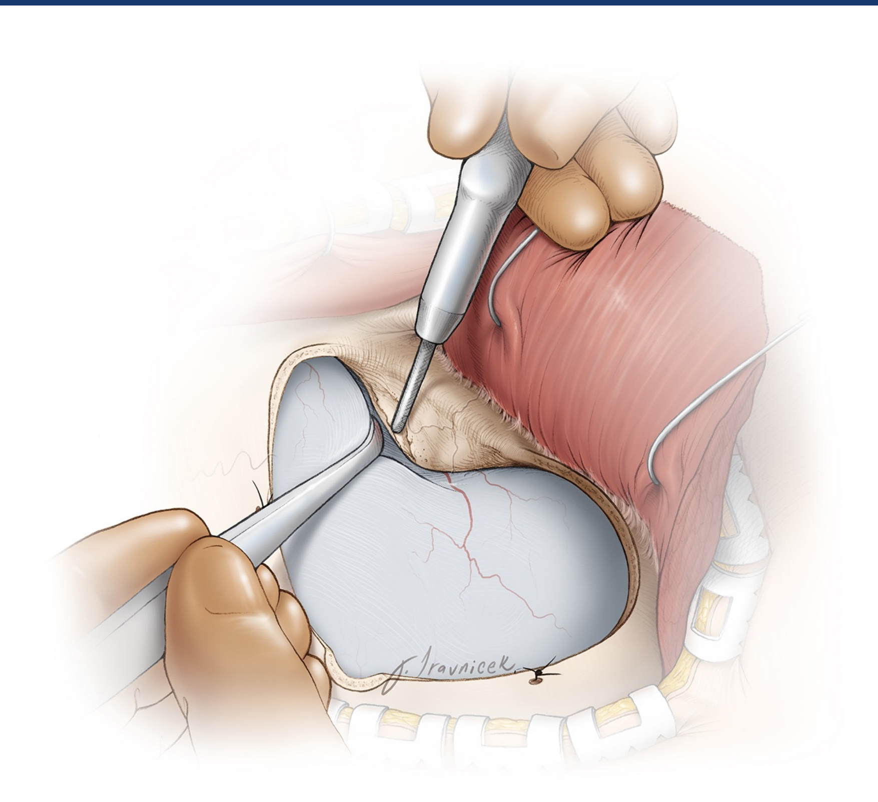


Open Approach: Pterional Craniotomy

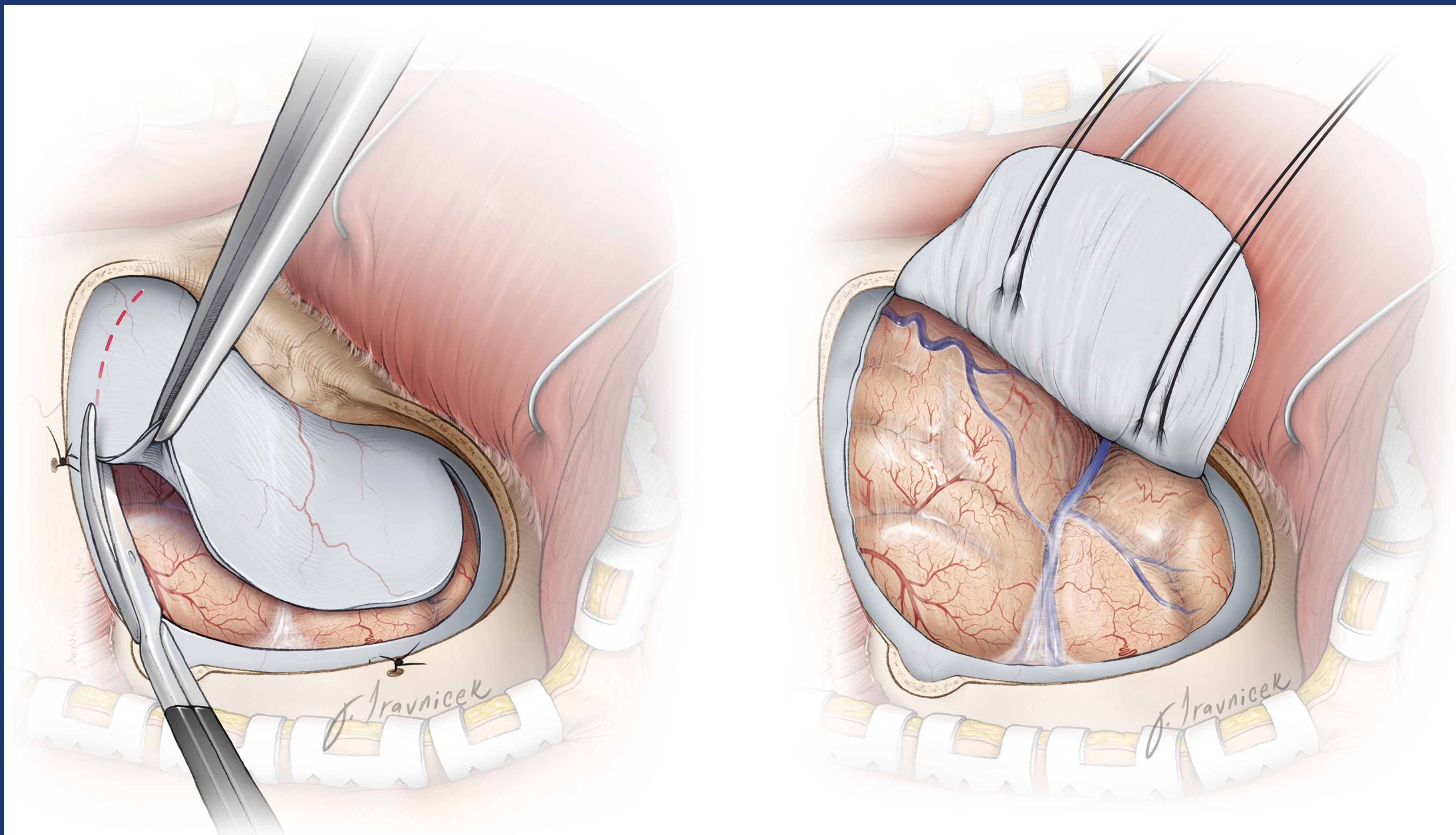




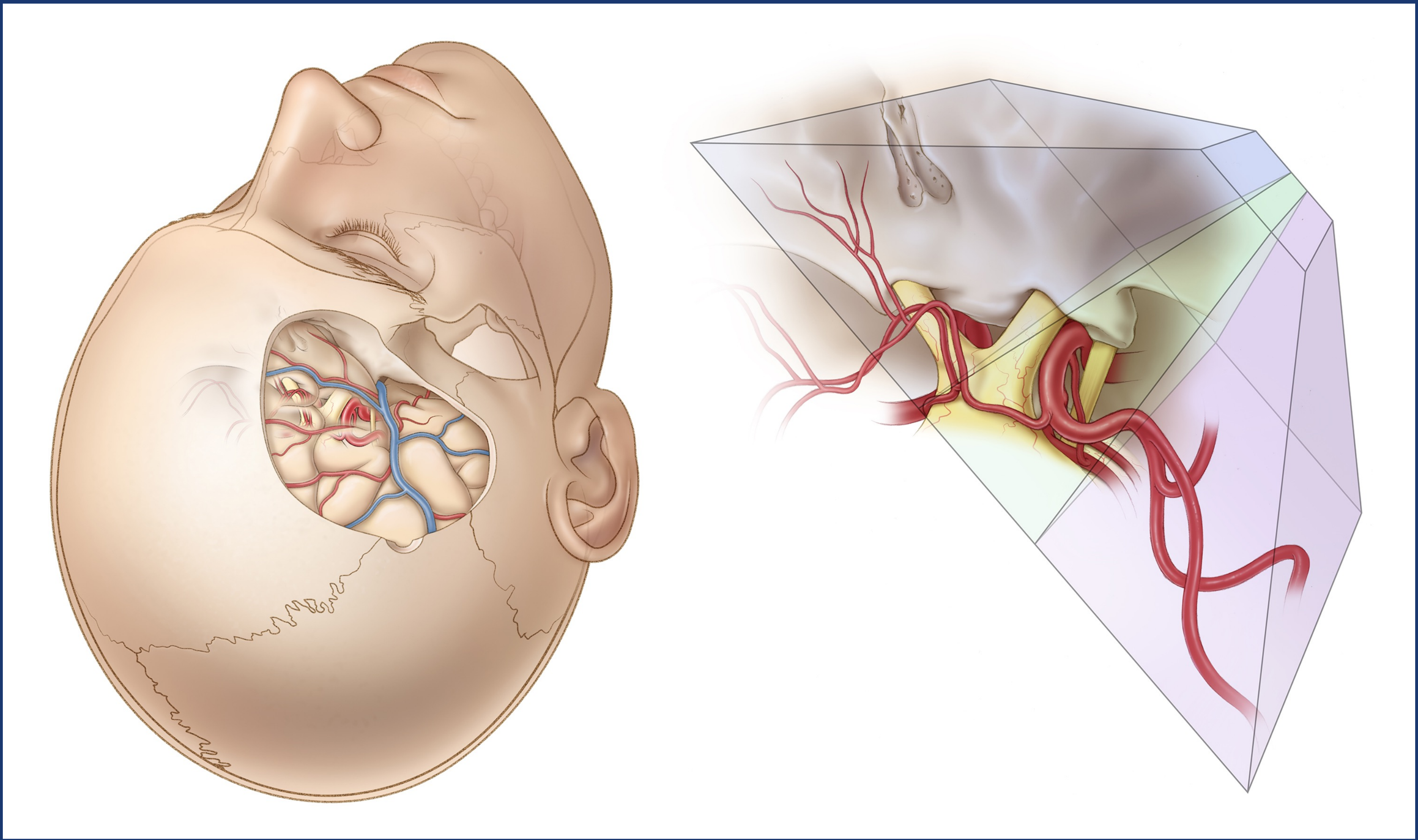
Open Approach: Pterional Craniotomy

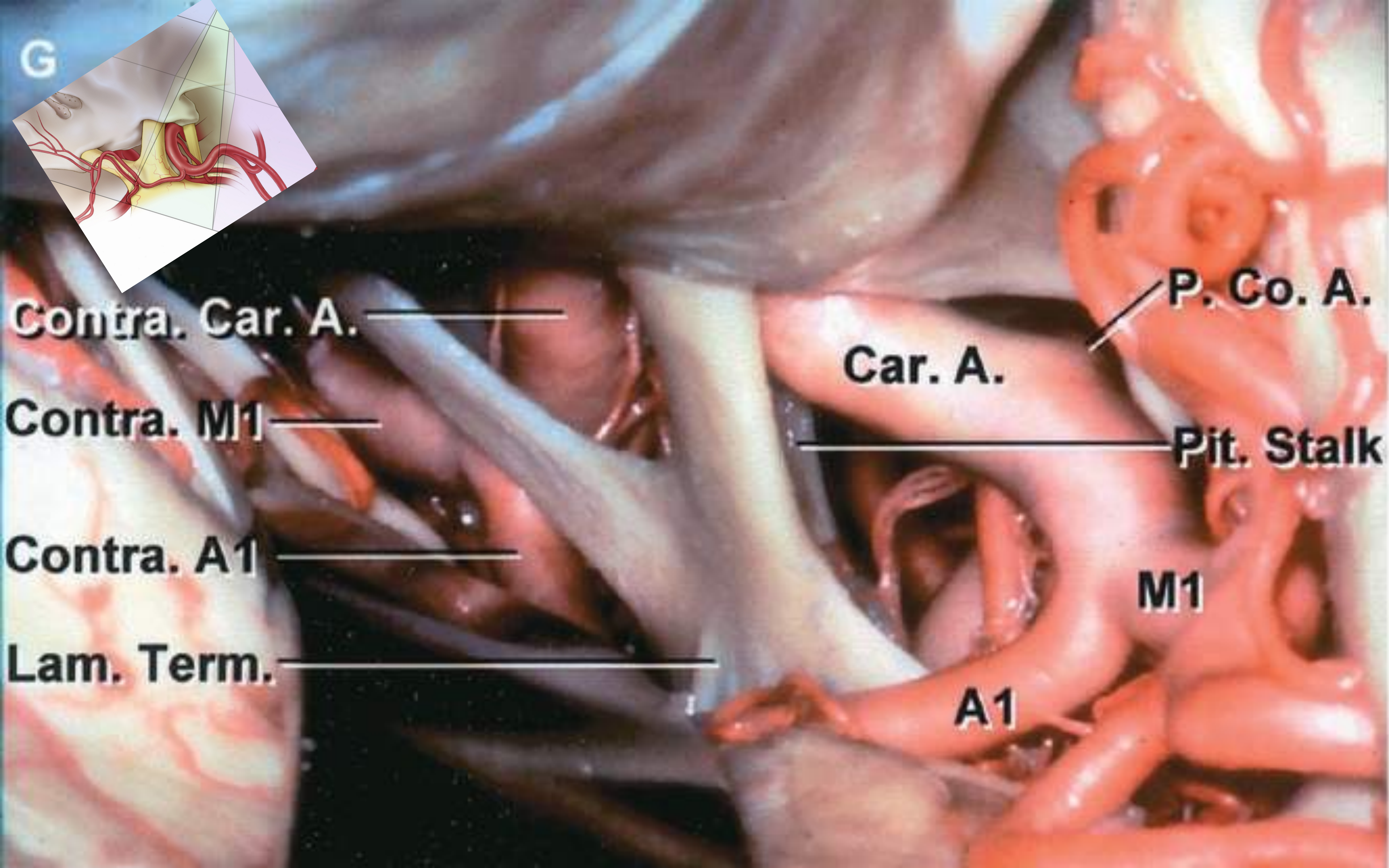


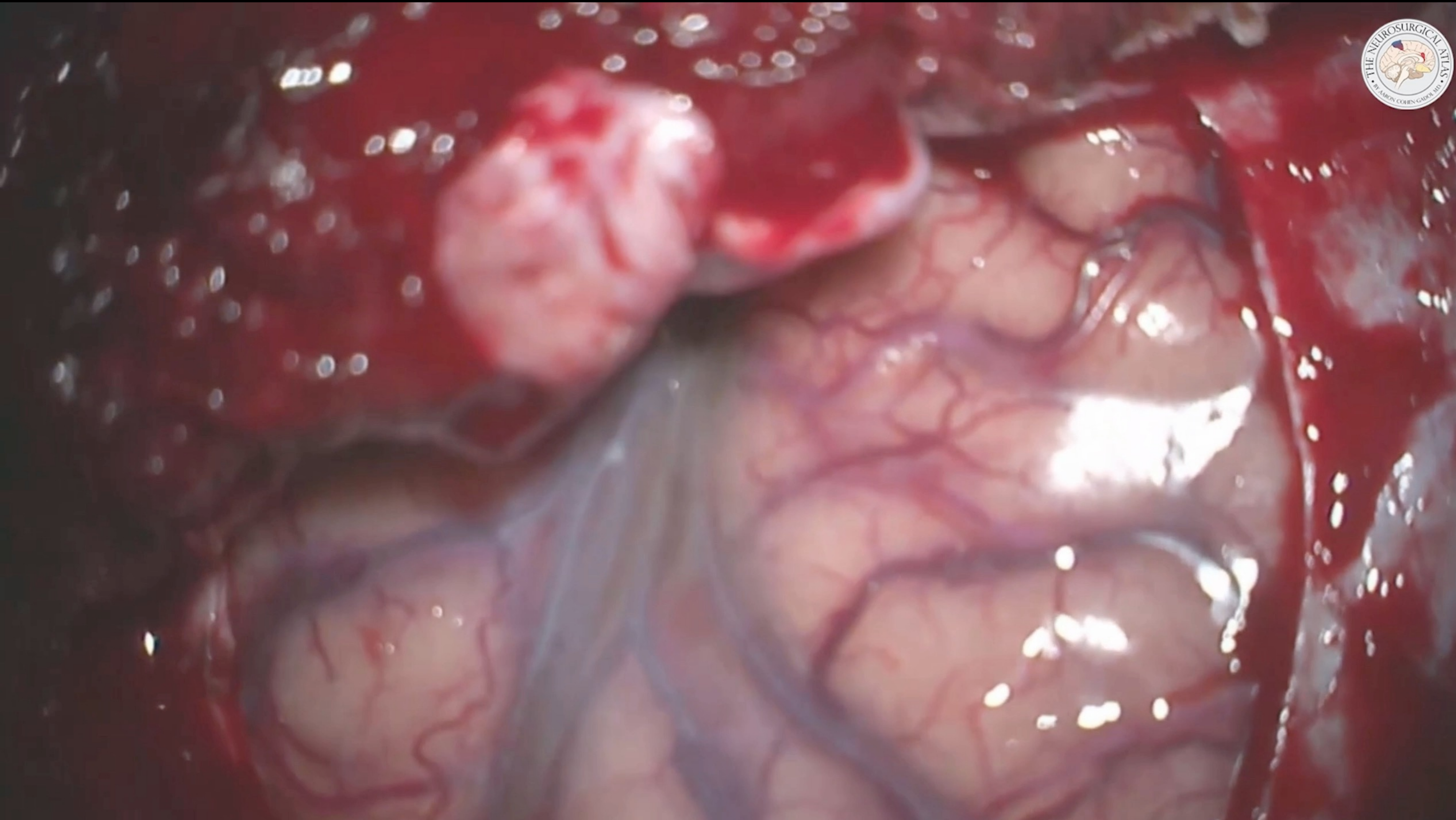
Open Approach: Pterional Craniotomy



Open Approach: Pterional Craniotomy




G
Contra. Car. A.
Contra. M1
Contra. A1
Lam. Term.
P. Co. A.
Car. A.
Pit. Stalk
M1
A1

