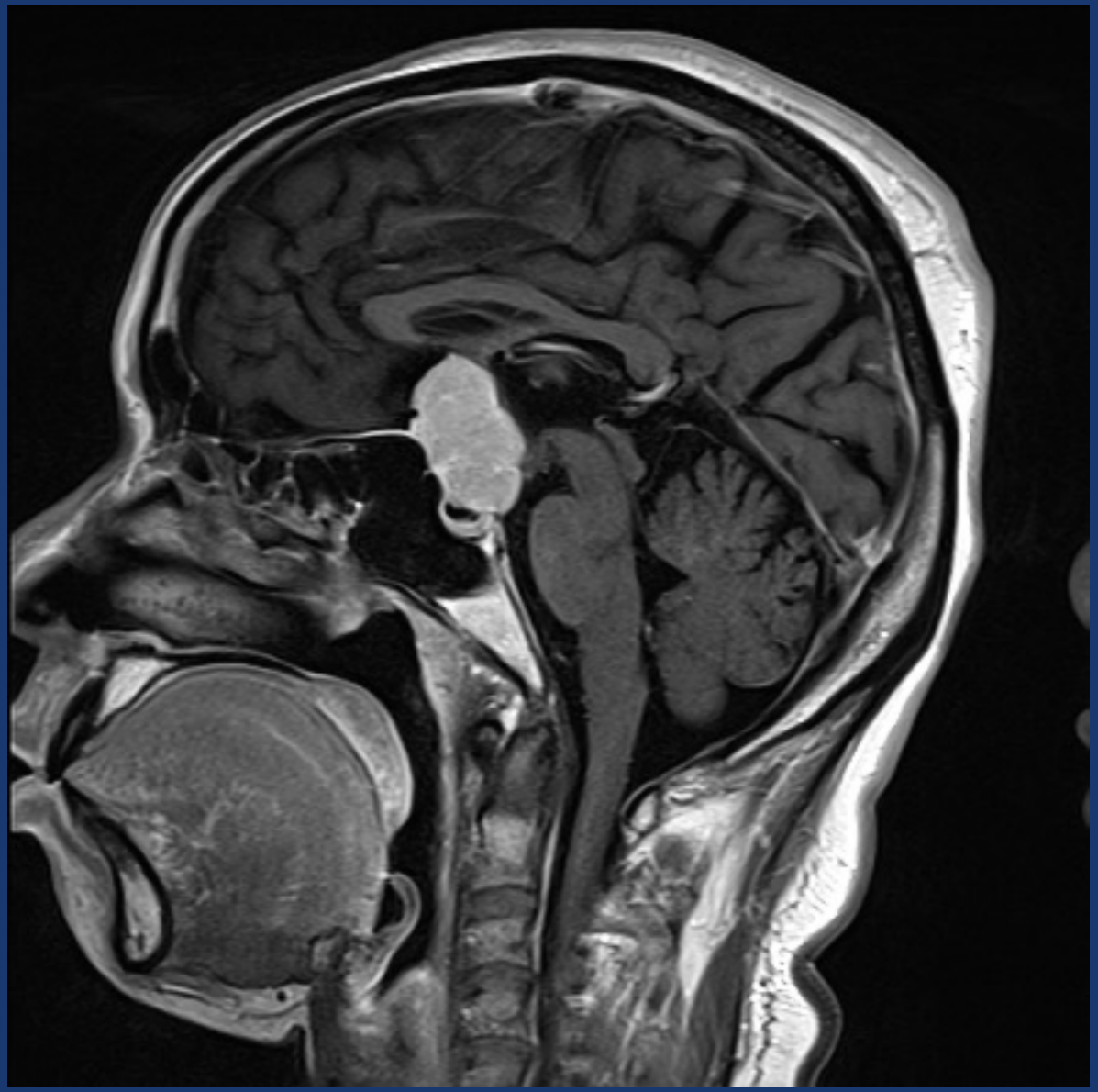


Computer-Integrated Surgery: Applications in Neurosurgery

Jose “Tito” Porras, MD

October 10, 2023

Disclosures

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

Outline

- Neurosurgery: An Overview
- Computer Integration to Modernize Neurosurgery
- Robotics in Neurosurgery

Outline

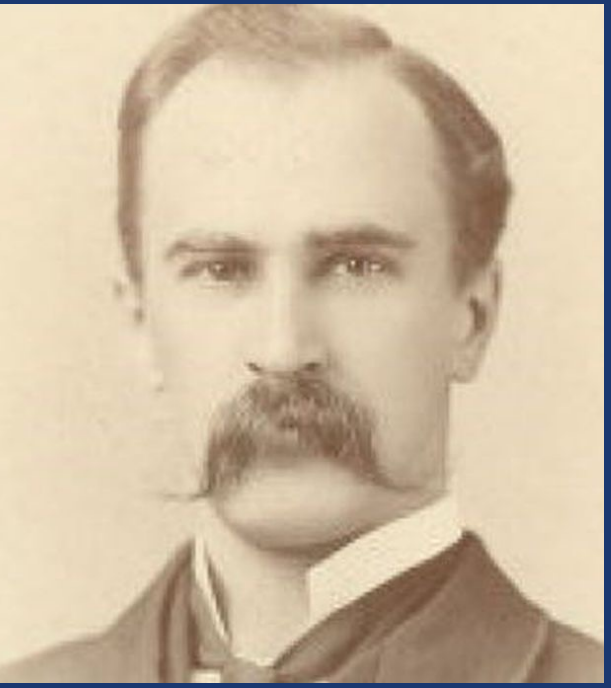
- Neurosurgery: An Overview
- Computer Integration to Modernize Neurosurgery
- Robotics in Neurosurgery

1889 – Johns Hopkins Hospital founded

Harvey Cushing

1896 – Surgical assistant to **William Halsted**

Osler



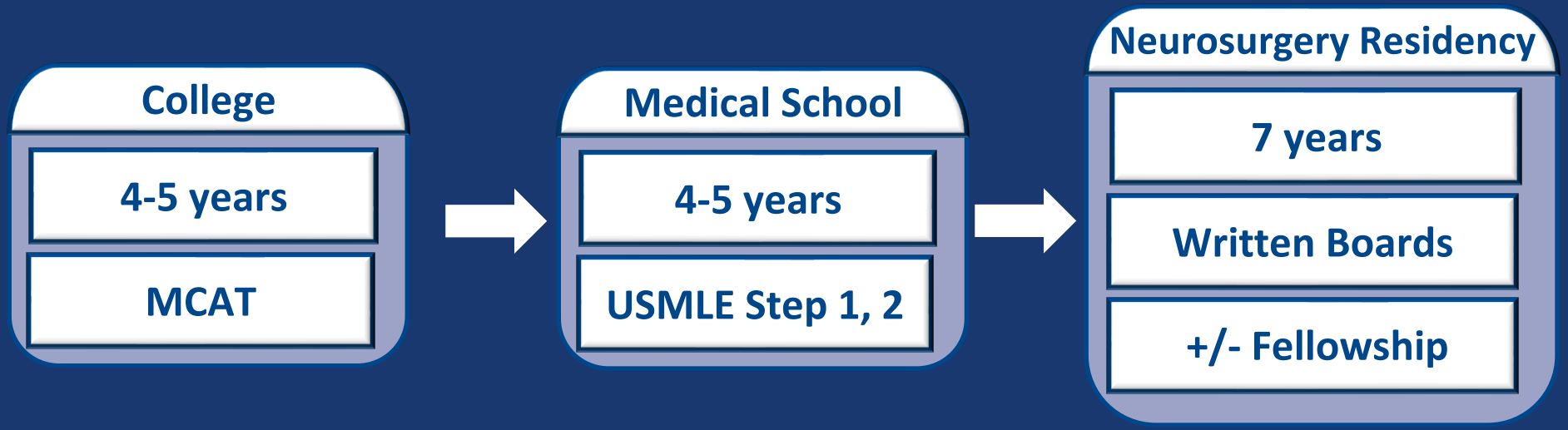
Cushing

Halsted

Harvey Cushing – founded modern neurosurgery at Hopkins

The Department of Neurosurgery

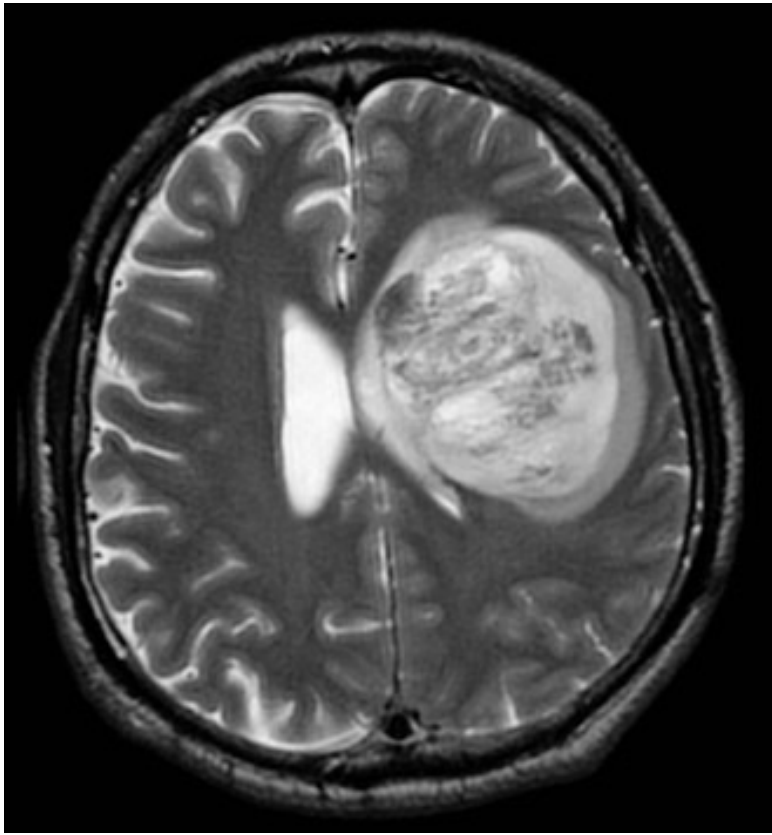
Path to becoming a neurosurgeon



Tumor – Neuro-Oncology

Comprehensive management of brain tumors.

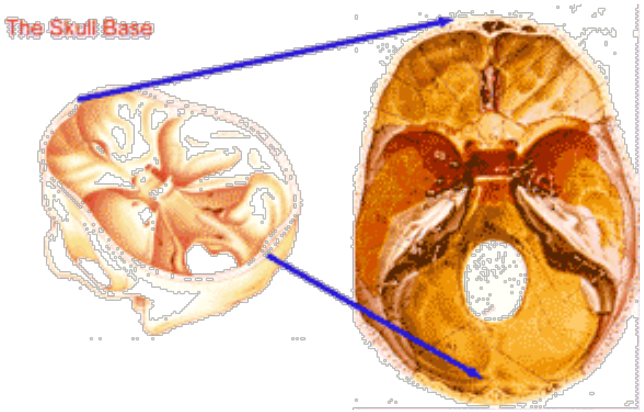
- Awake surgery
- Electrophysiological mapping
- Laser-induced thermal therapy
- Gamma Knife radiosurgery



Tumor – Skull Base

Emphasis on tumors arising along base or floor of skull

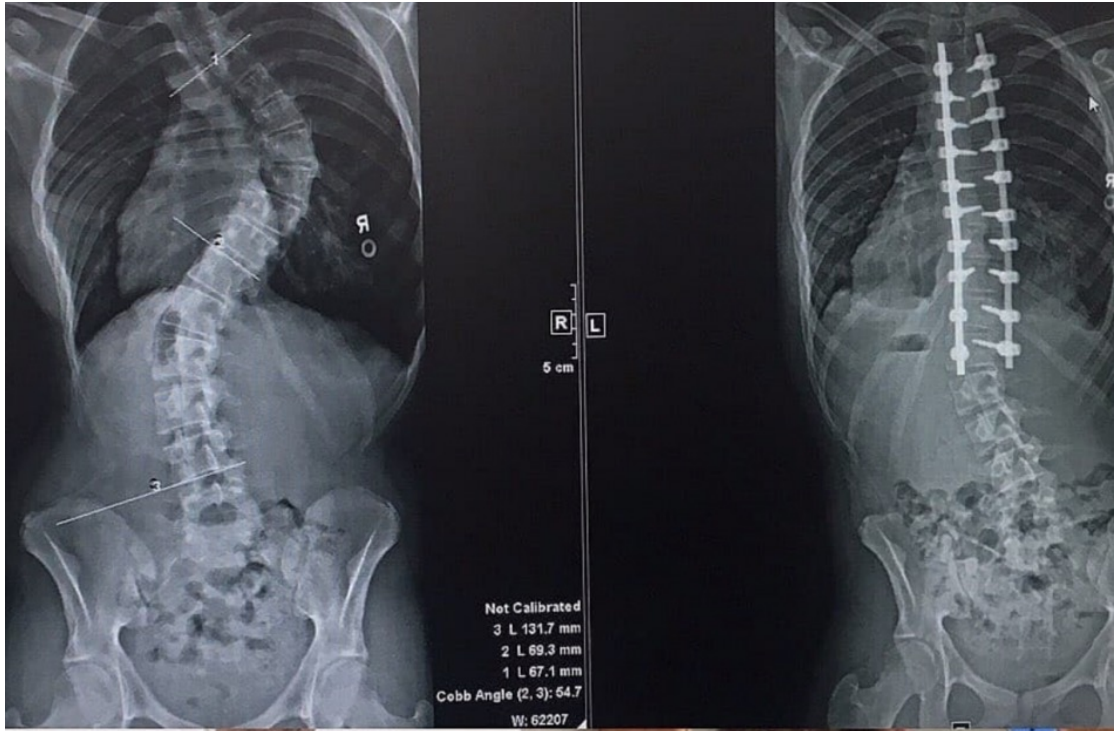
- Transcranial microsurgical approaches
- Endoscopic endonasal surgery
- Transorbital surgery
- Endoscopic/exoscopic port surgery



Spine

Craniocervical, cervical, thoracic, lumbar, sacral spine

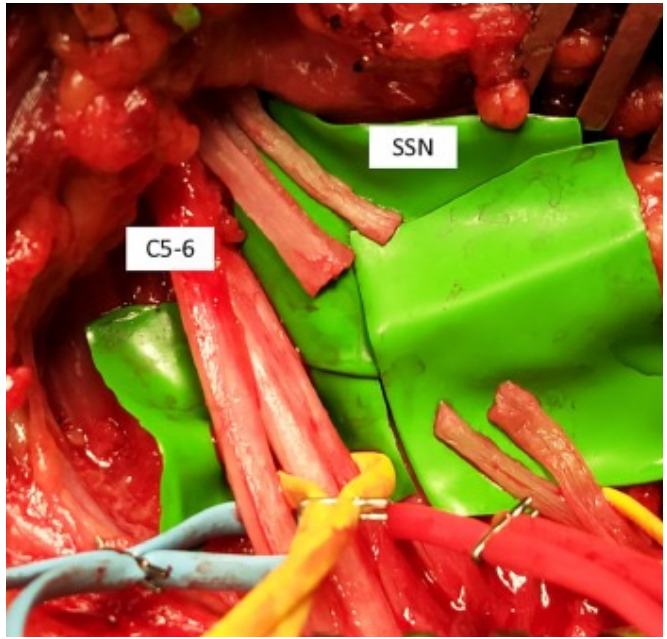
- Degenerative
- Trauma
- Congenital
- Tumor
- Infection/Inflammatory

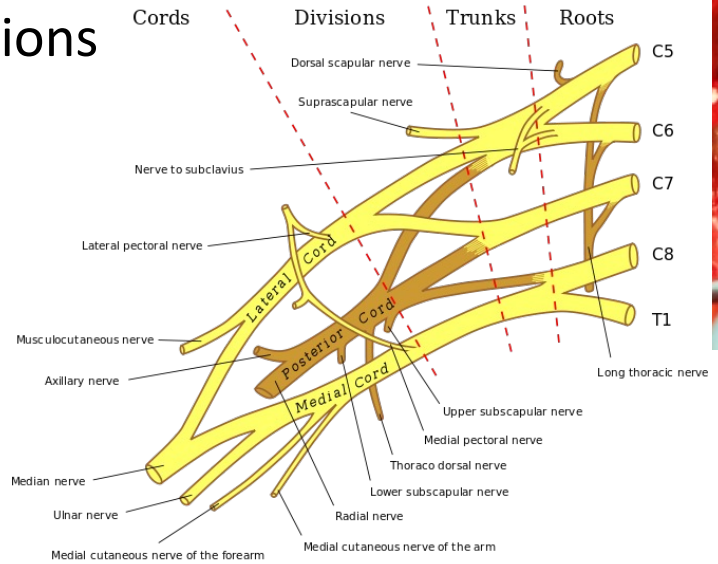


Peripheral Nerve

Nerves outside the brain/spinal cord including brachial plexus

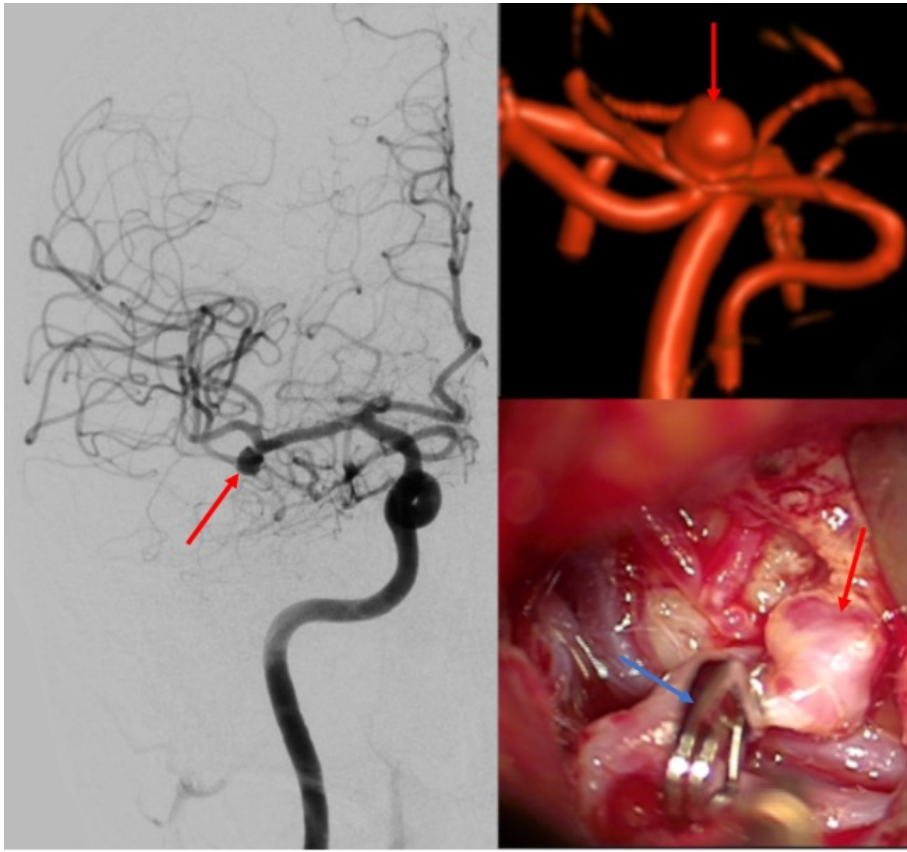
- Brachial plexus injuries
- Metabolic and other neuropathies
- Compression syndromes
- Inflammatory lesions
- Tumors
- Pain





Vascular - Open

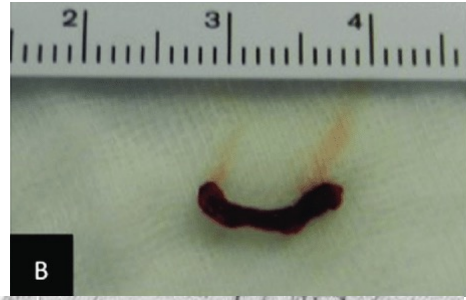
- Aneurysms
- Arteriovenous malformations
- Cavernous malformations
- Fistulas
- Carotid stenosis
- Developmental

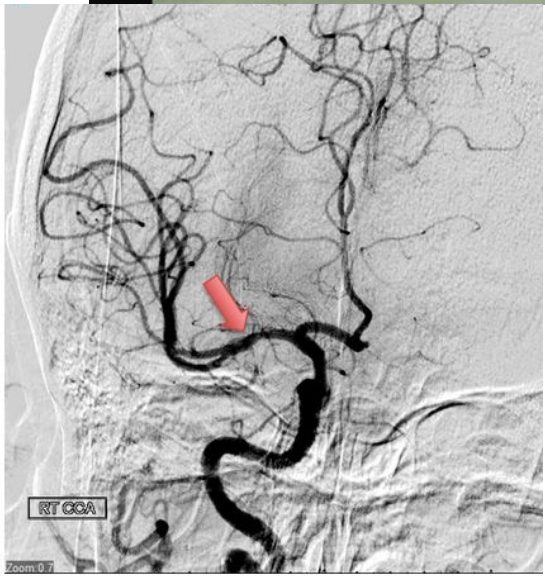


Vascular - Endovascular

Minimally invasive, access through peripheral arteries

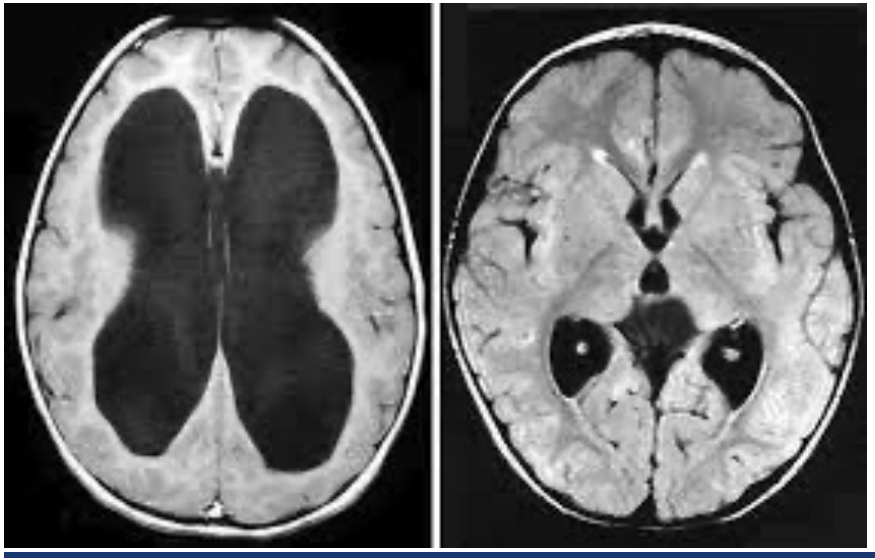
- Aneurysms
- Arteriovenous malformations
- Cavernous malformations
- Fistulas
- Carotid stenosis
- Developmental
- **Stroke**