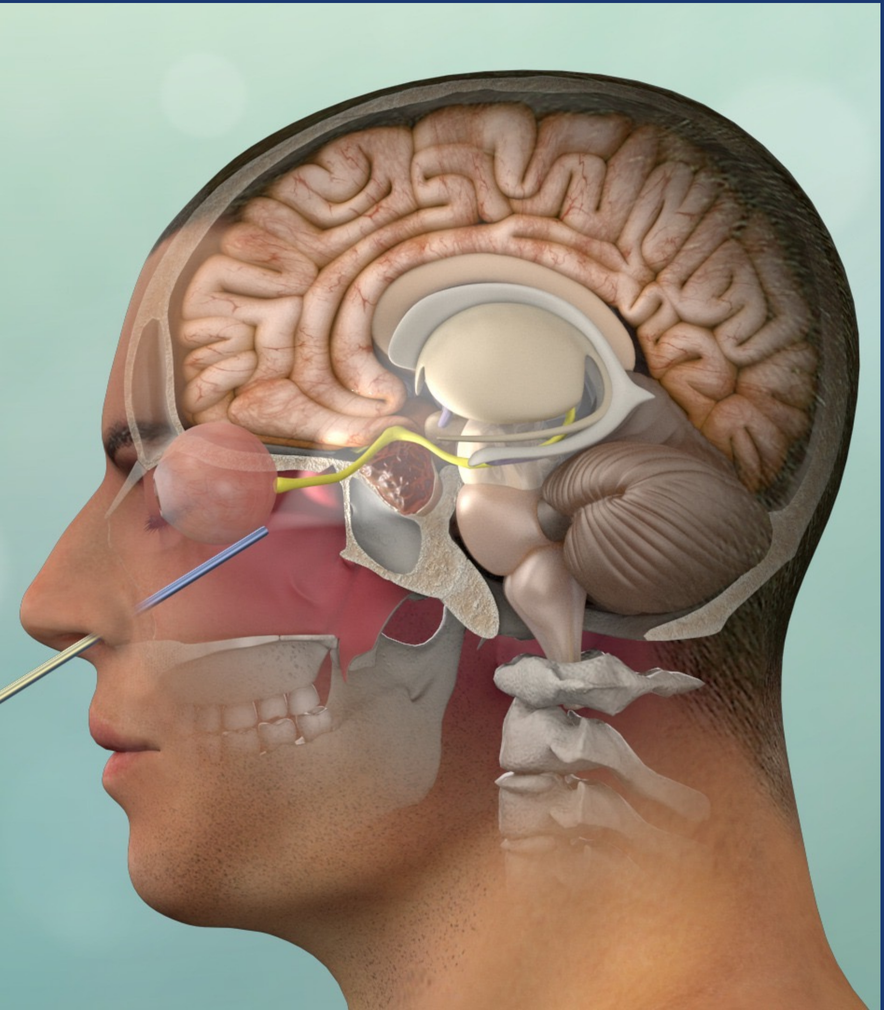


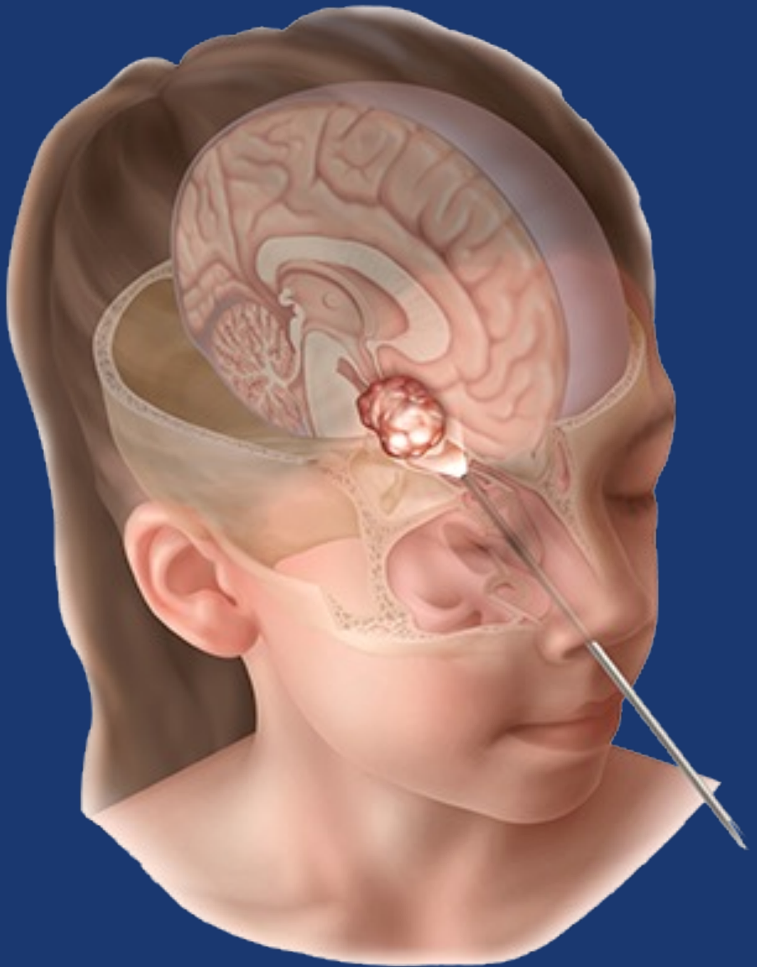
Drawbacks of Open Surgery

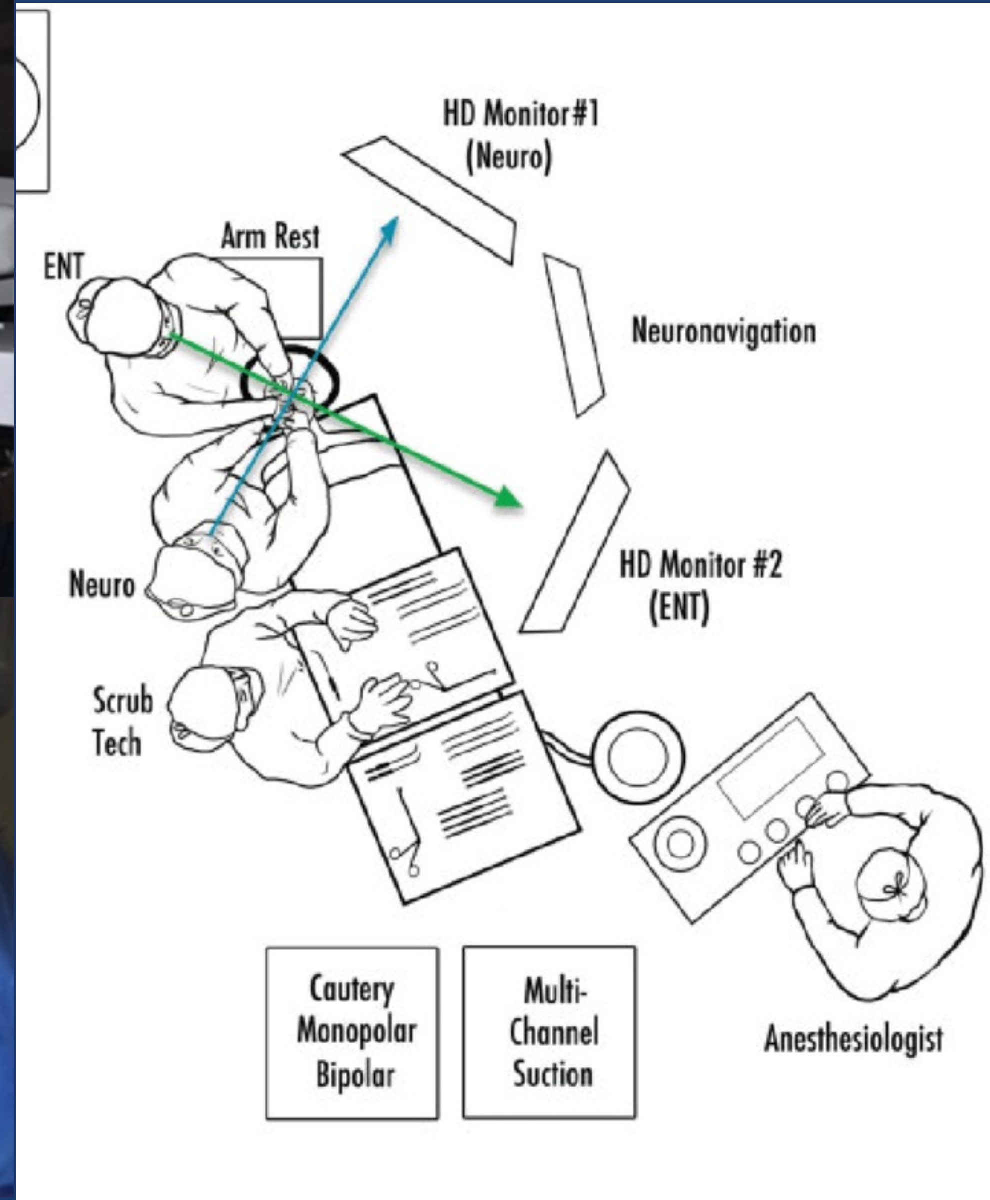
Wound healing, infection, neurological damage, etc

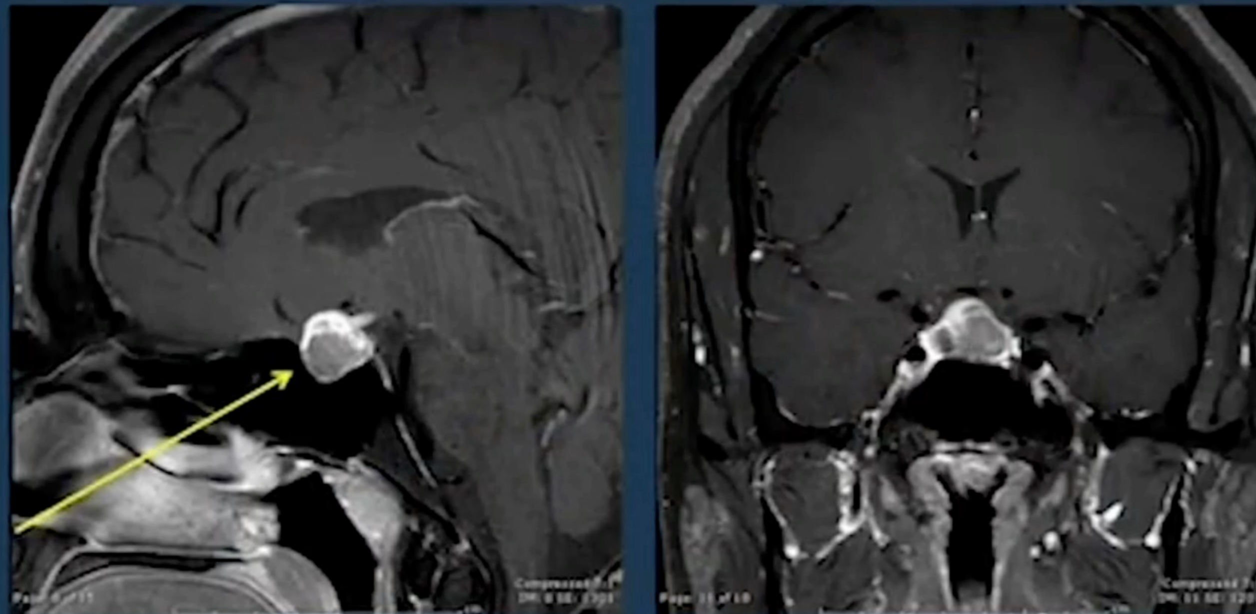
Alternative to an **open** approach?

Endoscopic Endonasal Approach






HD Monitor#1
(Neuro)
Arm Rest
ENT
Neuronavigation