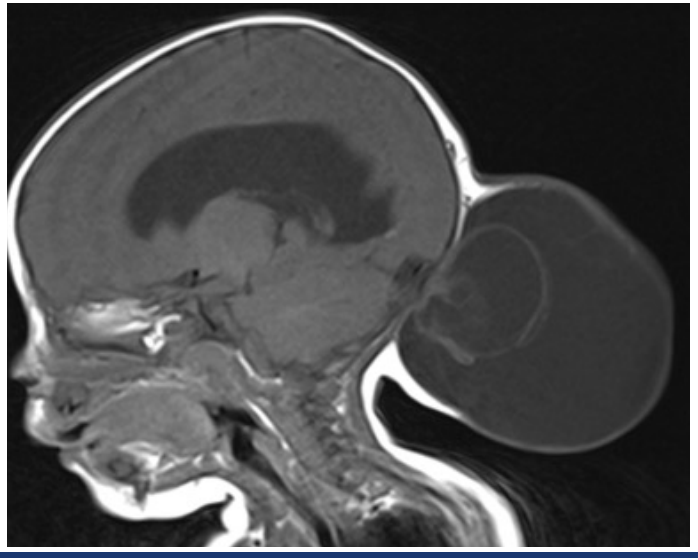




Pediatrics

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

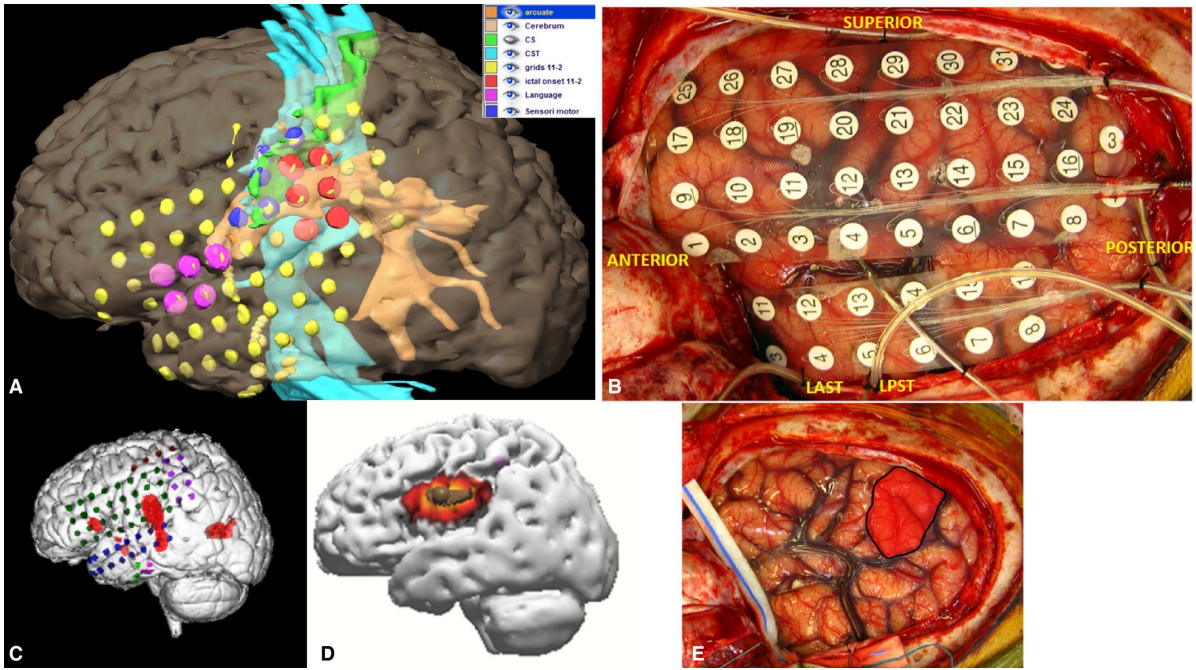




Functional

Emphasis on restoring quality of life/neurological function

- Cognitive & neuropsychiatric
- Epilepsy
- Movement disorders
- Pain



Outline

- Neurosurgery: An Overview
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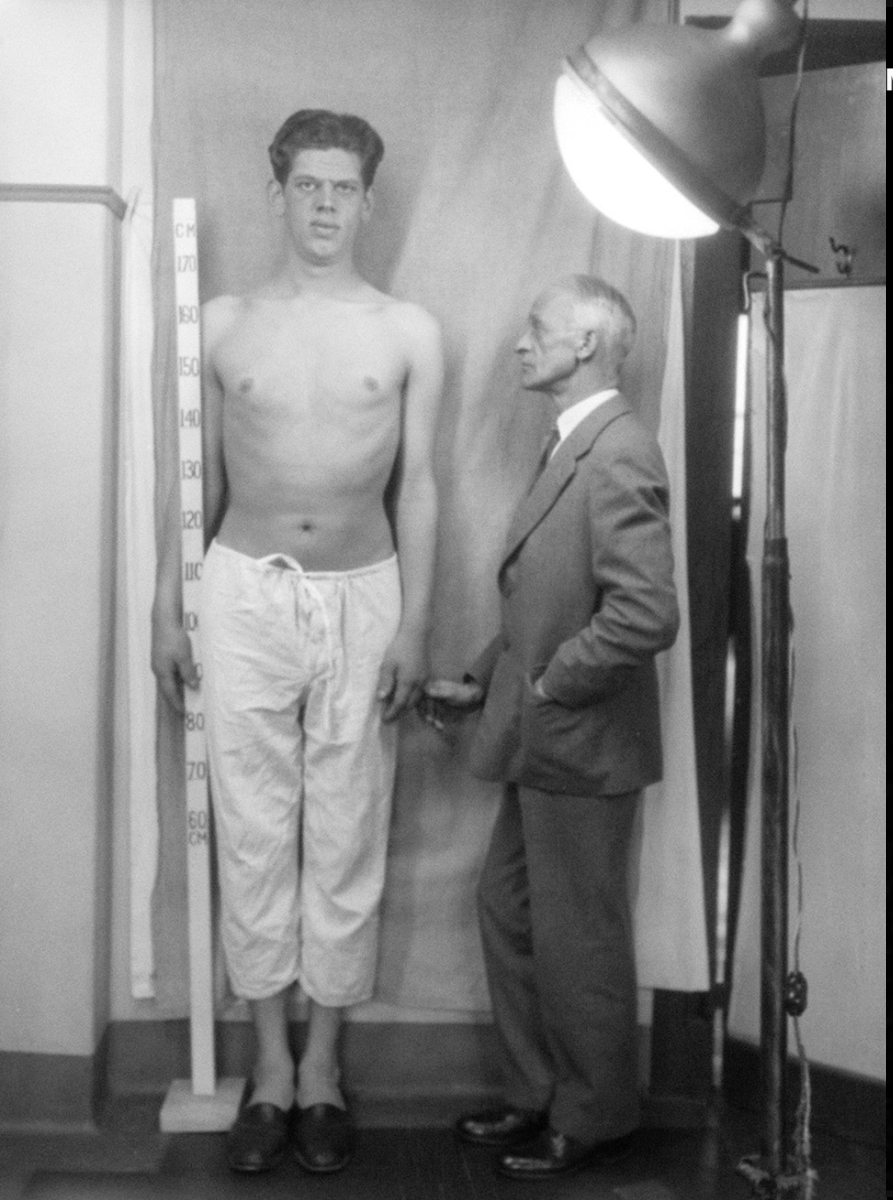
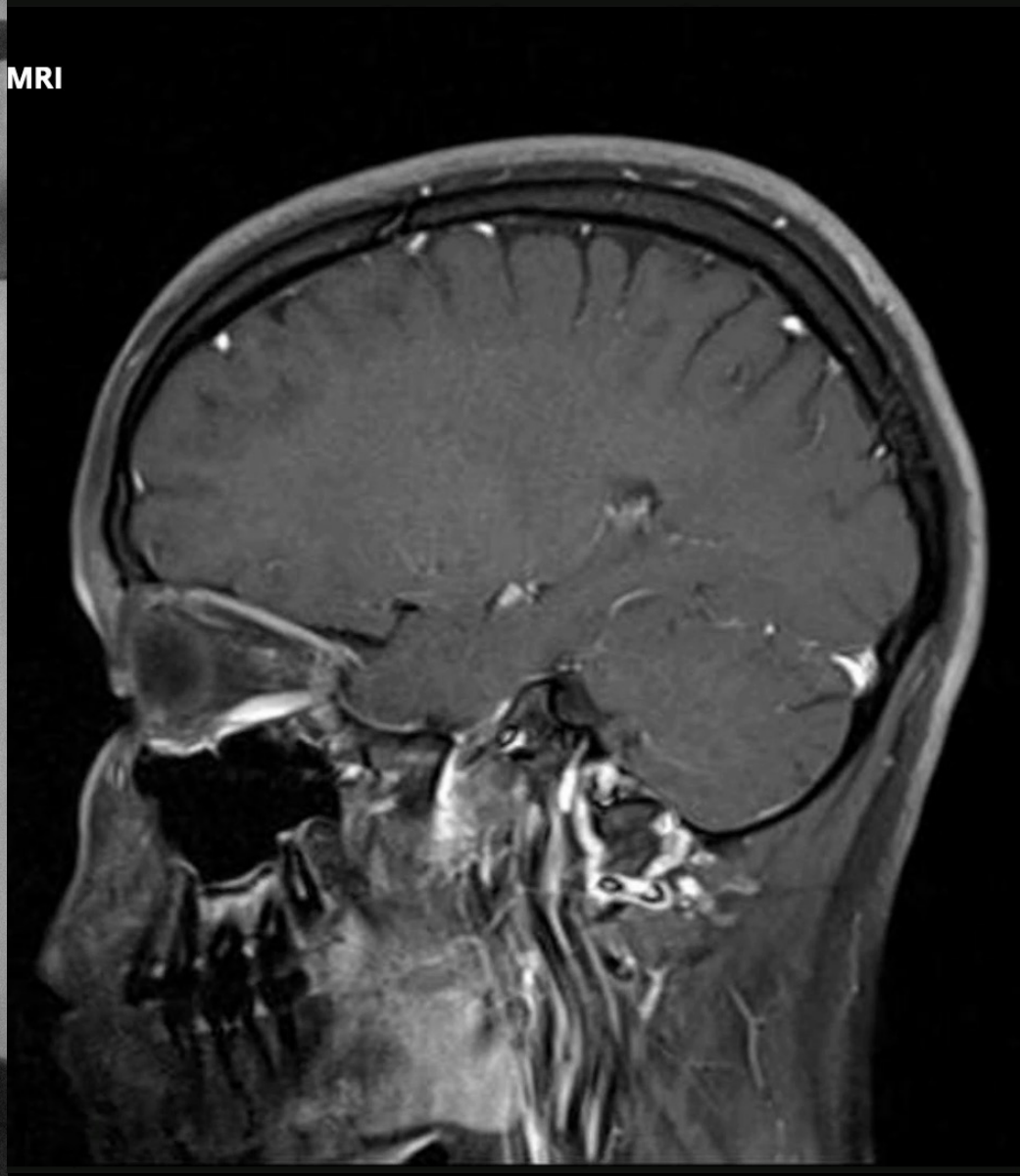
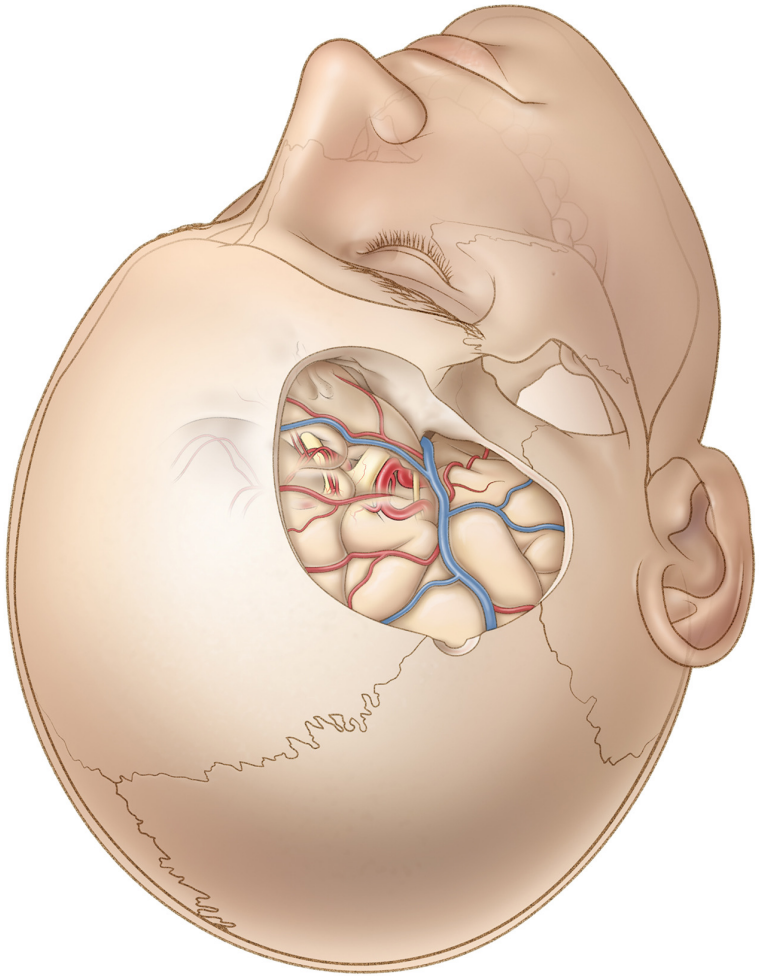
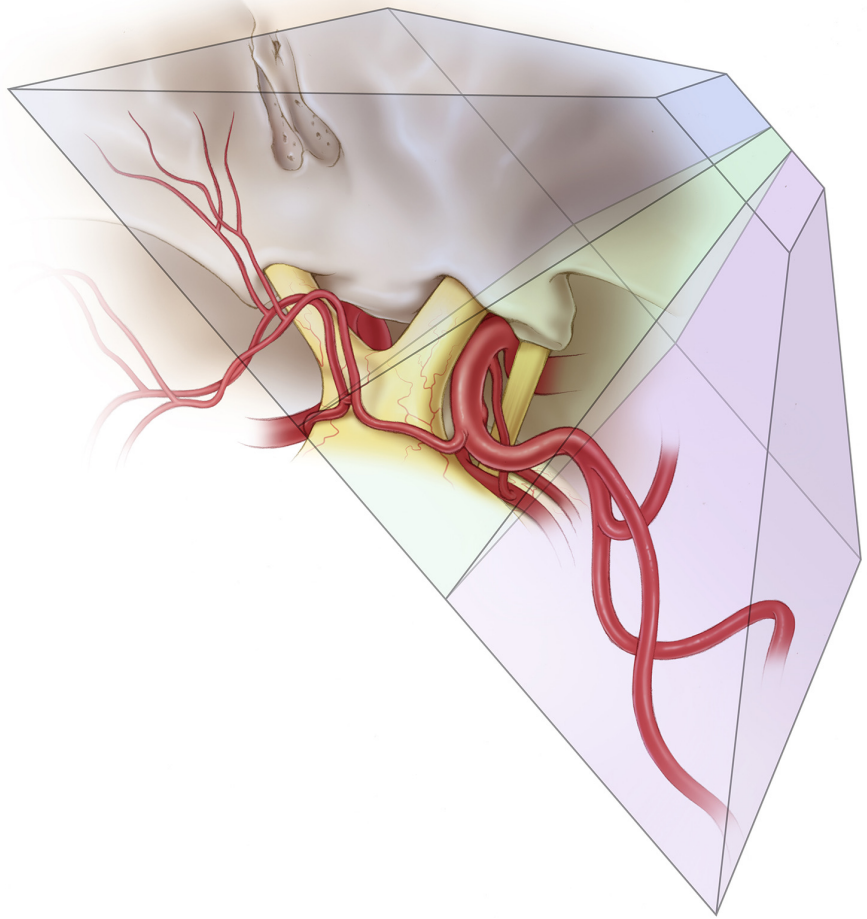
If you needed to get to **center** of head for an operation, how would you get there?



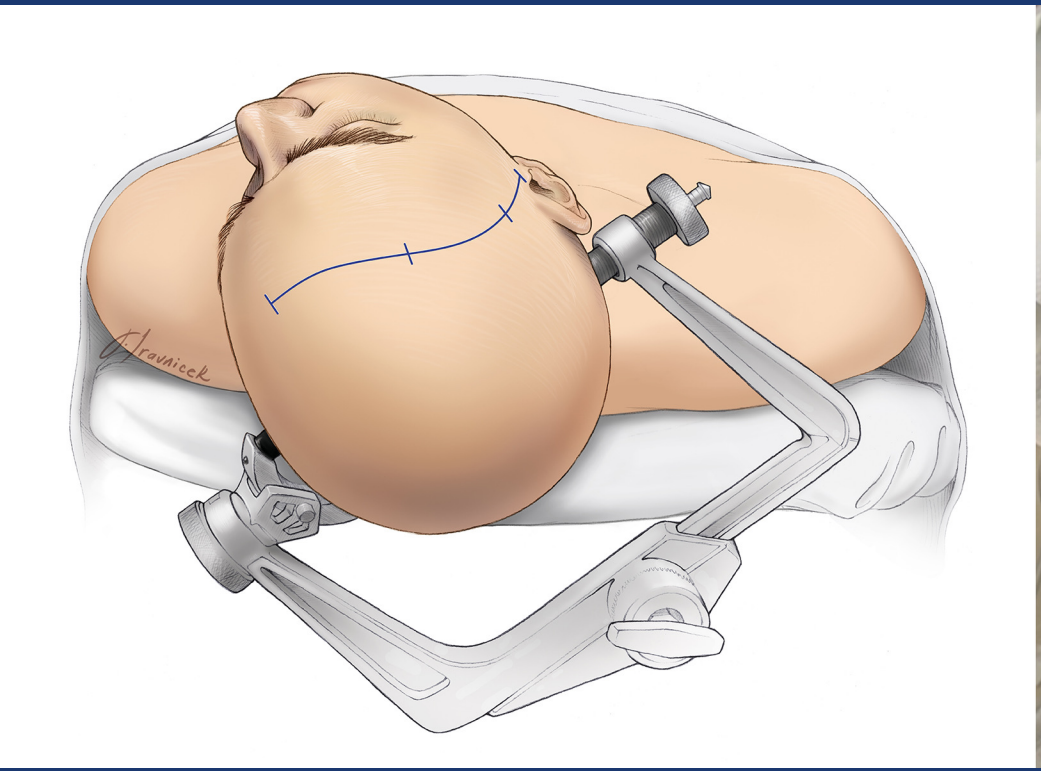

MRI

Open Approach: Pterional Craniotomy

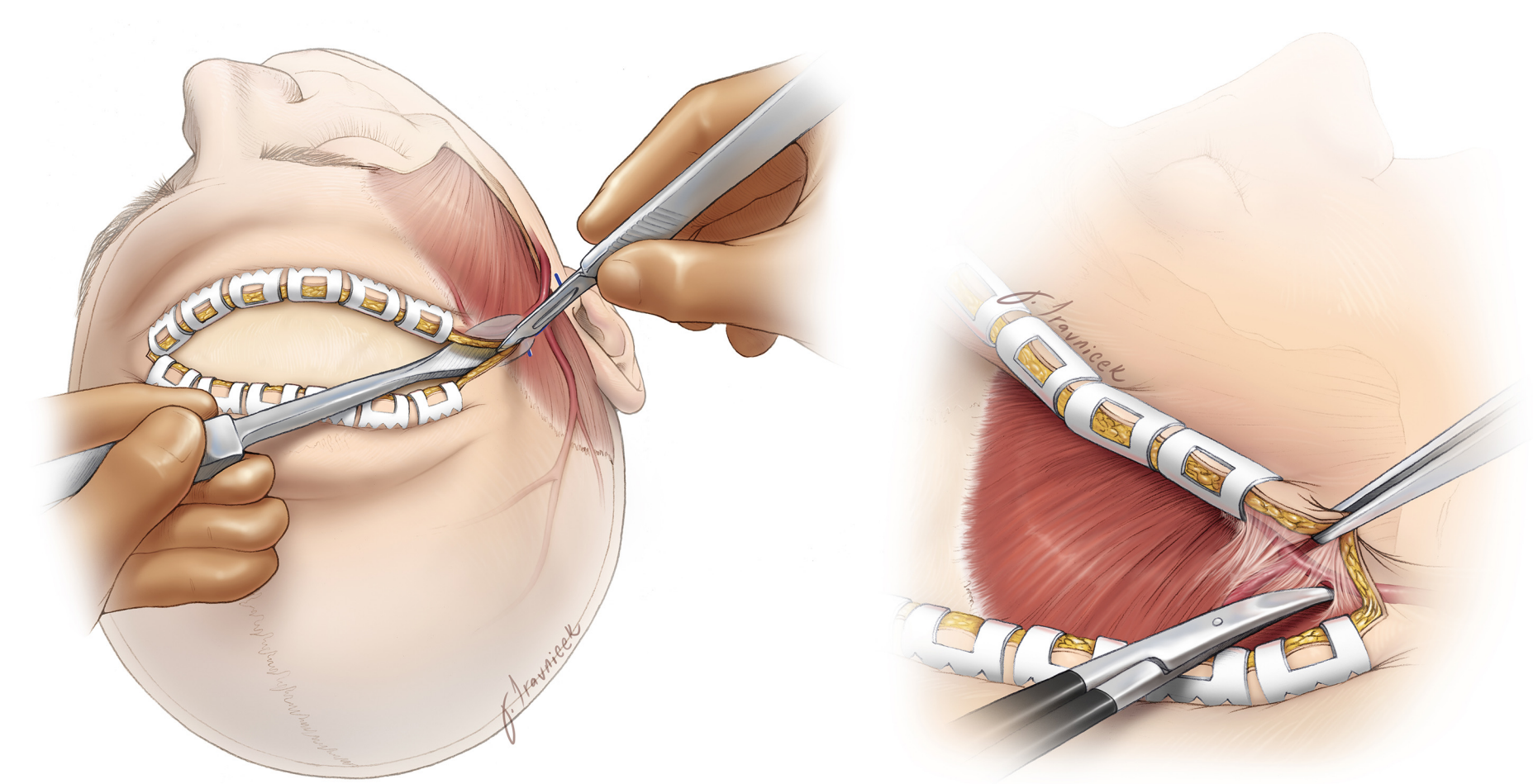




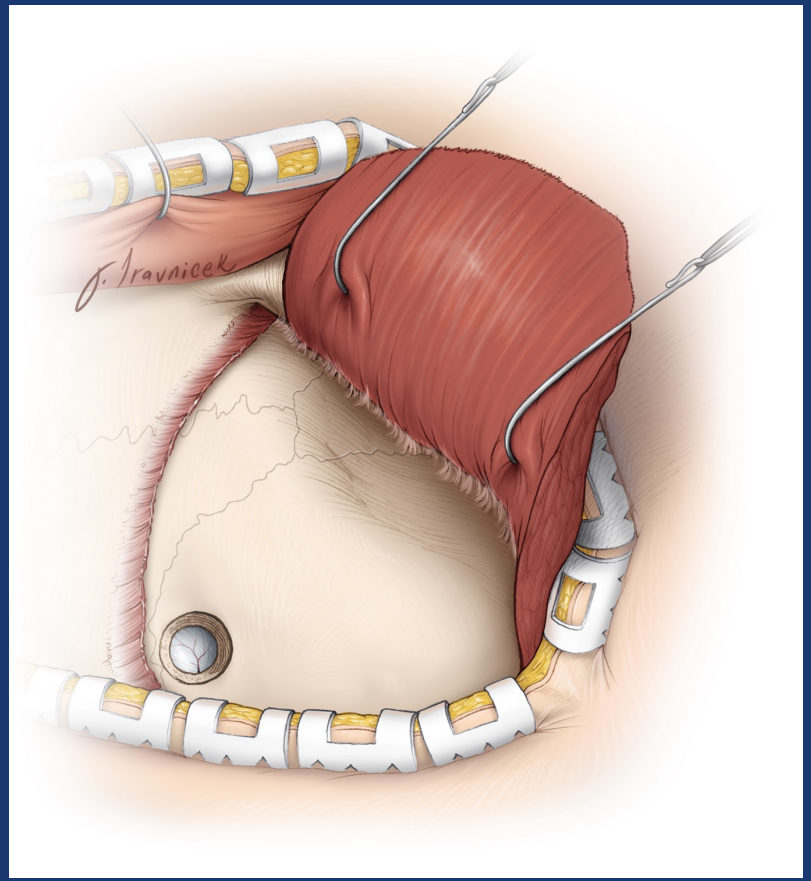
Open Approach: Pterional Craniotomy

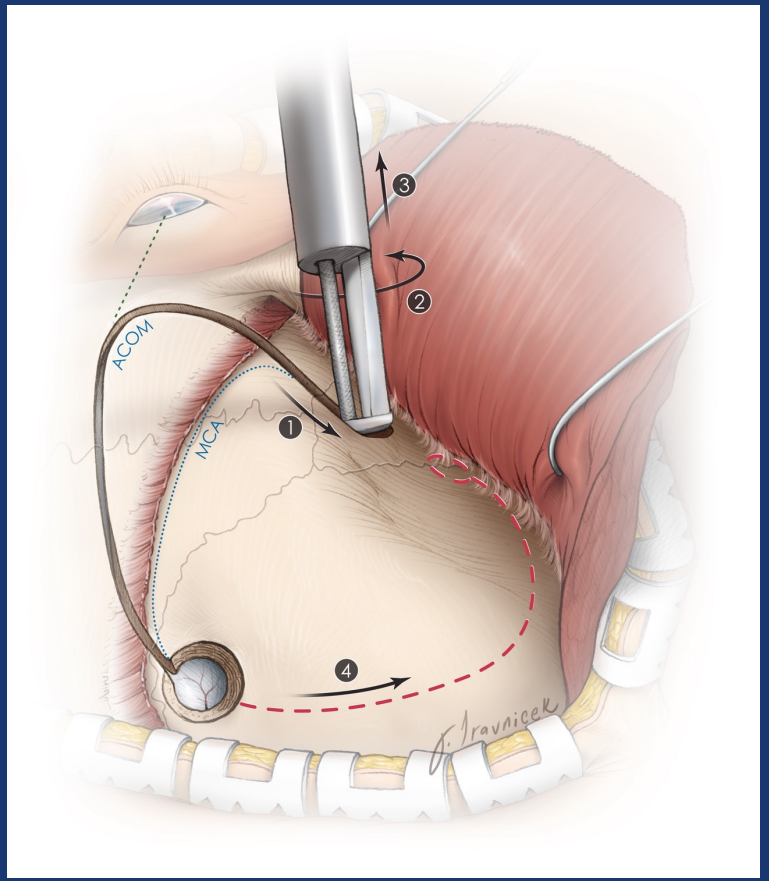


Open Approach: Pterional Craniotomy

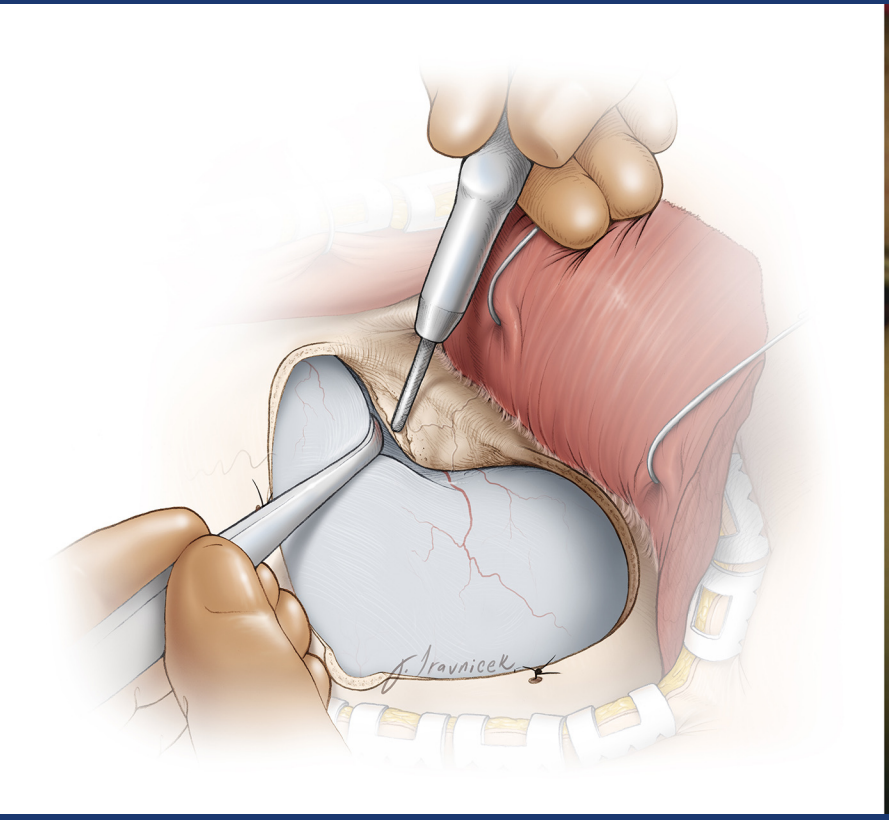


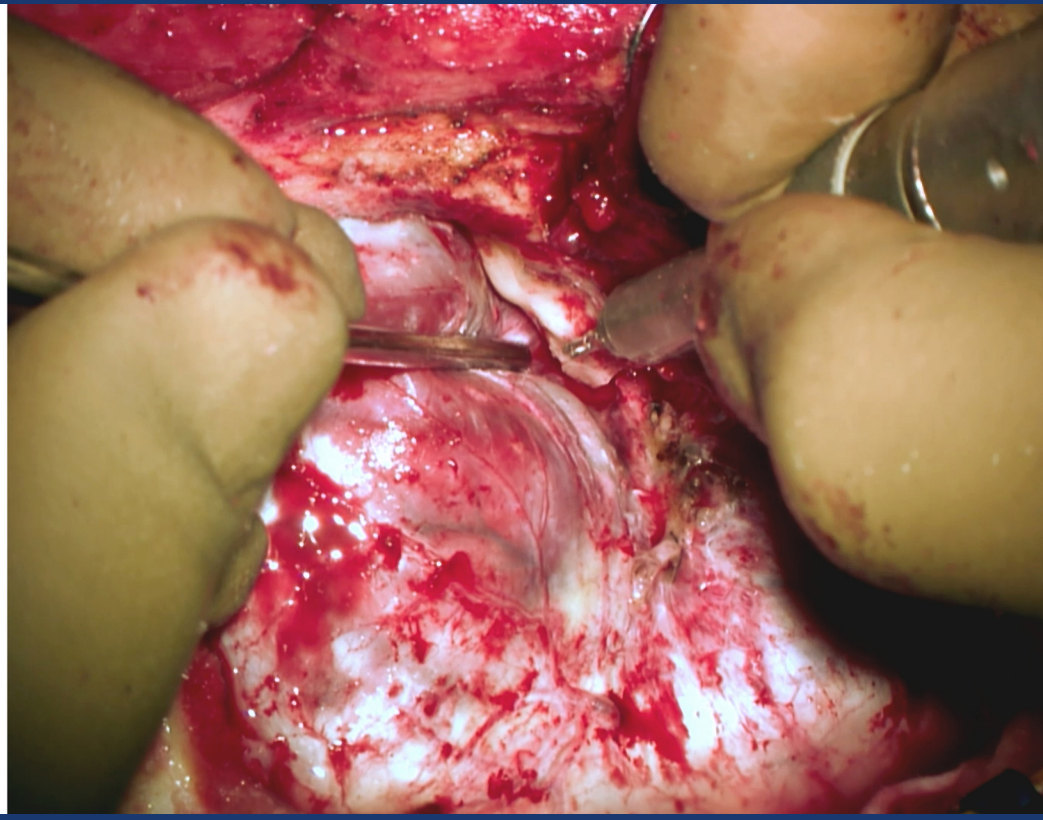
Open Approach: Pterional Craniotomy



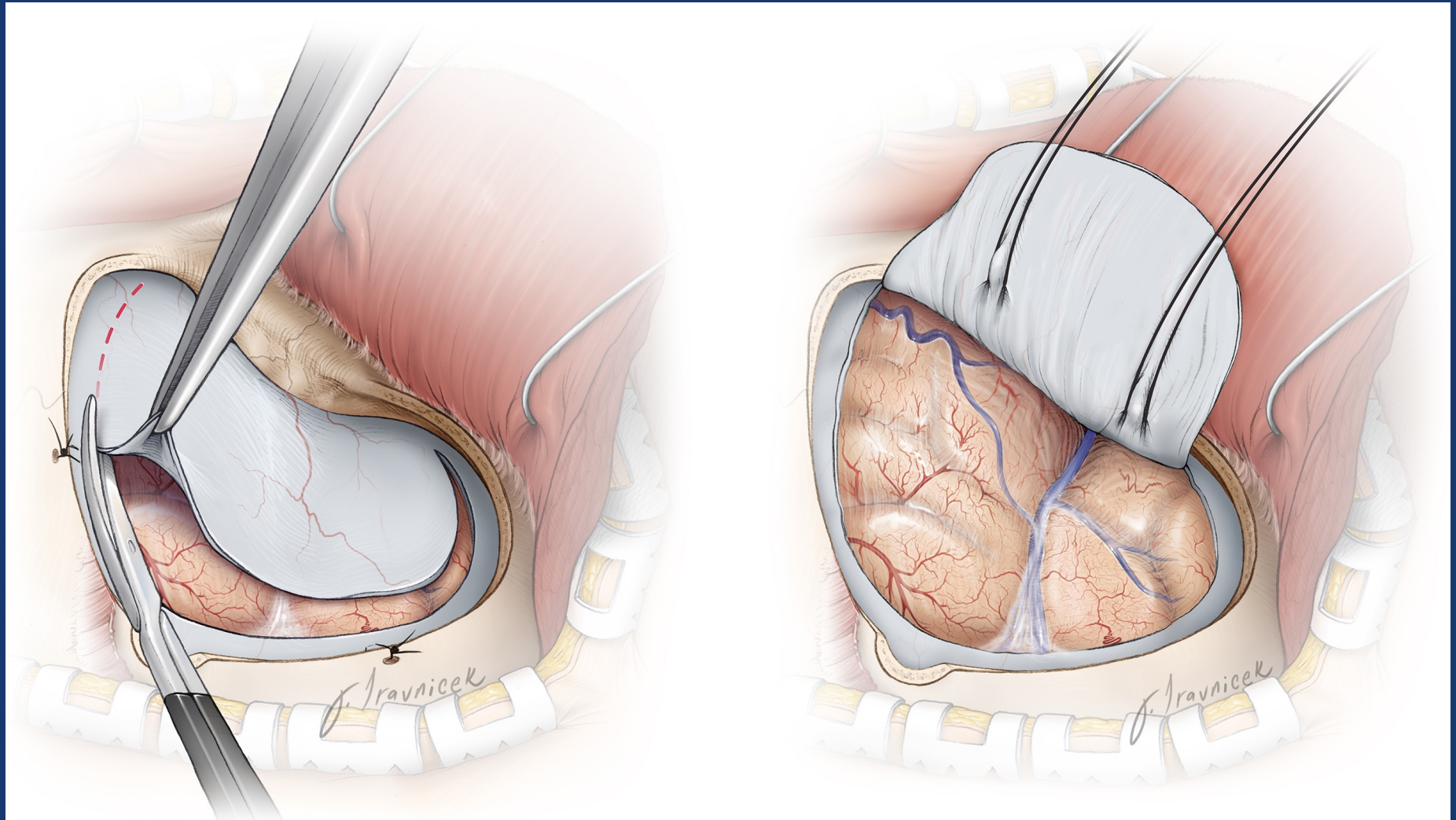


Open Approach: Pterional Craniotomy