Neuro
HD Monitor #2
(ENT)
Scrub
Tech
Cautery
Monopolar
Bipolar
Multi-
Channel
Suction
Anesthesiologist



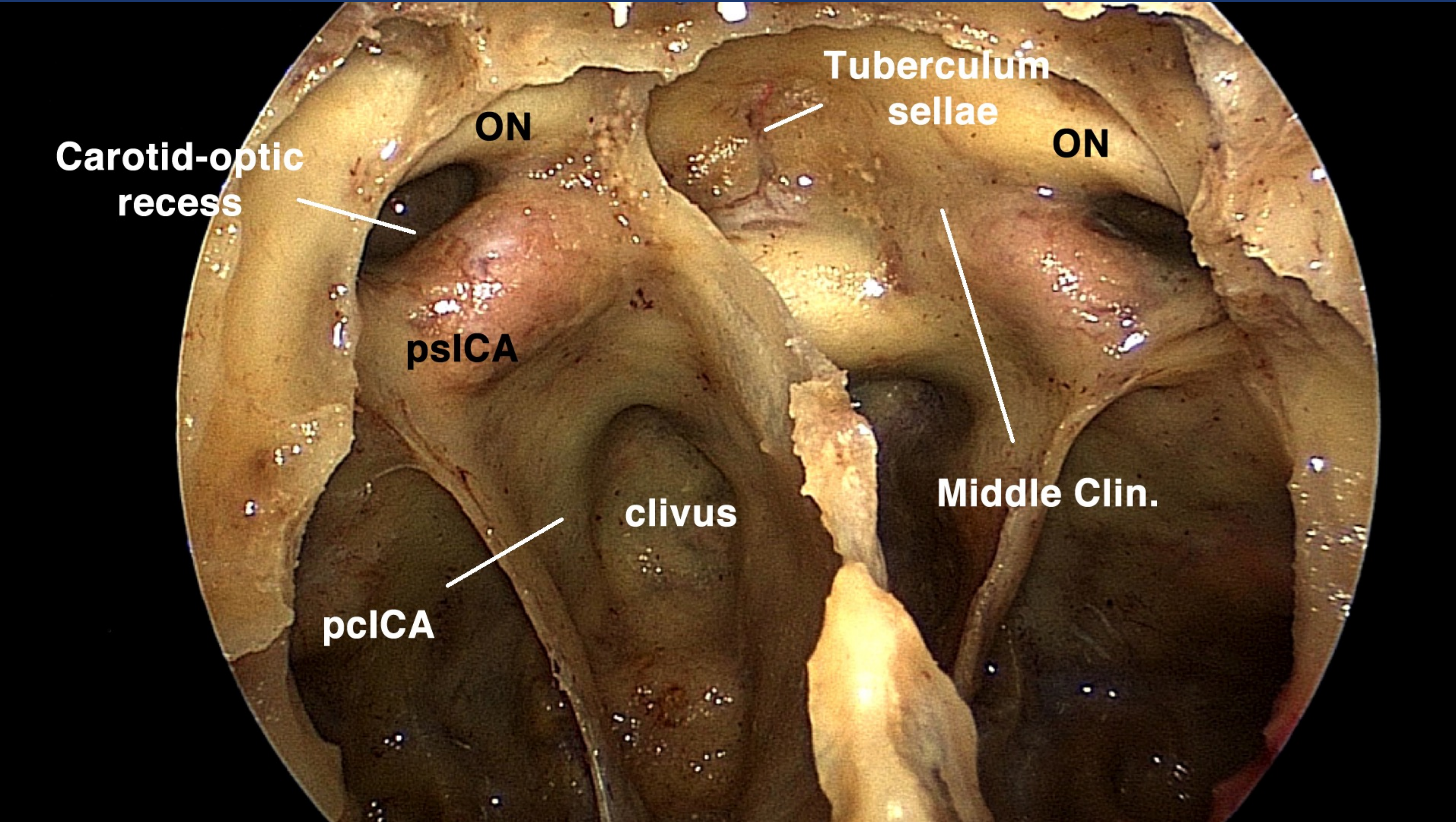
Endonasal endoscopic removal of pituitary macroadenoma

PACIFIC NEUROSCIENCE INSTITUTE®

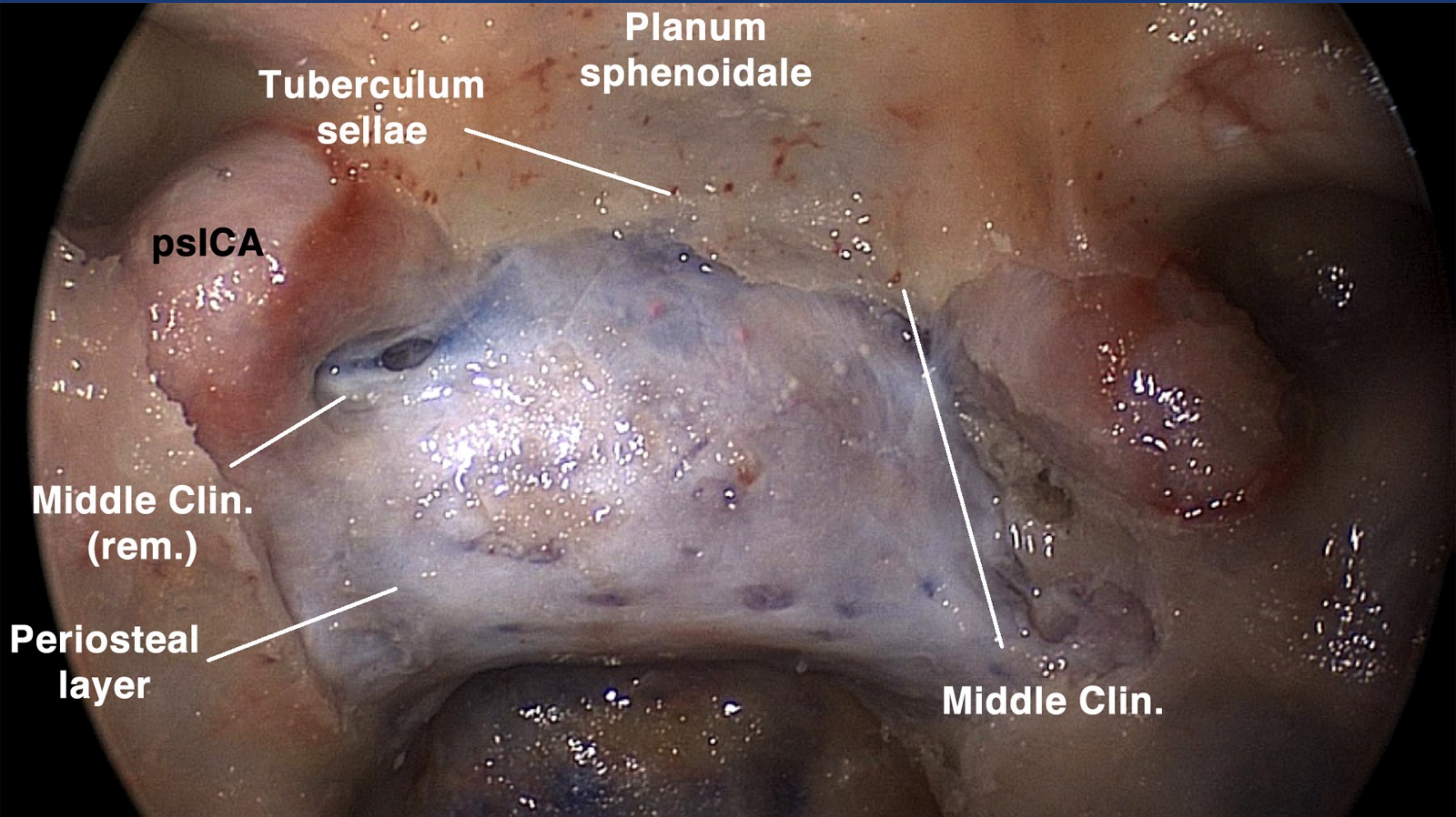
is shown. The initial portion of the
procedure involves removing bone at the