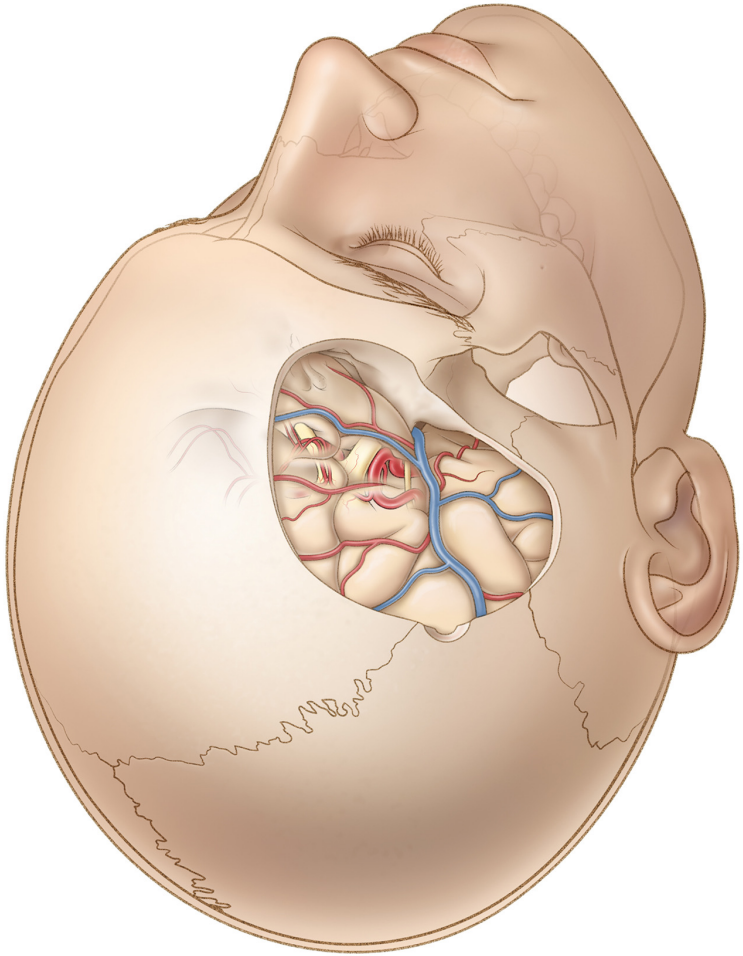


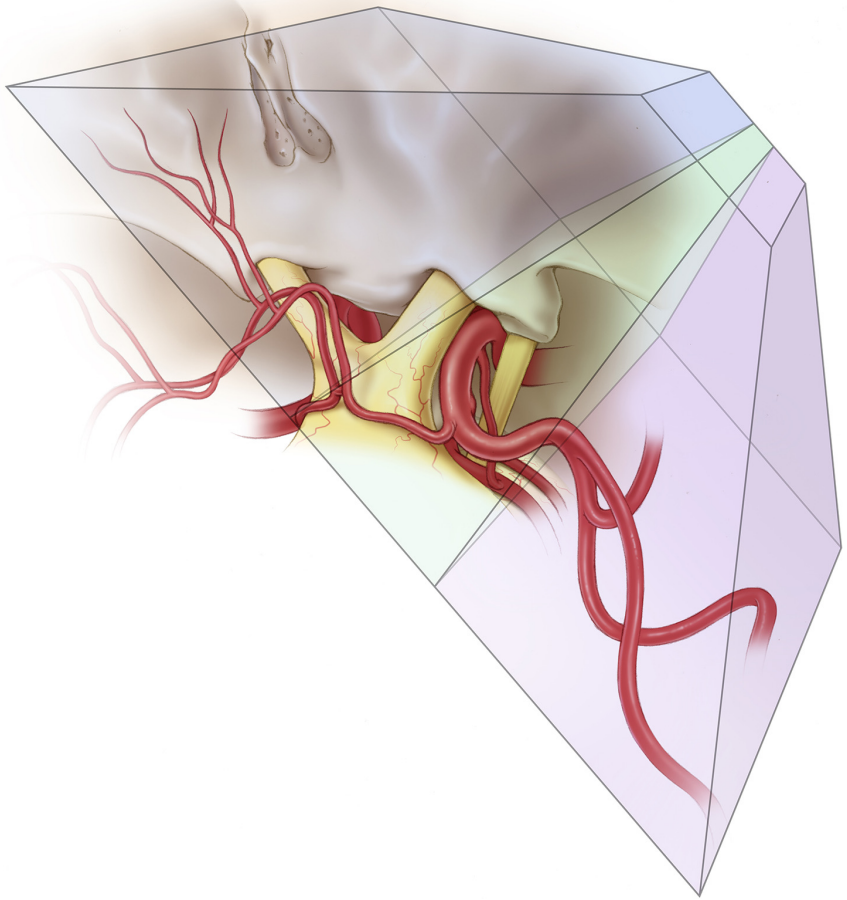


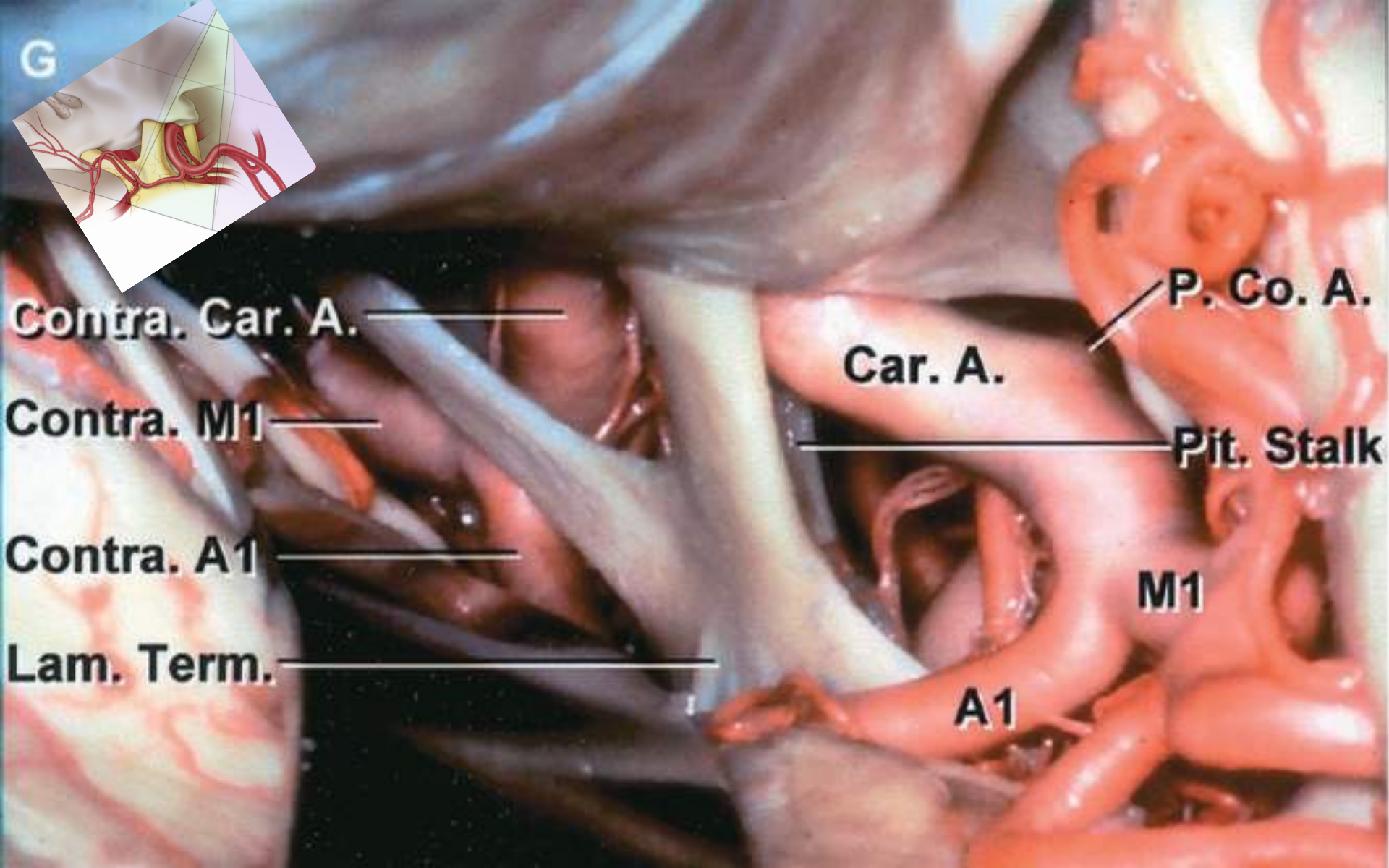
Open Approach: Pterional Craniotomy

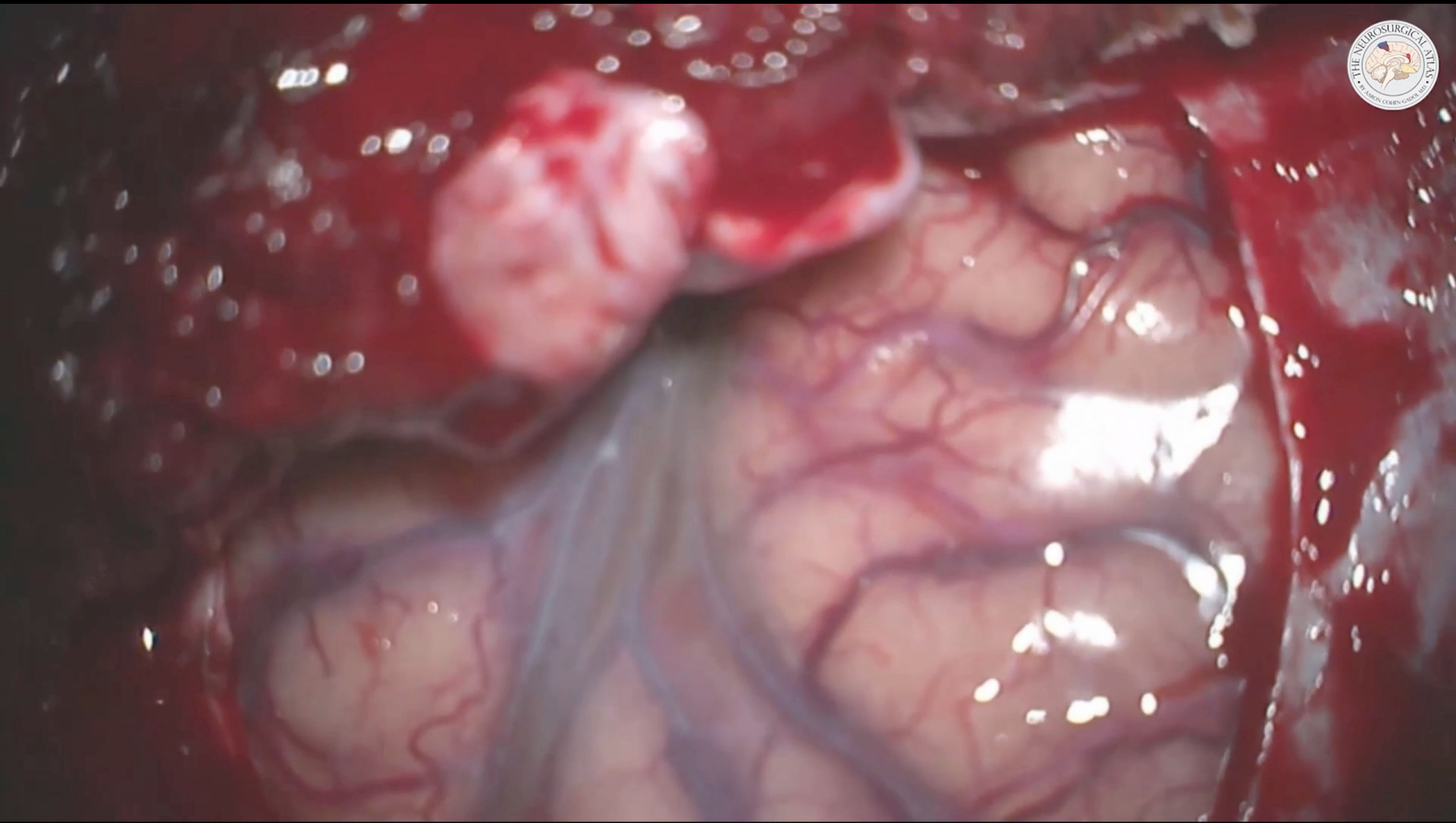


Open Approach: Pterional Craniotomy






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

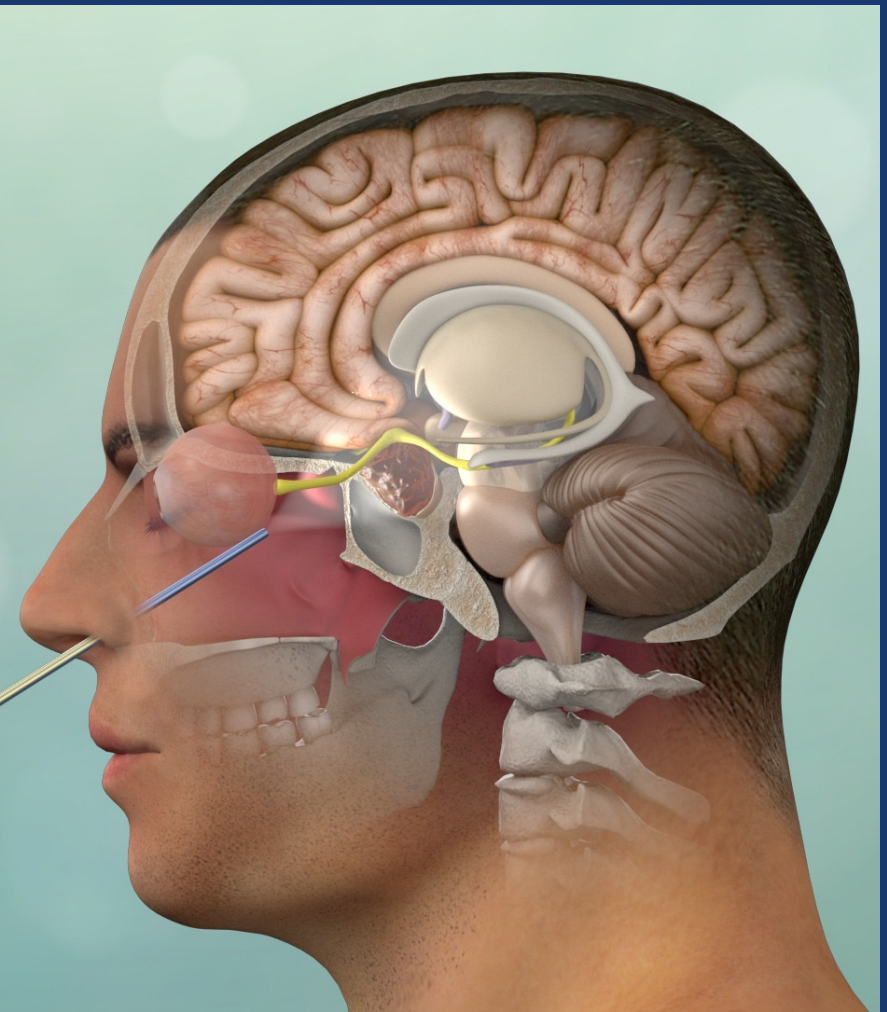


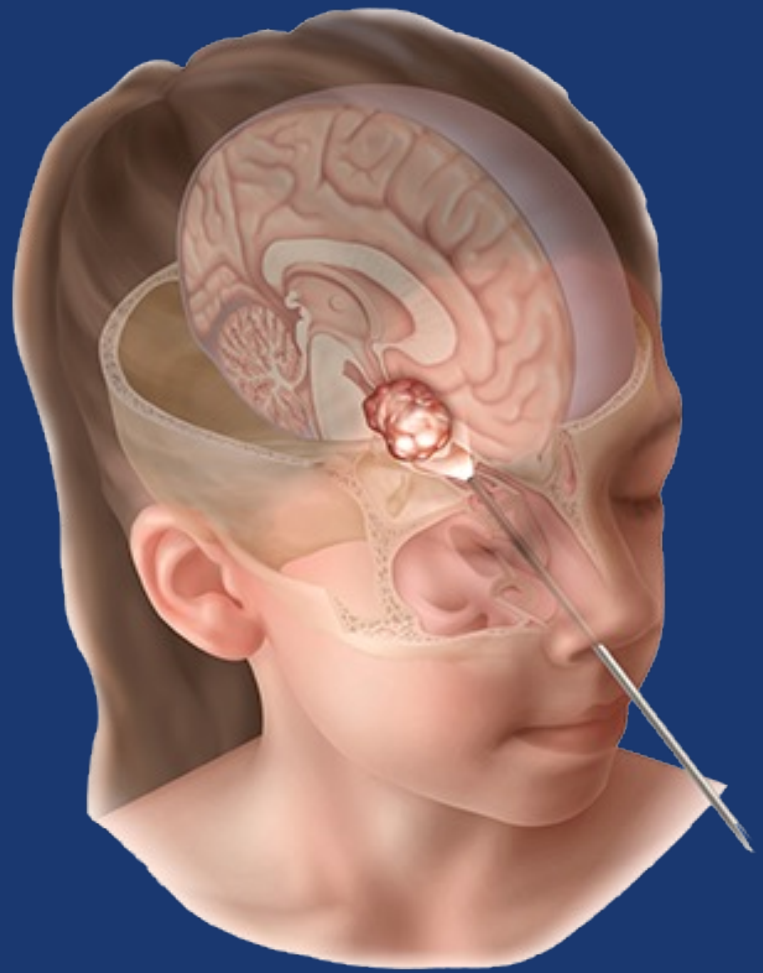
Drawbacks of Open Surgery

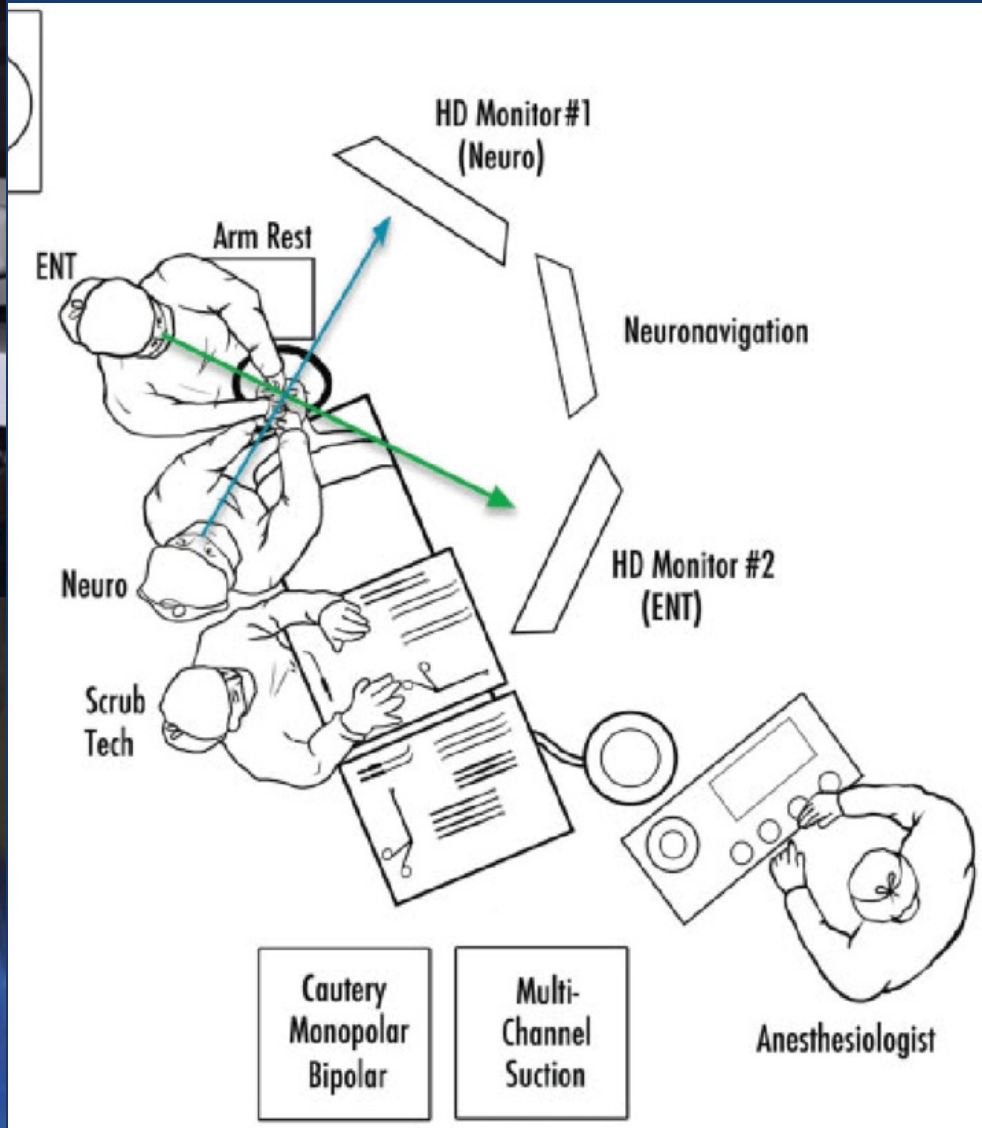
Wound healing, infection, neurological damage, etc

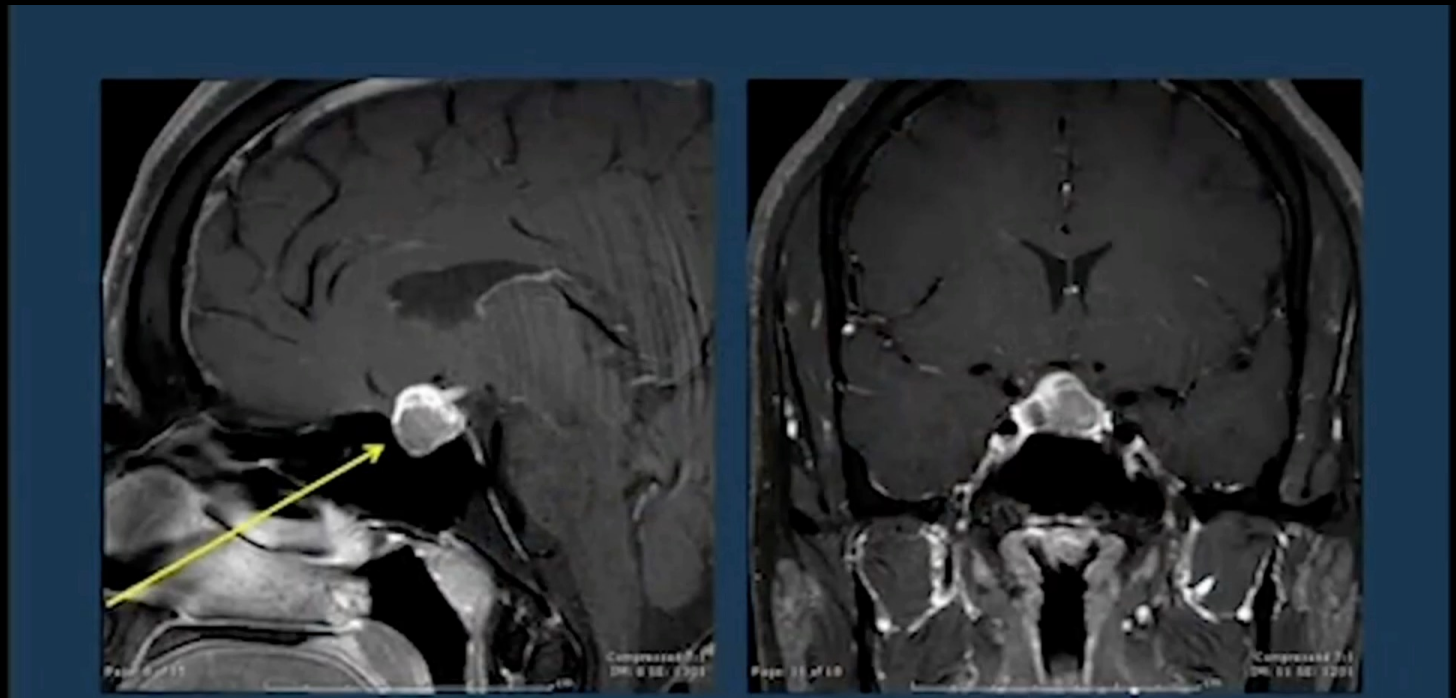
Alternative to an **open** approach?

Endoscopic Endonasal Approach





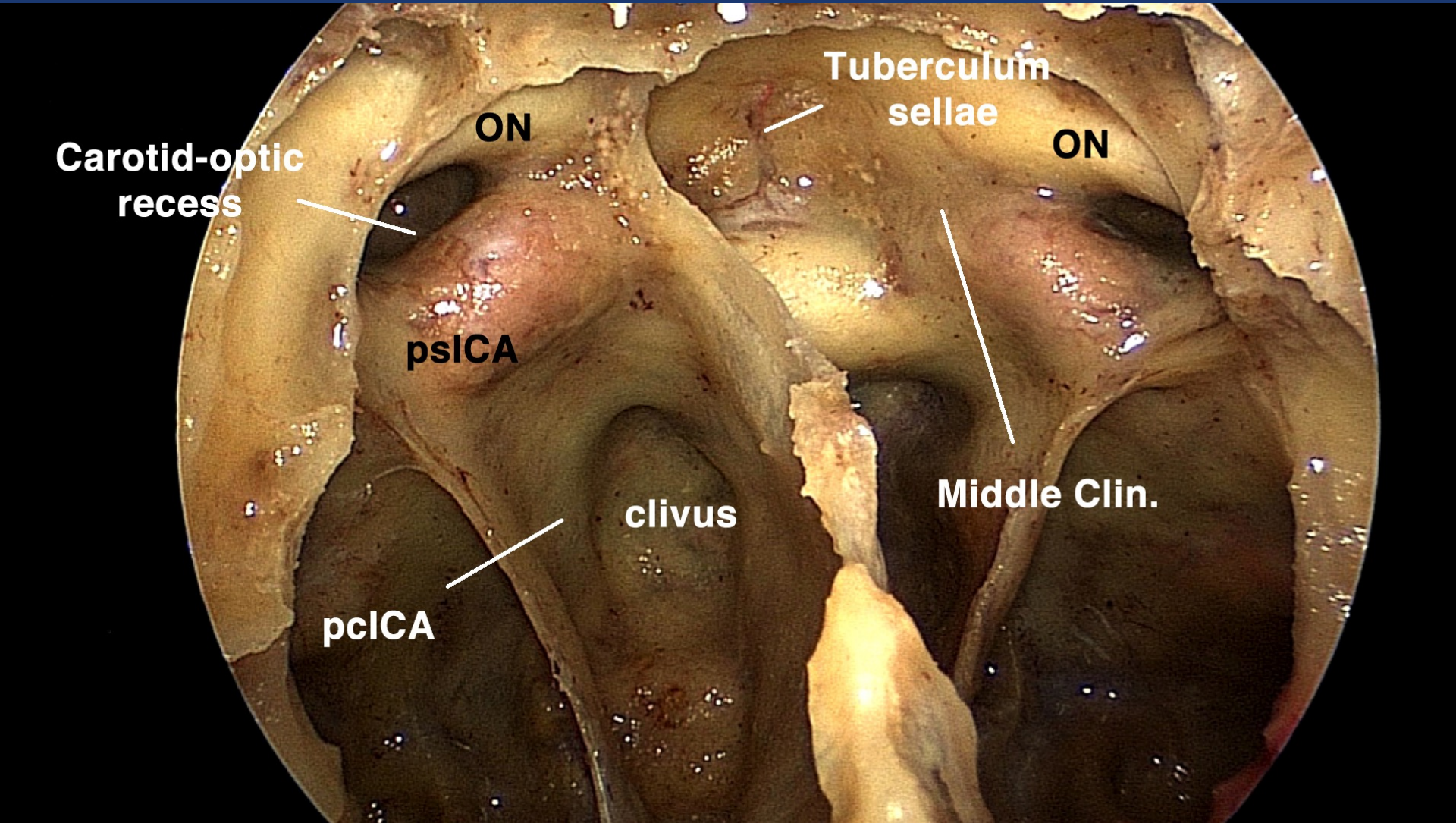

HD Monitor#1
(Neuro)
Arm Rest
ENT
Neuronavigation
HD Monitor #2
(ENT)
Neuro
Scrub
Tech
Cautery
Monopolar
Bipolar
Multi-
Channel
Suction
Anesthesiologist



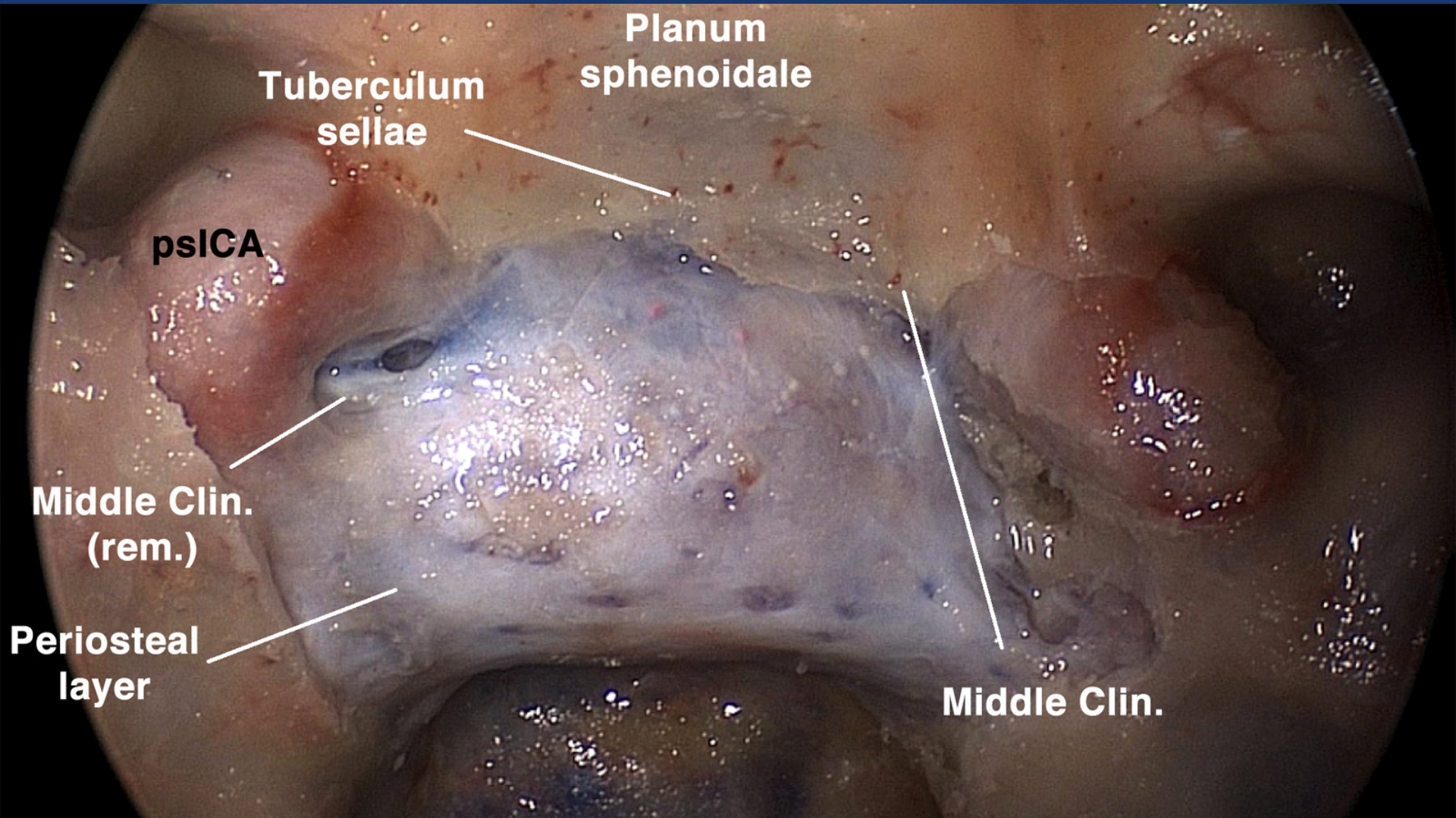
is shown. The initial portion of the
procedure involves removing bone at the