PNI

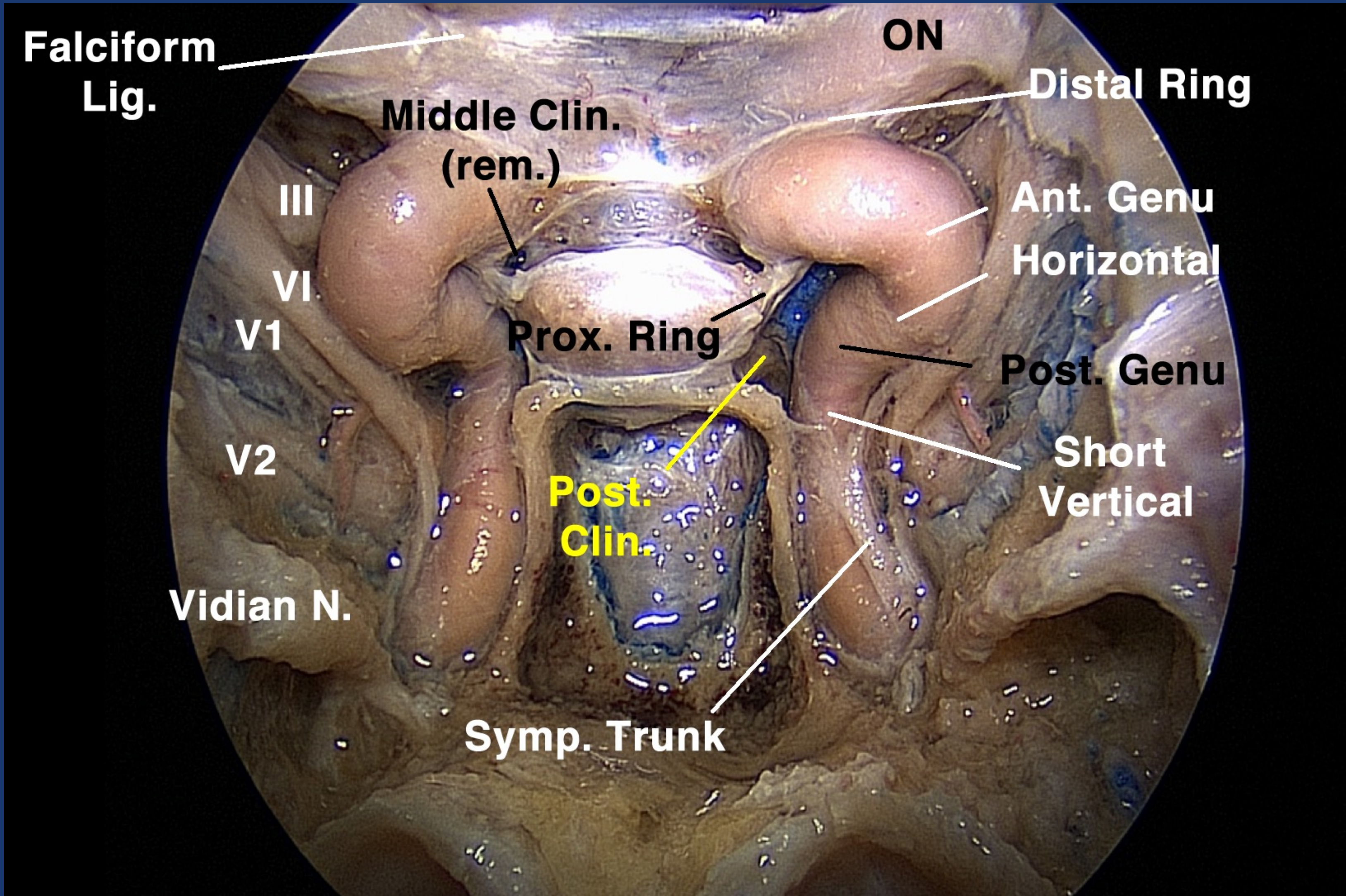
Endoscopic Endonasal Approach

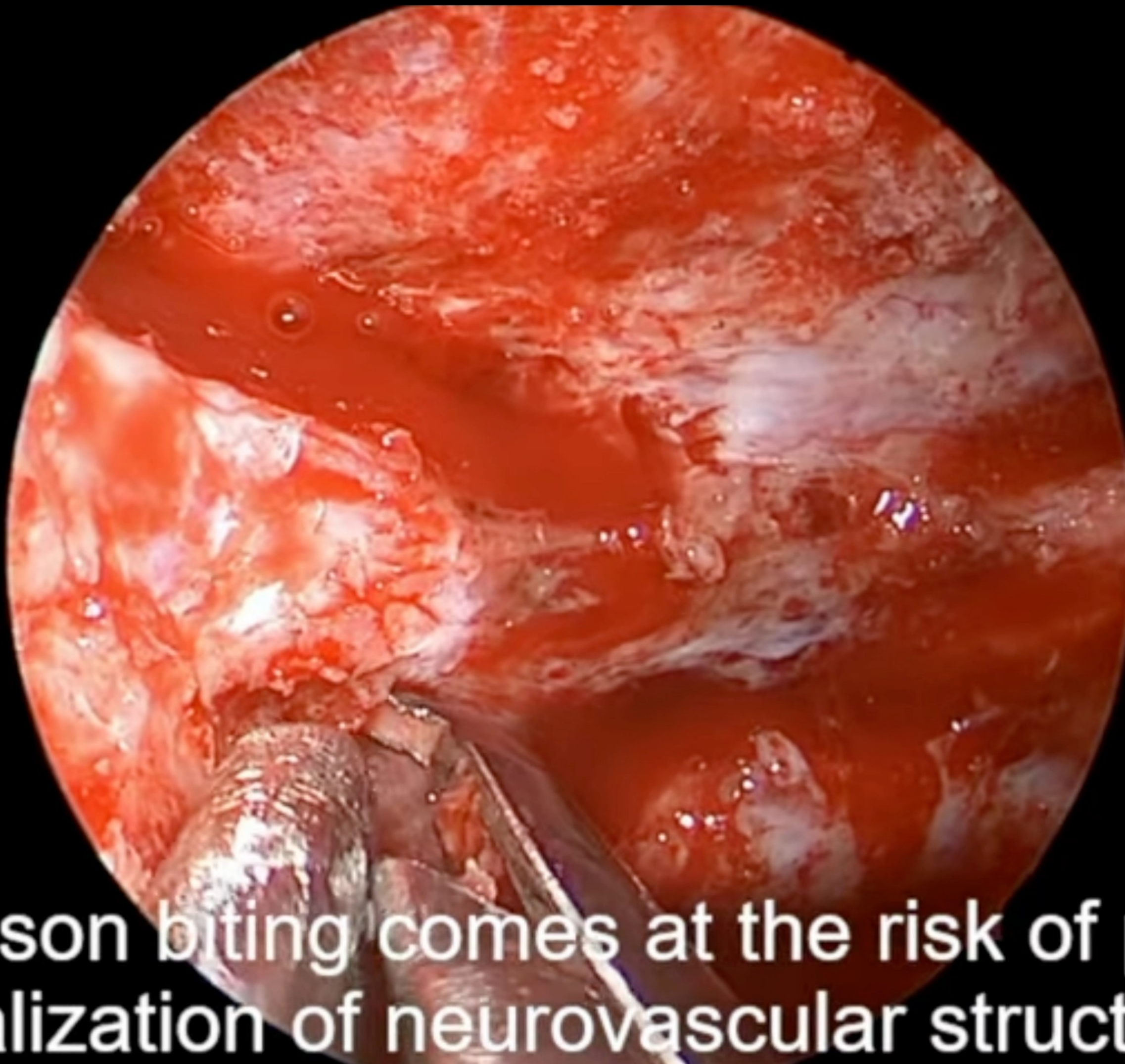


Endoscopic Endonasal Approach

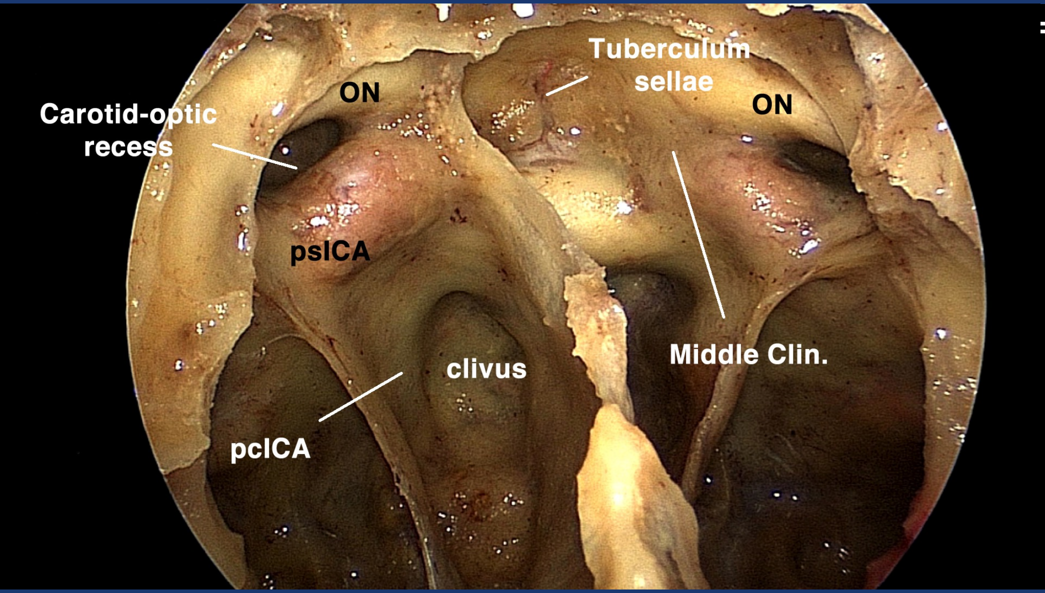


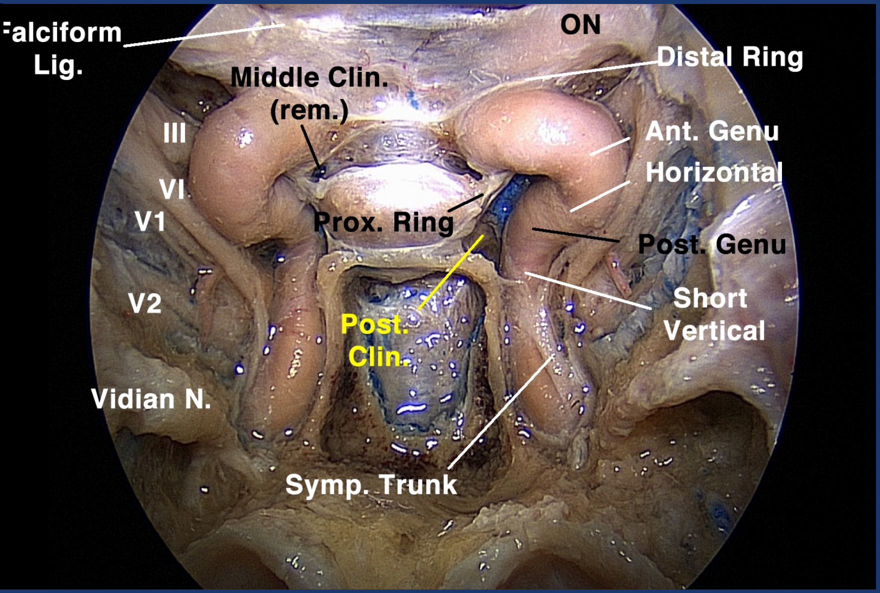
Endoscopic Endonasal Approach



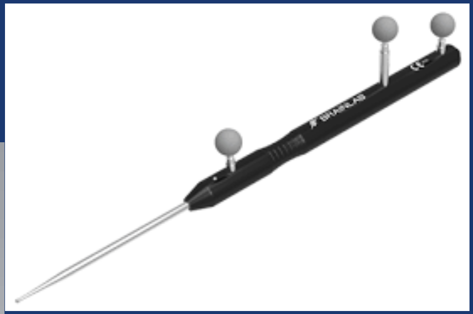

Kerrison biting comes at the risk of poor visualization of neurovascular structures

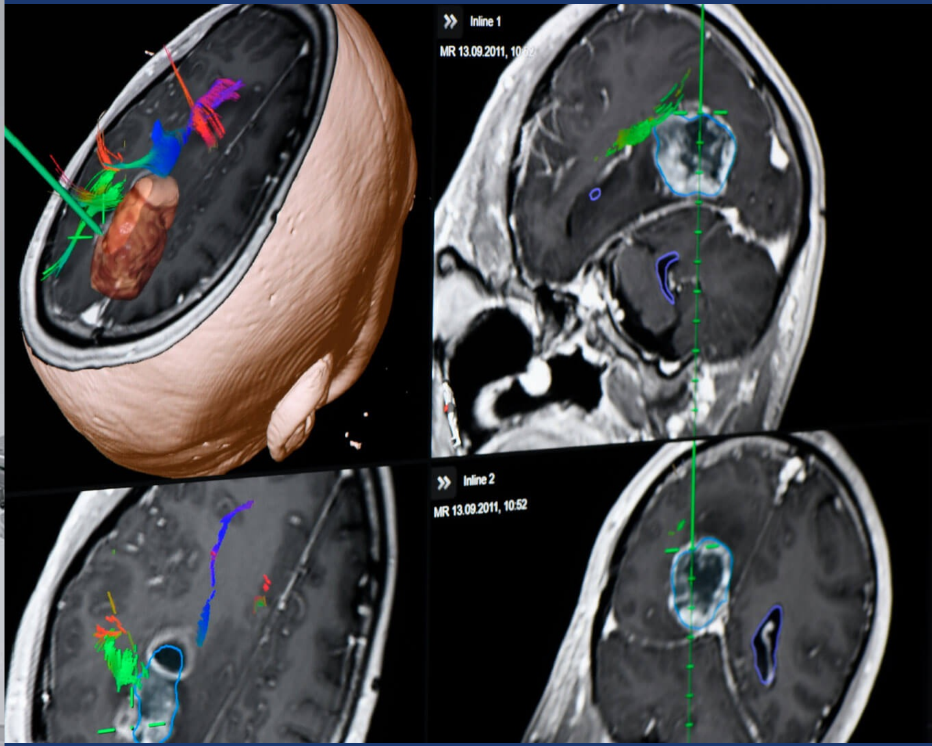
How then is surgery safely performed around such high-stakes anatomy?

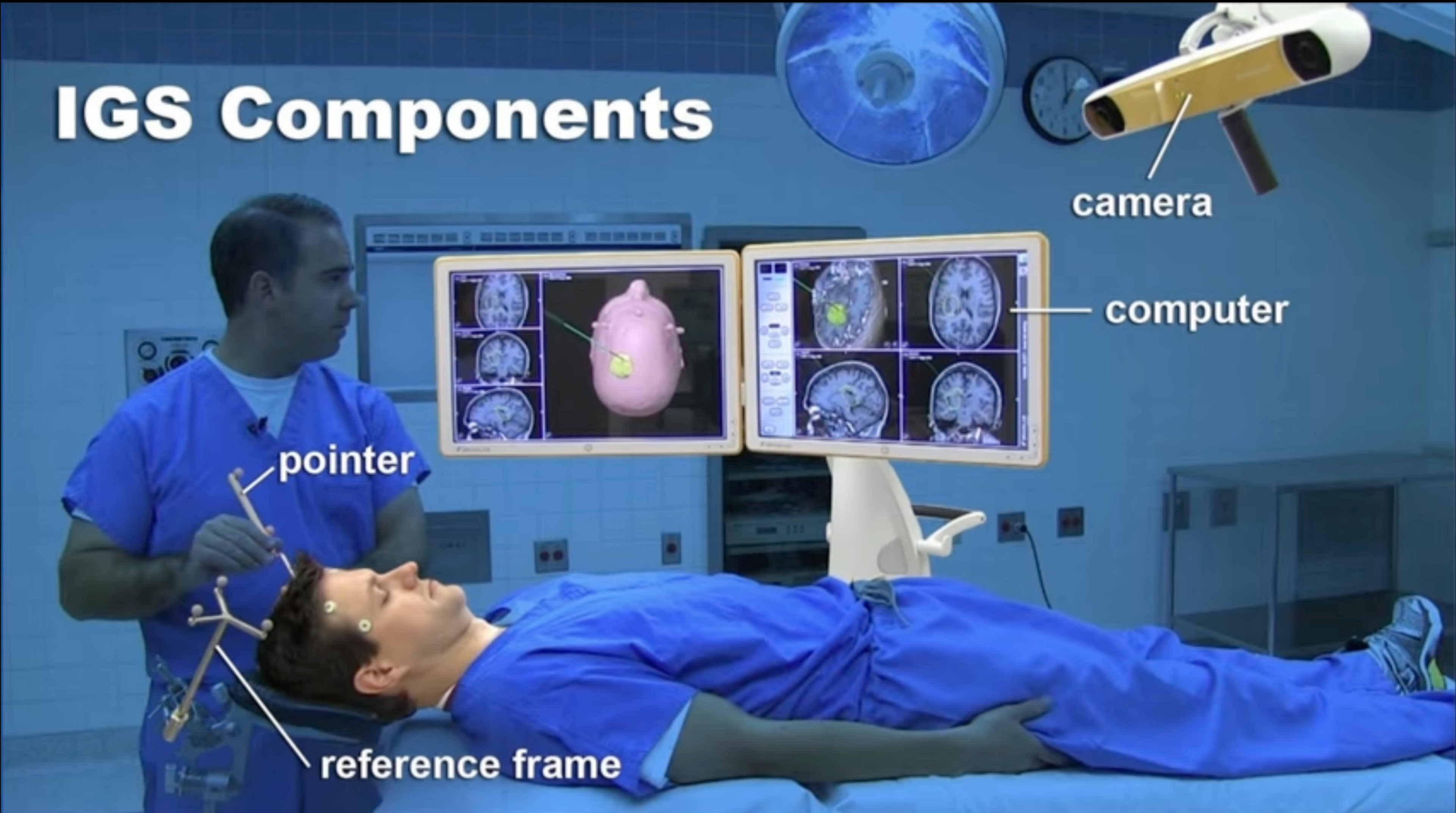




Surgical Navigation Systems






IGS Components
camera
computer
pointer
reference frame

Surgical Navigation

Registration defines a correlation between a reference point in a 3D data set such as CT or MRI with the corresponding reference point in a patient.

Most navigation systems achieve **position errors on the order of 2mm**

- Vulnerable to **physical displacement** or **computer malfunction**
- Requires **repeated visual confirmation** of registration accuracy during surgery

Surgical Navigation

Surgical navigation systems display the **same image information even as anatomy changes**.

- Relationship between endoscopic view and navigation view is **lost** over time

Intra-operative cone-beam or CT imaging is a way to **update** visualization

- BrainLab Brainsuite iCT
- Medtronic O-Arm system

Drawbacks of Intra-Operative CT

- Additional radiation, operative time, and costs.
- Inferior reconstruction quality if using cone-beam.

Rationale for improving navigation

- Enhance **patient safety** and **outcomes** by reducing potential **complications** and **radiation exposure**
- Reduce costs by improving **clinical workflow** and clarity of **intraoperative visualization**

How then do we **improve navigation** during **endoscopic endonasal surgery**?

Proposal:
Utilize images from the **endoscope** as a basis for **registration to pre-operative imaging** and **reconstruction** of anatomical surfaces.

Quantitative Endoscopy (QE)

Goal: transform the endoscope from a visualization device to an instrument for quantitative 3D measurement.

Endoscopic measurements combined with CT or MRI to provide:

- enhanced navigation (**goal accuracy 0.5mm**),
- tissue surface reconstruction,
- and fused image visualization.

Video-Based Navigation System Overview

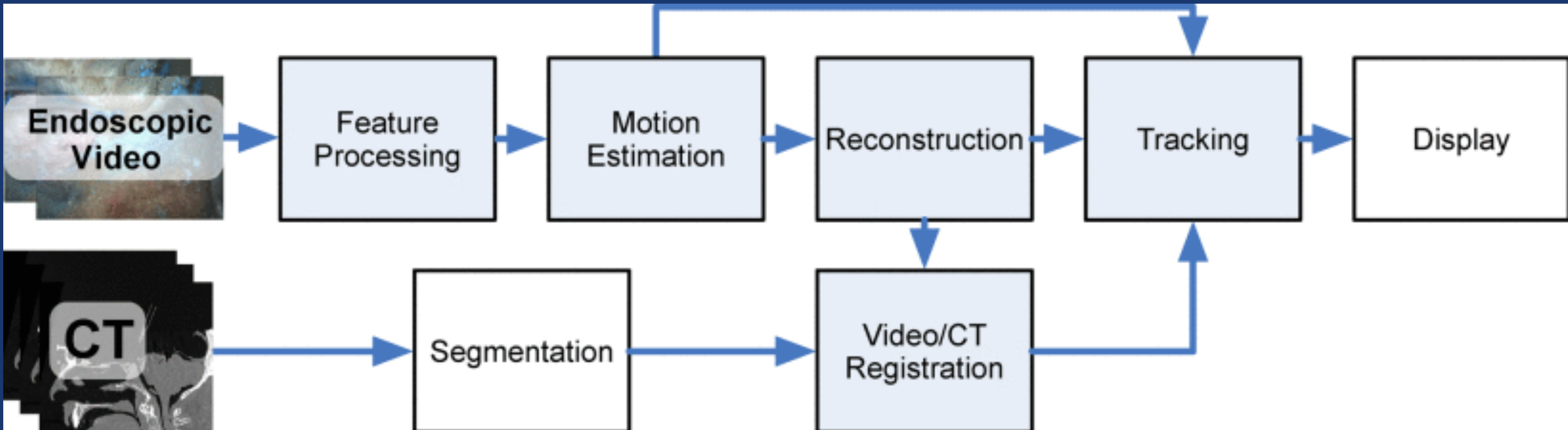
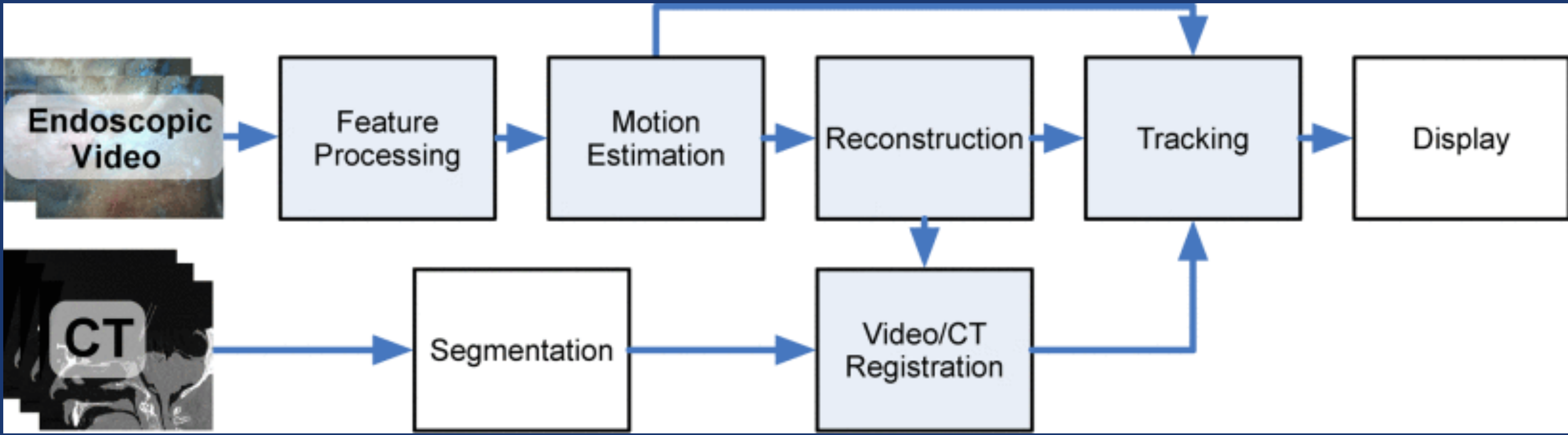


Image features detected and matched in two temporally adjacent images.