PNI

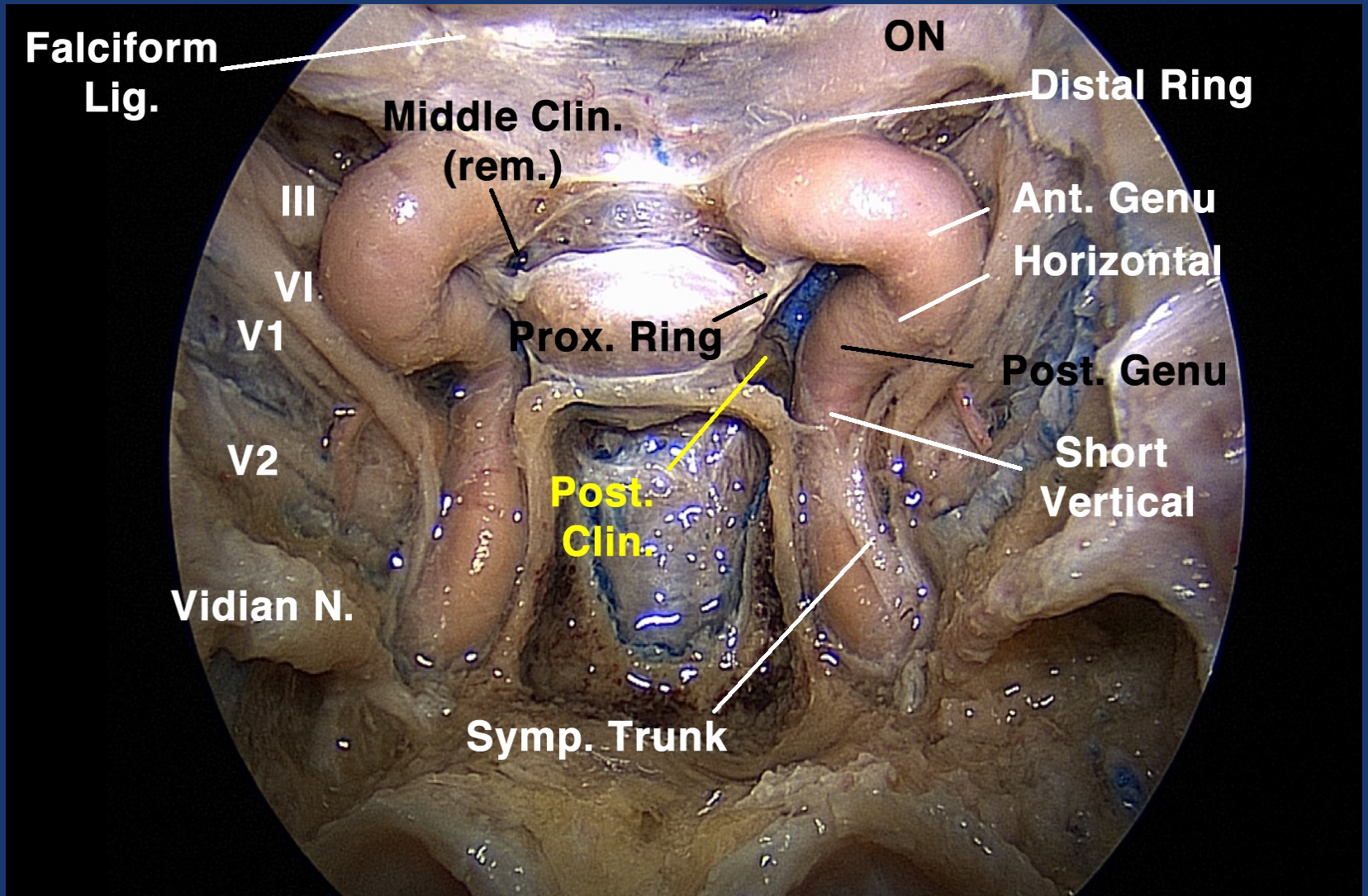
Endoscopic Endonasal Approach

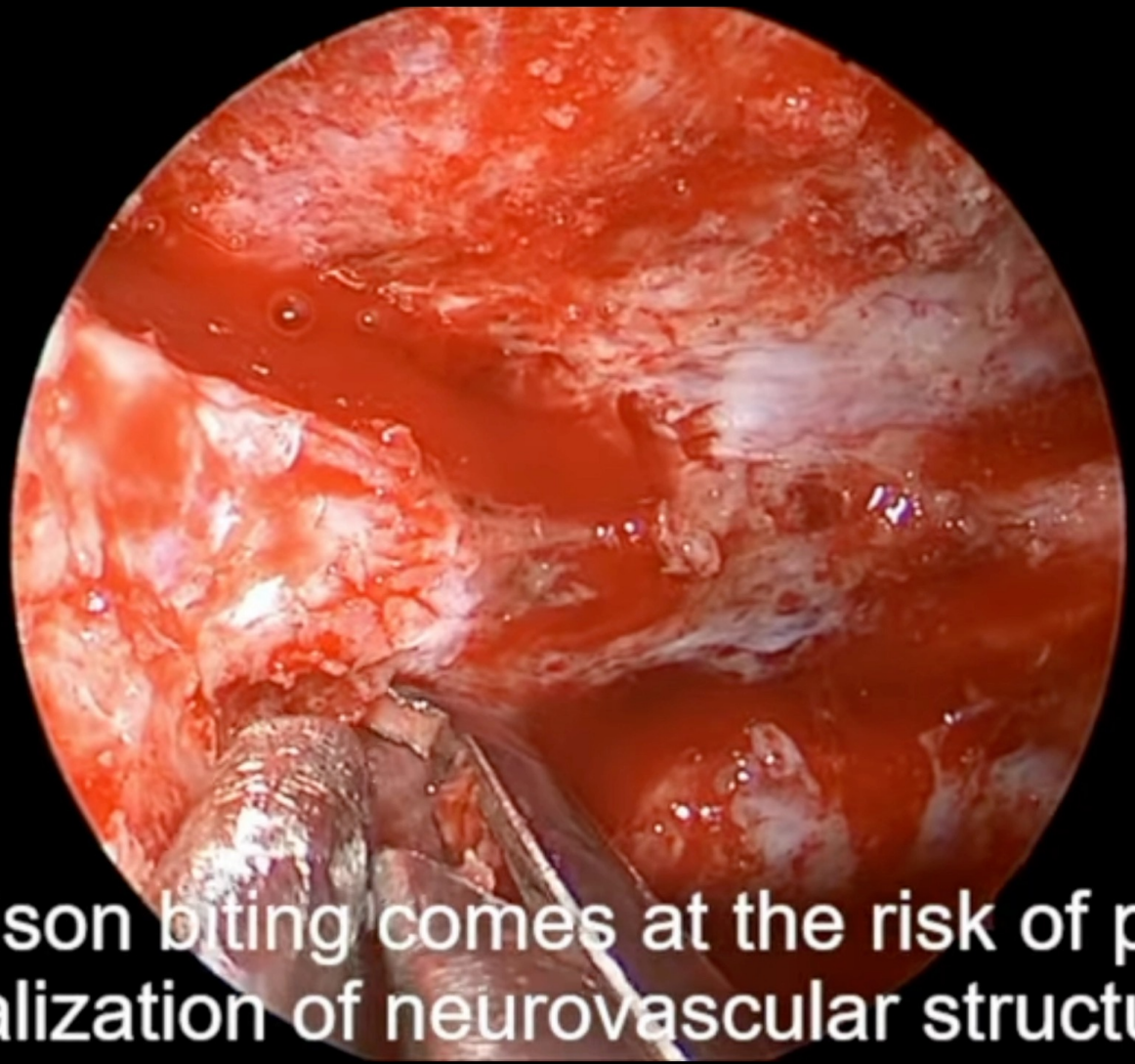


Endoscopic Endonasal Approach

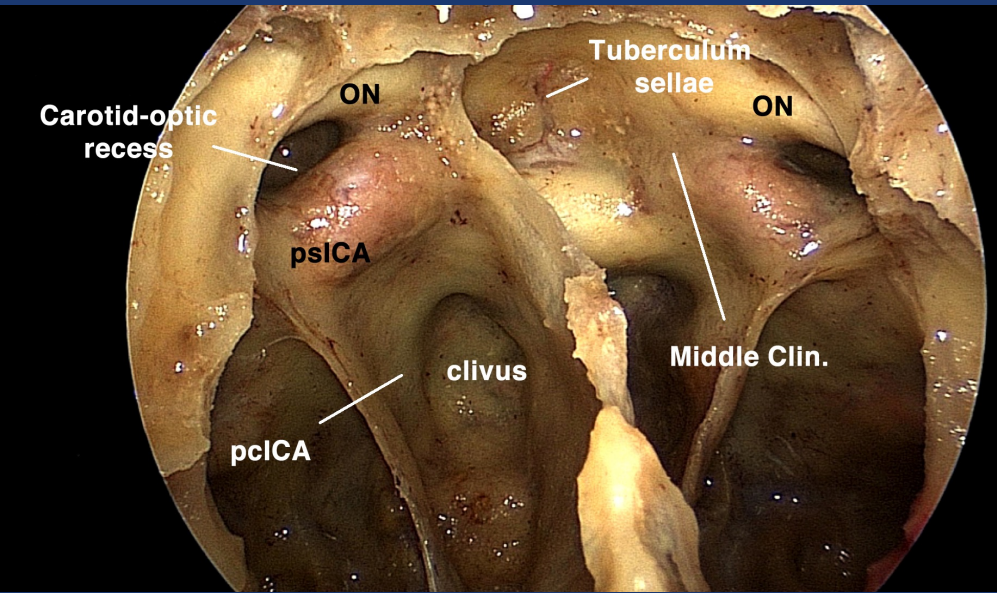


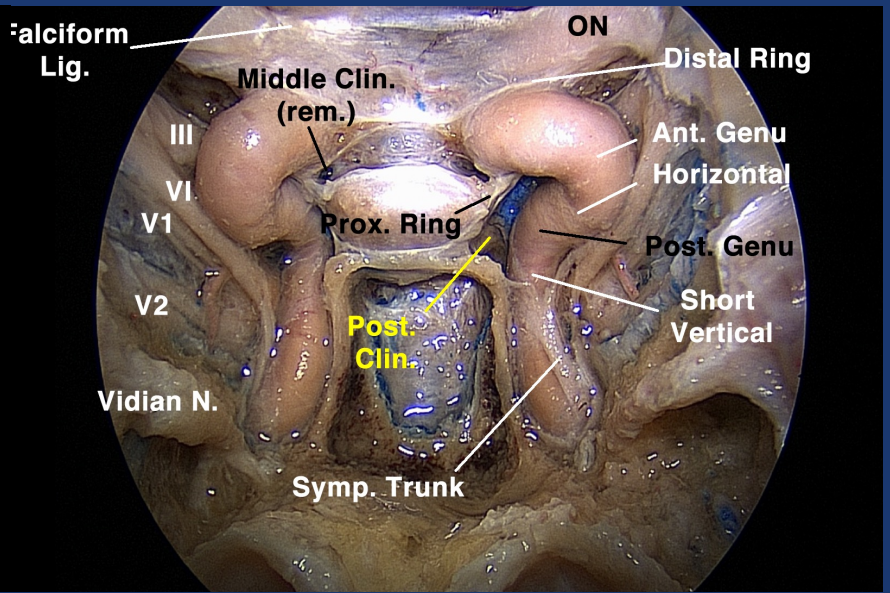
Endoscopic Endonasal Approach



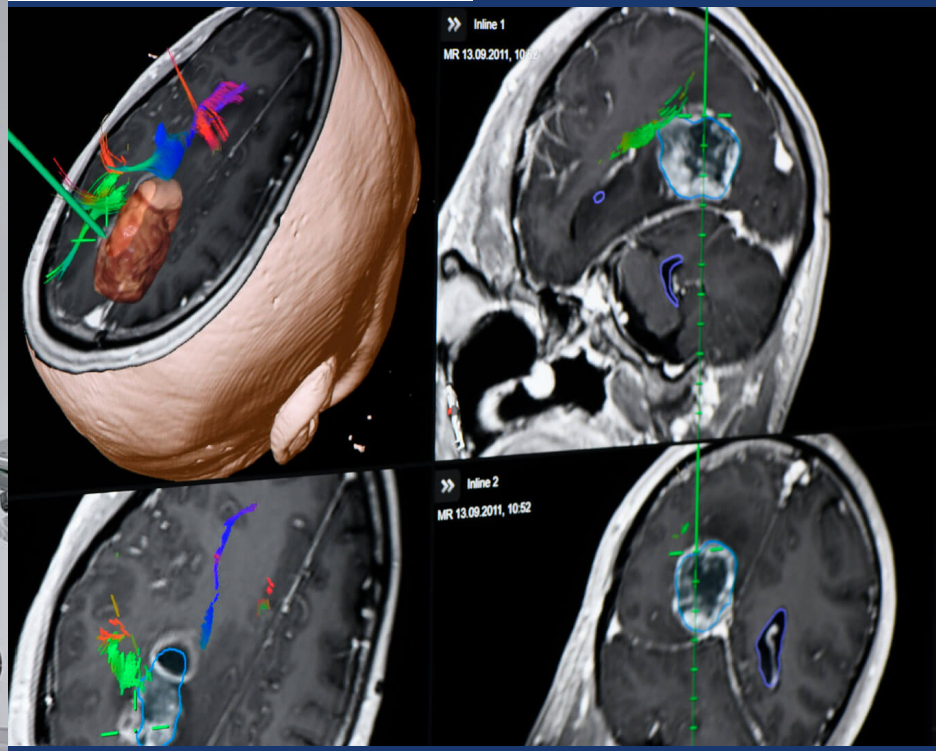

Kerrison biting comes at the risk of poor
visualization of neurovascular structures

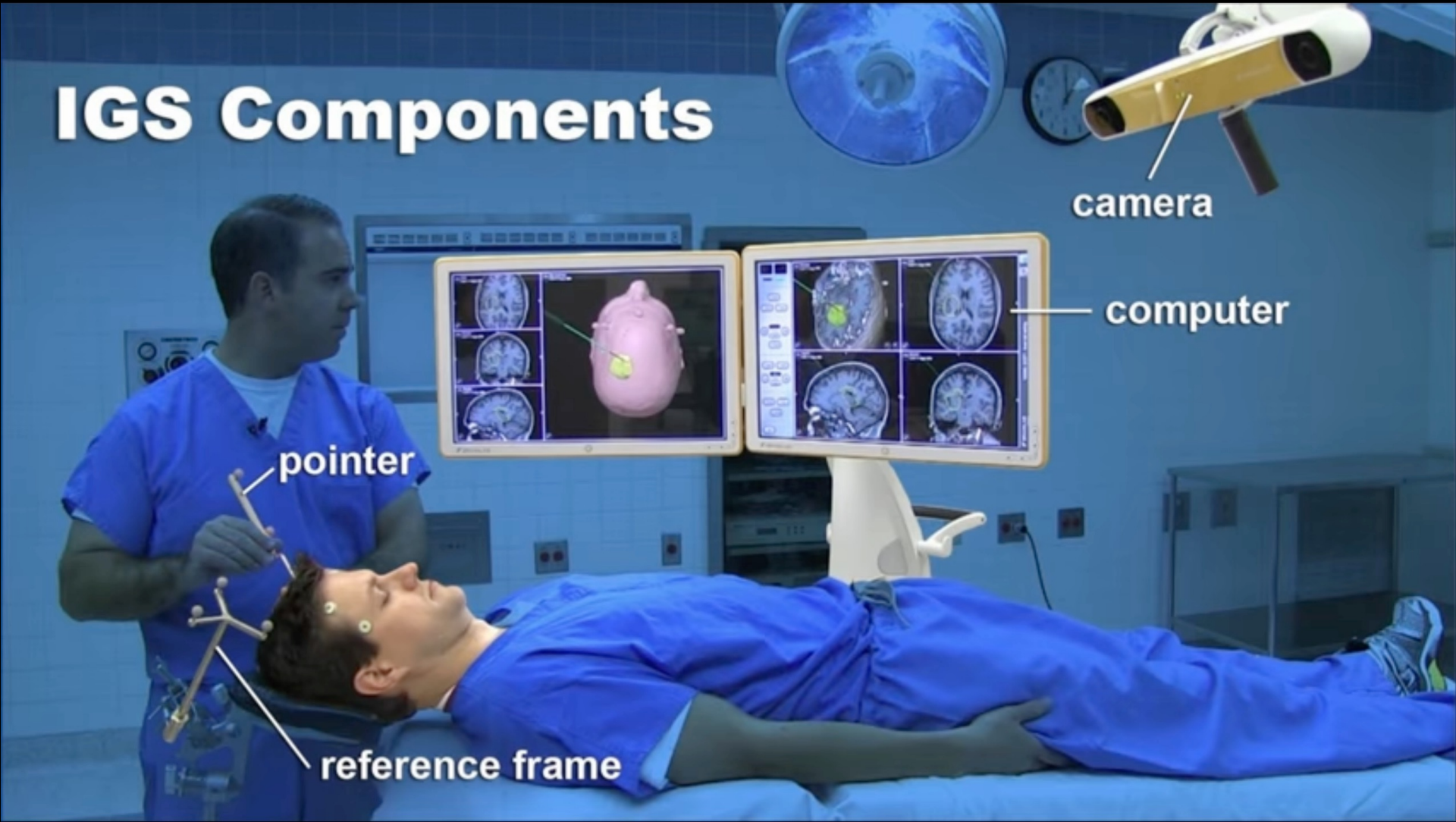
How then is surgery safely performed around such high-stakes anatomy?