These matching pairs are then used to estimate the camera motion using a robust estimator we have developed

Video-Based Navigation System Overview



Once the camera motion is estimated, the 3D location of the matched features are reconstructed.

The reconstructed 3D surface points are then passed to the 3D-3D registration component.

Target Registration Error (TRE)

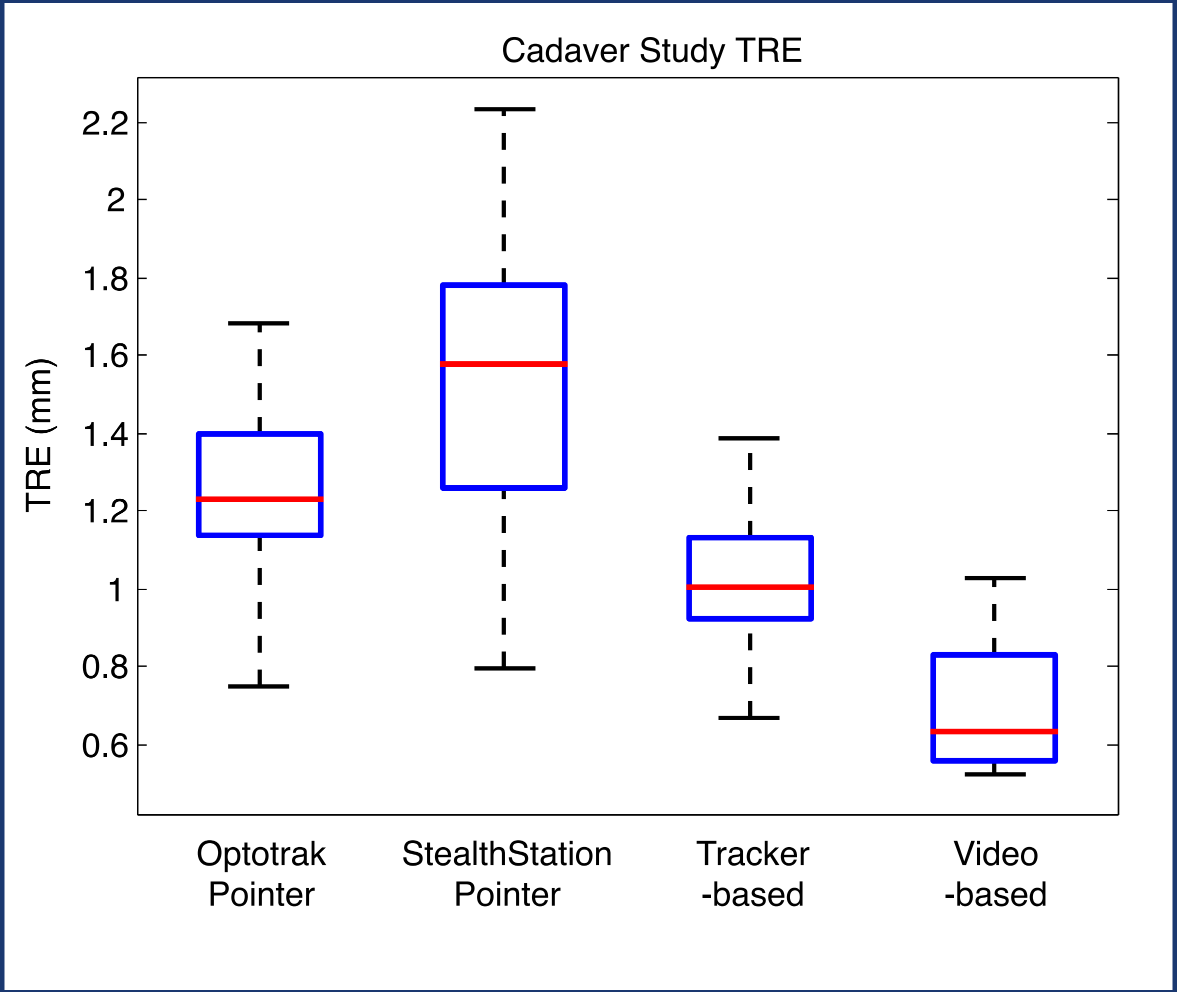
TRE_1	Metric for evaluating pointer-based methods
TRE_2	Metric for evaluating tracker-based and video-based methods
NGE	Same as TRE_2, however, the target is not visible in the endoscope image.

$$TRE_1 = \left\| \mathbf{p}_{CT} - \left({}^{CT}T_{Navigation} \right) \mathbf{p}_{pointer} \right\|$$

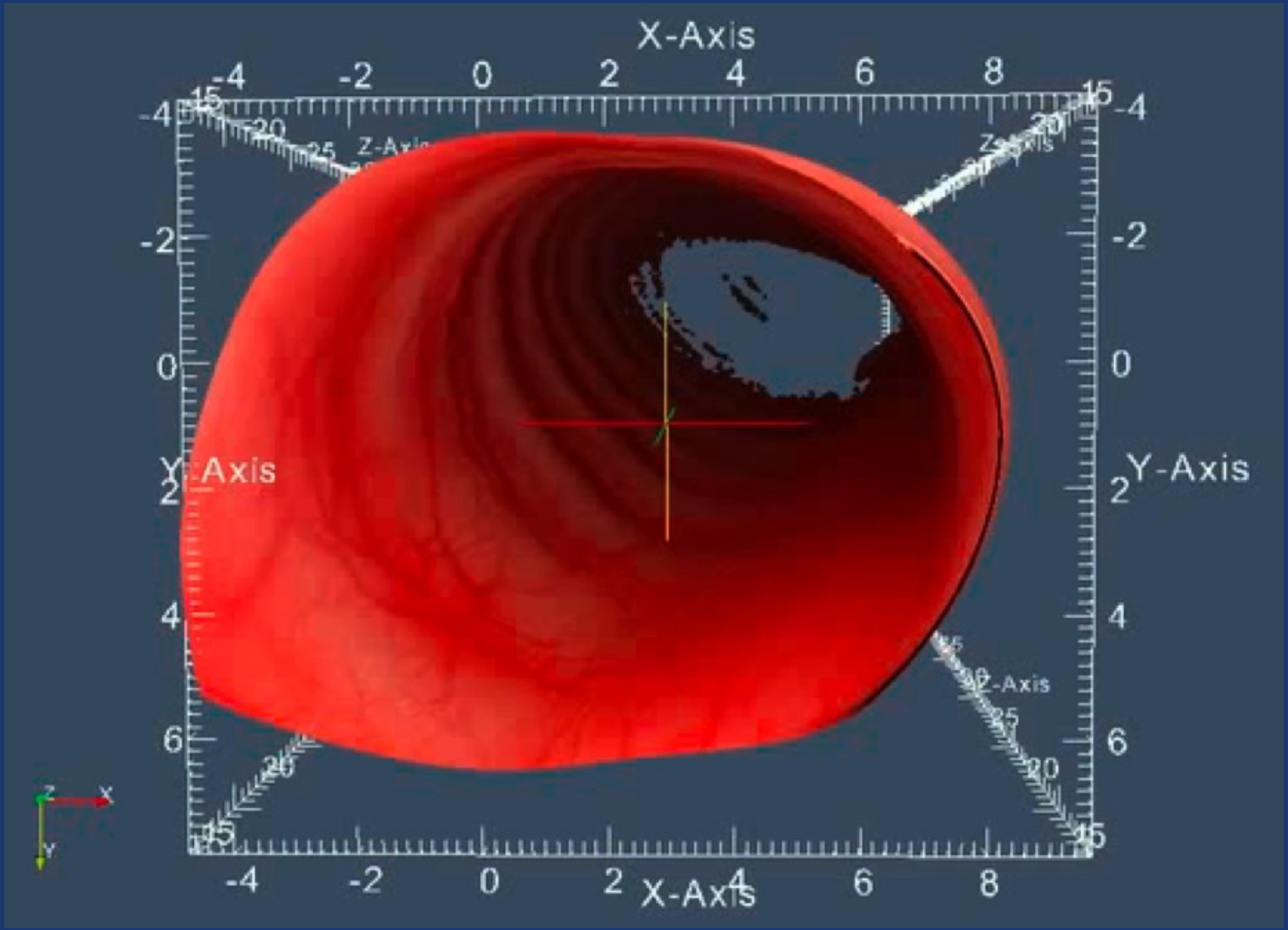
experir

$$TRE_2 = \left\| \mathbf{p}_{CT} - \left(\mathbf{t} + \mathbf{r} \left(\frac{\mathbf{r} \cdot (\mathbf{p}_{CT} - \mathbf{t})}{\mathbf{r} \cdot \mathbf{r}} \right) \right) \right\| \quad \text{where} \quad \mathbf{r} = RK^{-1}\mathbf{q}_{image} - \mathbf{t},$$

Key result: TREs using video-CT methods are measurably improved over traditional methods



Key result: tissue surfaces can be reconstructed in 3D using endoscope video.



Quantitative Endoscopy (QE)

Incorporation of computational vision algorithms with traditional navigation methods provides several benefits.

- Improves usability of **existing** navigation technology in sinus surgery with **no additional cost or equipment**.
- **Minimal disruption** to the surgical workflow.

Next Steps: Translation to Sinuses/Skull Base

- **Aim #1:** Develop video-CT registration algorithms that are accurate to CT resolution.
- **Aim #2**: Develop methods for surface shape estimation from endoscopic images.
- **Aim #3:** Perform comparative evaluation of video-CT-based navigation on patient data.
- **Aim #4:** Assess the accuracy and reliability of intraoperative surface estimation on patient data.


CAUTION
X-RAY RADIATION
Loop-X

Sinus Reconstruction

Outline

- Neurosurgery: An Overview
- History of Neurosurgery at Johns Hopkins
- Computer Integration to Modernize Neurosurgery
- Computer Integration to Improve Surgical Training

Technology is also being leveraged to **improve traditional surgical methods** and our **training system**.

Constraints of Modern Surgical Training

Surgical training translates to

- prolonged operative times,
- increased resource usage,
- and therefore, higher operating room costs.[1]

Constraints of Modern Surgical Training

In 2003, the ACGME mandated an 80-hour duty limit on residents.

- This modernization required that surgeons be **trained in fewer hours**, and therefore **more efficiently**.

Accreditation Council for Graduate Medical Education

Constraints of Modern Surgical Training

Surgical training is **susceptible to bias**

- Female trainees are more likely to receive **negative assessments** compared to males.[2-5]
- Bias may be an **assumption of a resident's skill** based on years of training.

Constraints of Modern Surgical Training

The **Objective Structured Assessment of Technical Skills (OSATS)** is a proposed solution for bias.[6]

Time and motion				
1	2	3	4	5
Highly tentative, unsure of movements		Efficient, but somewhat tentative, with some unnecessary moves		Clear economy of movements and maximum efficiency
Needle Insertion and bite sizes				
1	2	3	4	5
Inappropriate needle positioning and bite sizes resulting in poor suture placement		Generally appropriate techniques with some room for correction		Appropriate needle angle and size and distance of bites every time

- The OSATS is dependent on the presence of examiners, and thus **prone to subjectivity**.[7]

Advances in Modern Surgical Training

Artificial intelligence models of surgical ability have successfully measured:

- task completion time,
- motion smoothness,
- positioning/angling,
- bleeding amount,
- and kinematics such as applied force, speed, or acceleration.[10-12]

Advances in Modern Surgical Training

AI can assess skill level in surgical video with **overall accuracy between 92.75 and 100%** depending on the observed task.[13,14]

ML algorithms can also **match human expertise** in providing objective assessments of surgical skill.[10,15–18]

- AI may also be used to **predict surgical resident performance** to help **tailor training for at-risk residents**.[19,20]

The most common method for determining operative skill level through ML methods has been **retrospective, video-based assessment.**

To date, there has **not been an intra-operative use** of ML to provide real-time feedback for neurosurgeons.

Our aim is to **standardize** and **optimize neurosurgical resident education** by utilizing **machine learning** to provide both **real-time and longitudinal, non-biased feedback**.

Project Overview

Aim 1: Define a "gold standard" for craniotomy performance through review of intraoperative point-of-view video.

Aim 2: Develop a deep learning algorithm that compares trainee to attending performance during a craniotomy.

Aim 3: Assess the impact of real-time feedback on trainee performance in a cadaveric model of craniotomy.

Aim 4: Prospectively compare the impact of and bias within resident, attending, and AI feedback on resident performance.

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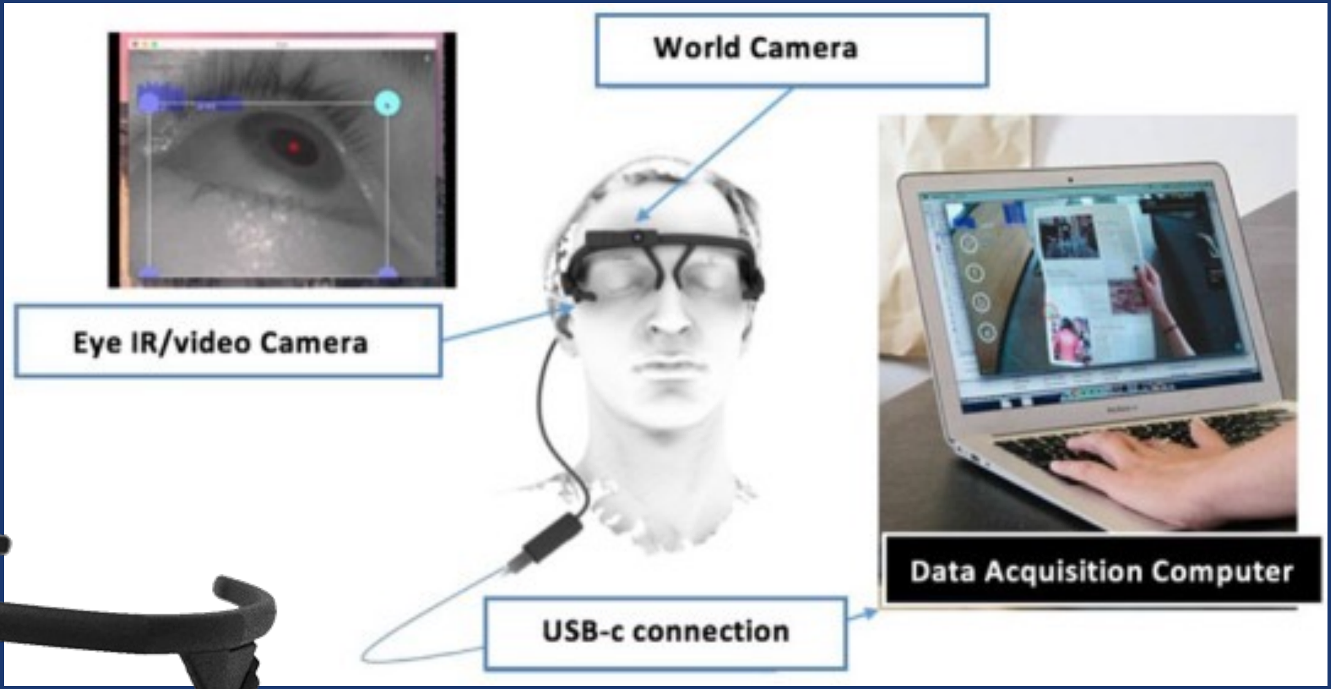
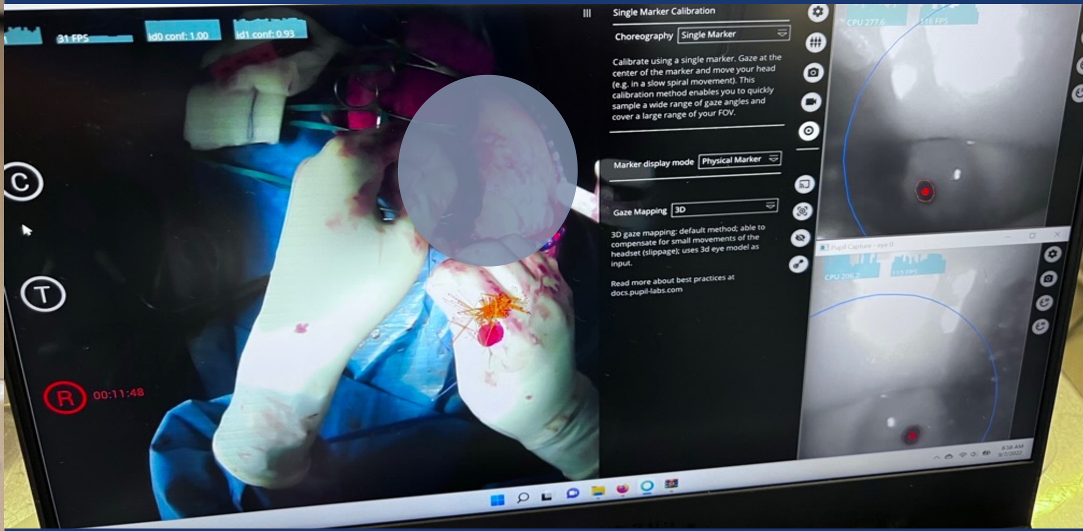
POV craniotomy video recorded from residents and attendings



Pupil Labs

Aim 1: Define a "gold standard" for craniotomy performance through review of intraoperative point-of-view video.



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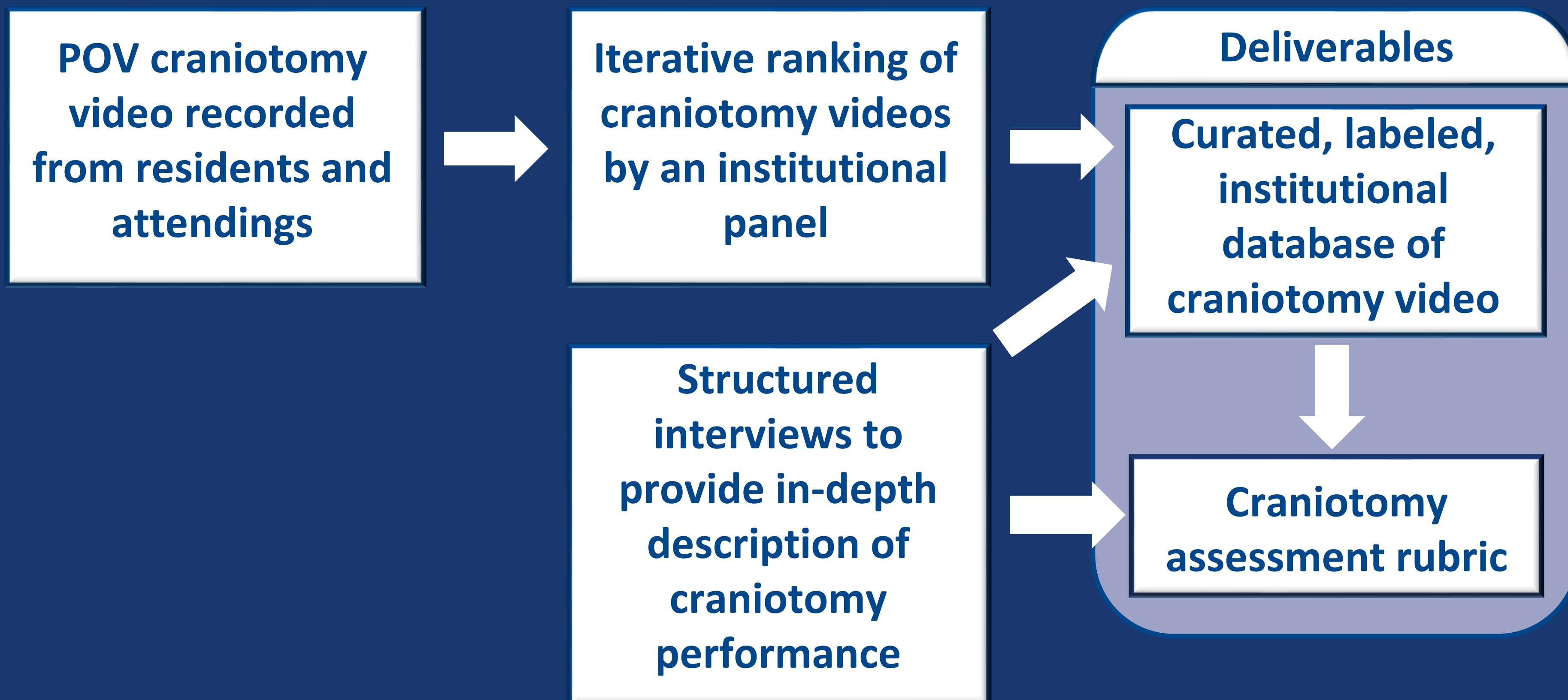

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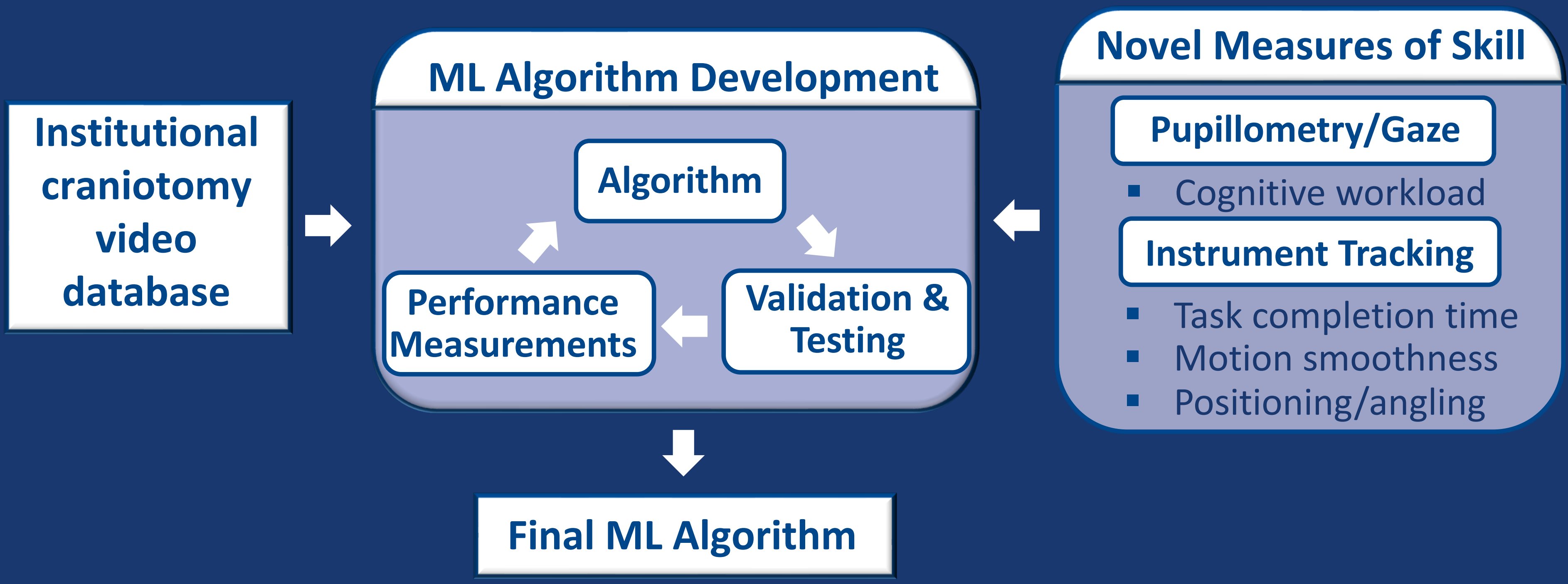

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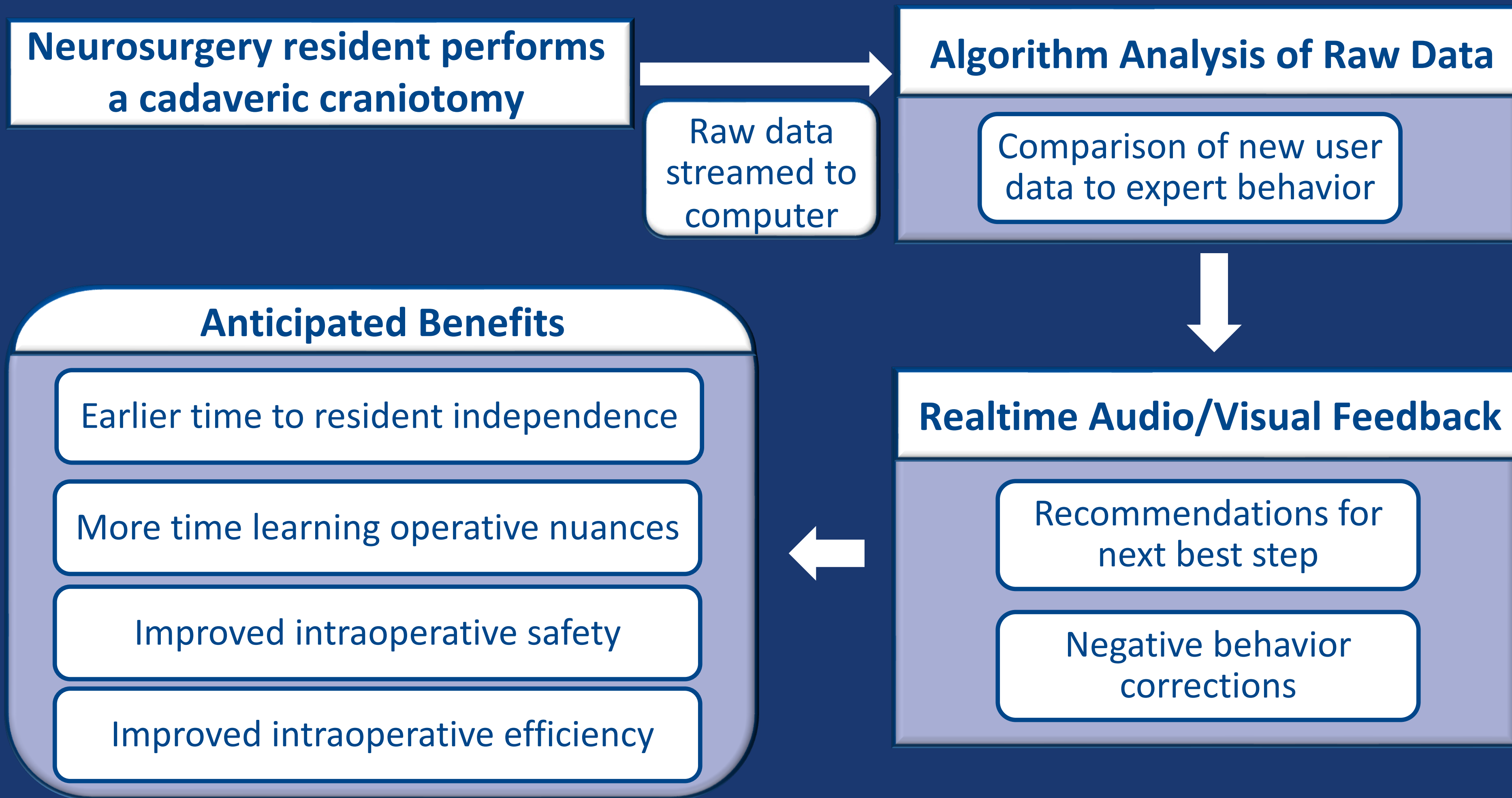

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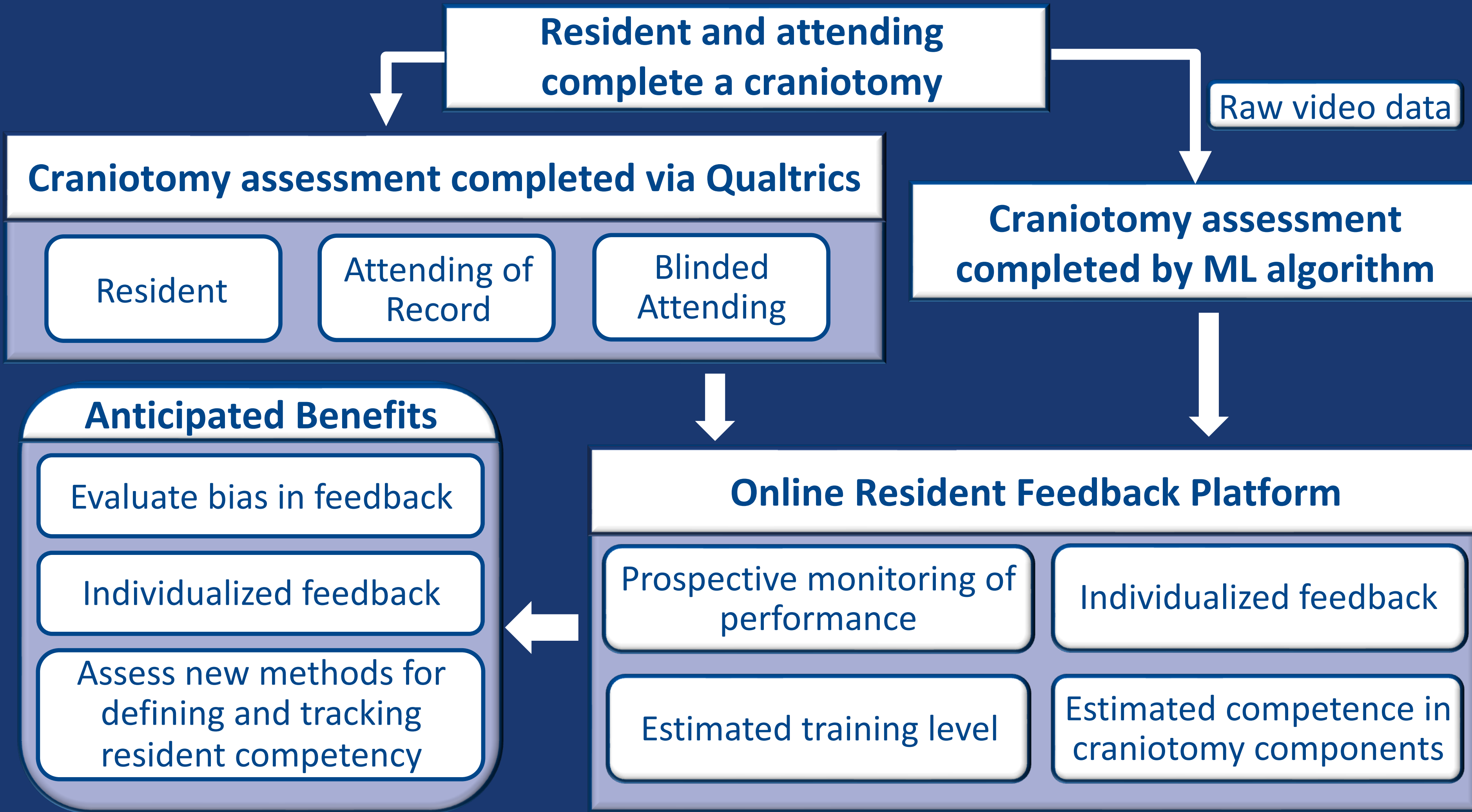
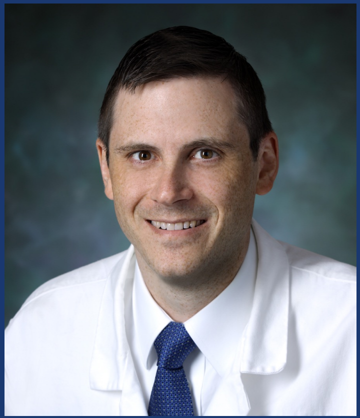
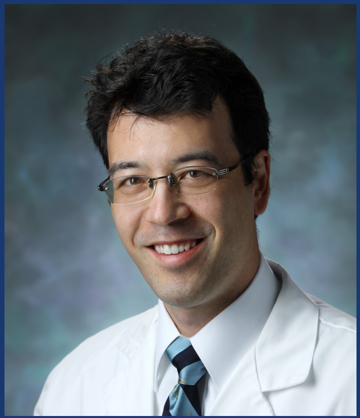


Mentorship/Collaboration

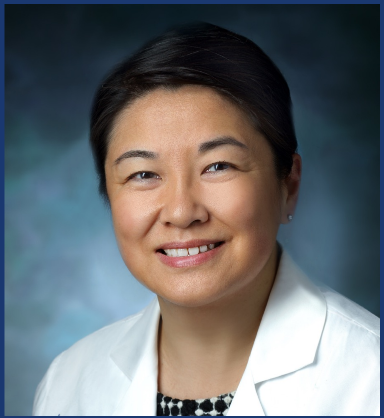


Gary Gallia, MD, PhD



Masaru Ishii, MD, PhD

Mathias Unberath, PhD

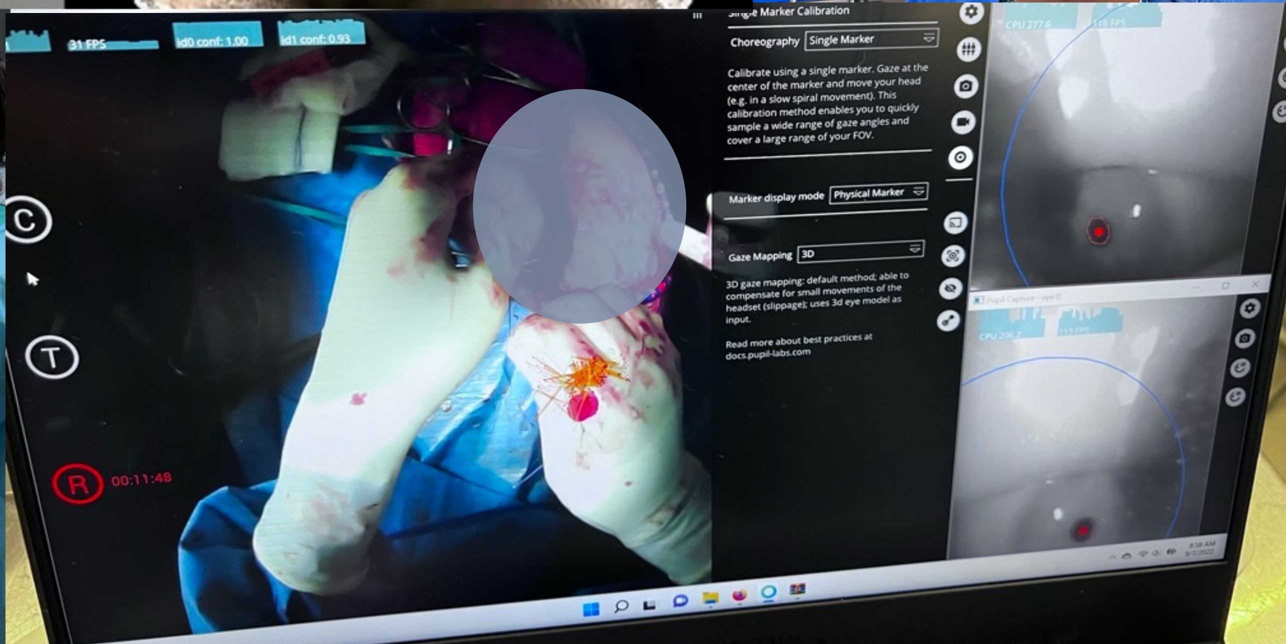


Judy Huang, MD

Henry Brem, MD

Russell Taylor, PhD

Questions?


31 FPS
id0 conf: 1.00
id1 conf: 0.93
Choreography
Single Marker
Calibrate using a single marker. Gaze at the center of the marker and move your head (e.g. in a slow spiral movement). This calibration method enables you to quickly sample a wide range of gaze angles and cover a large range of your FOV.
Marker display mode
Physical Marker
Gaze Mapping
3D
3D gaze mapping: default method; able to compensate for small movements of the headset (slippage); uses 3d eye model as input.
Read more about best practices at docs.pupil-labs.com
00:11:48

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