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

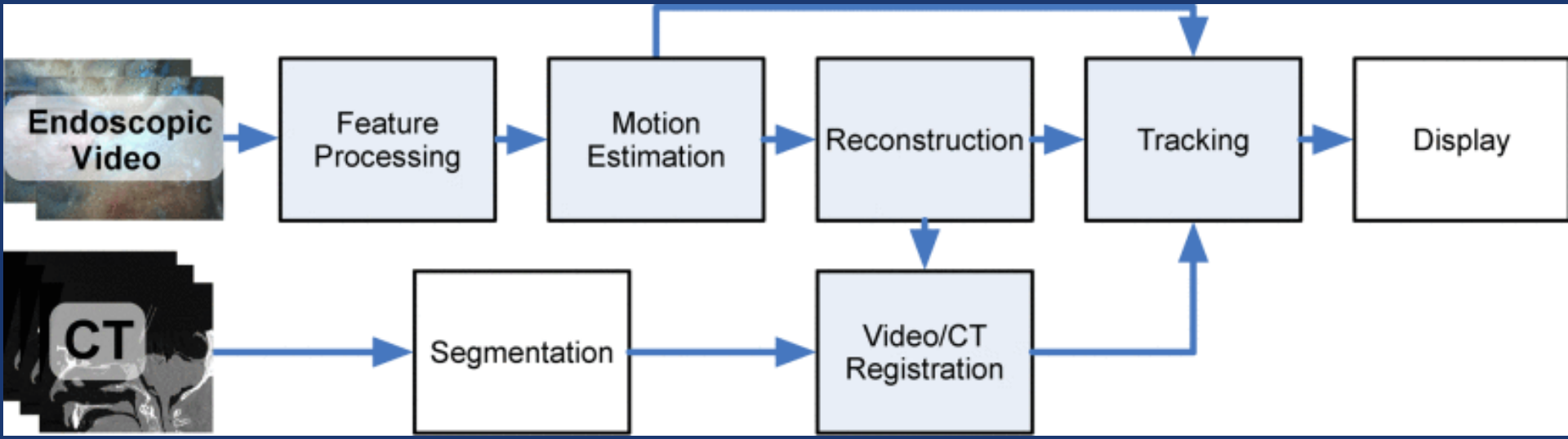
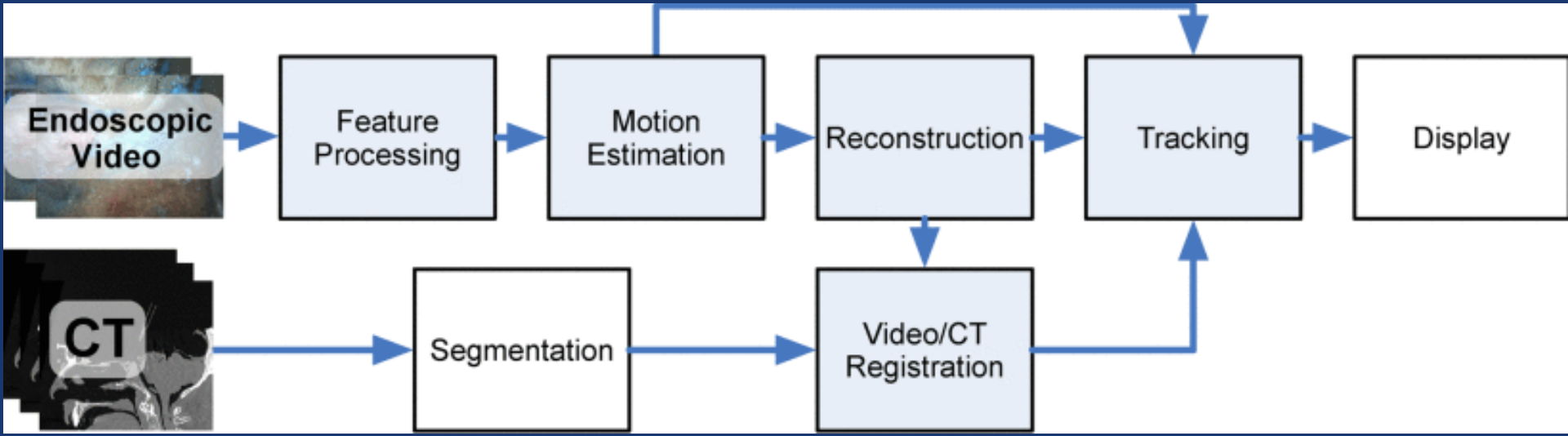


Image features detected and matched in two temporally adjacent images.

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)

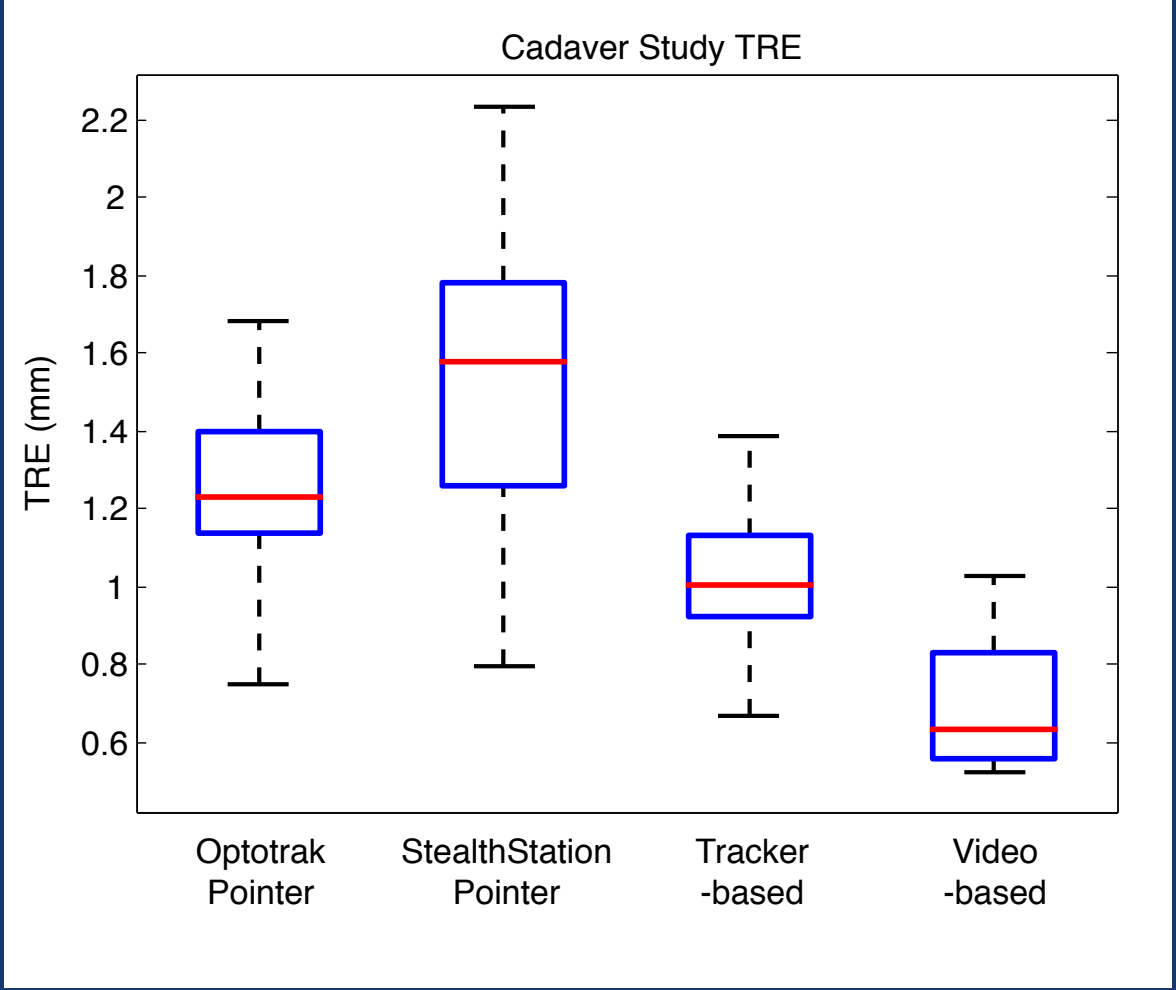
TRE_1	Metric for evaluating pointer-based methods
TRE_2	Metric for evaluating tracker-based and video-based methods
NGE	Same as TRE_2, however, the target is not visible in the endoscope image.

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

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

experir

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



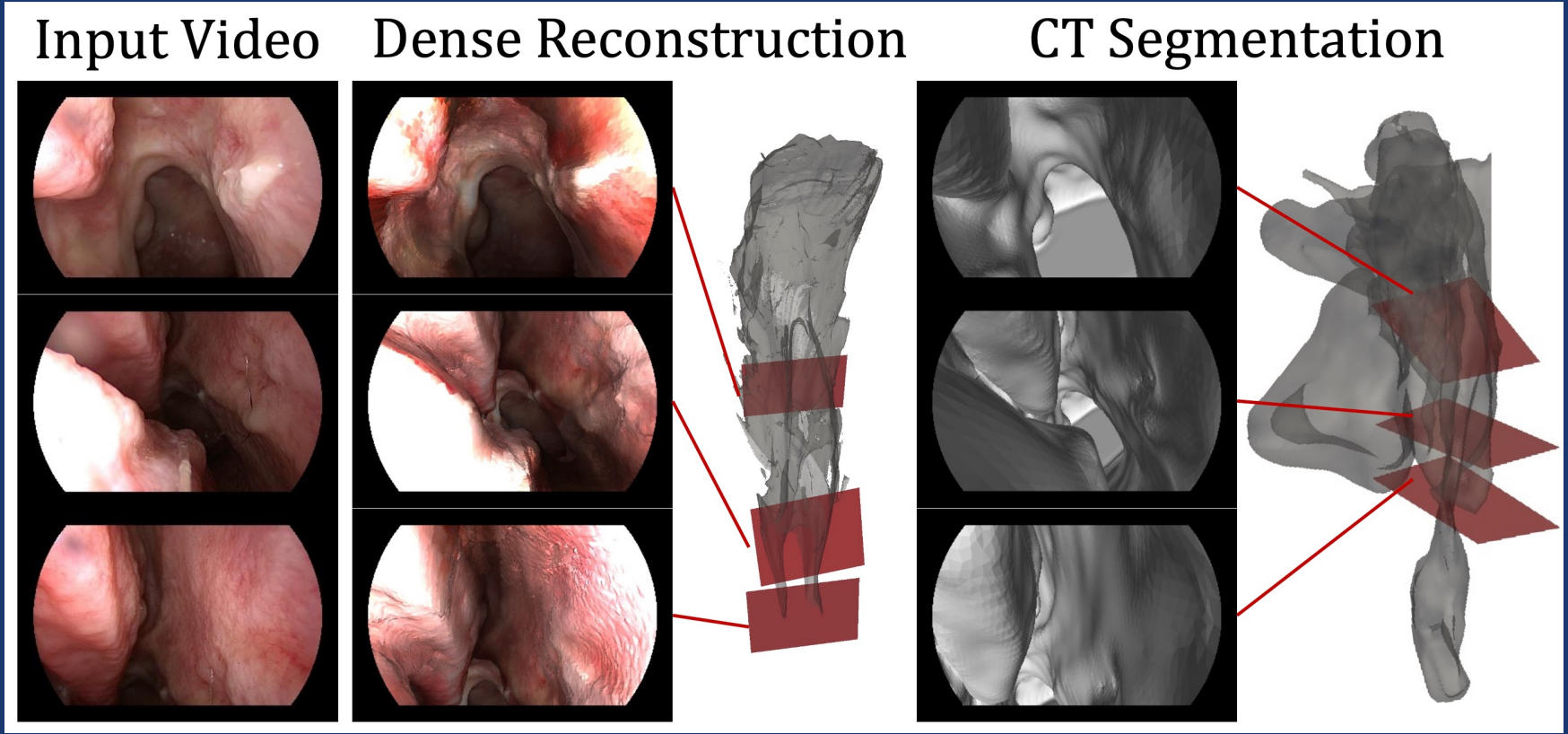
Quantitative Endoscopy (QE)

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

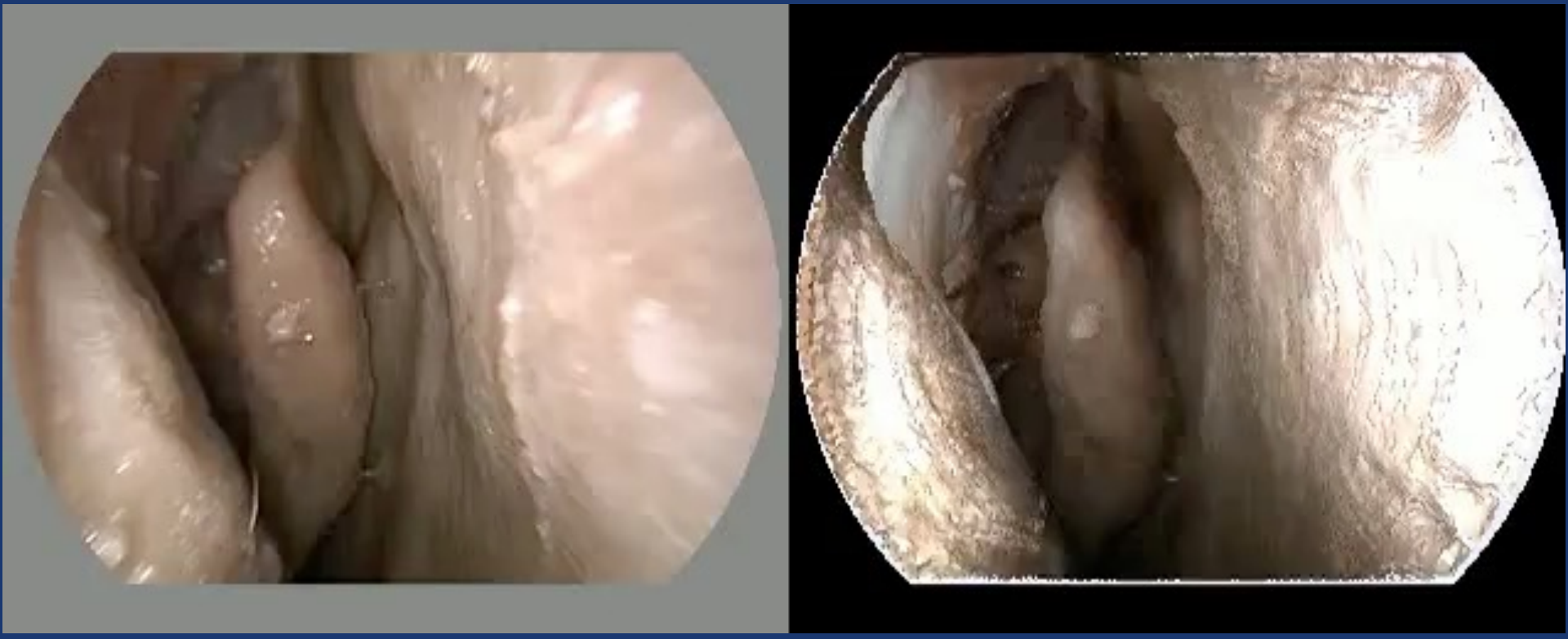
- Improves usability of **existing** navigation technology in sinus surgery with **no additional cost or equipment**.
- **Minimal disruption** to the surgical workflow.


CAUTION
X-RAY
RADIATION
Loop-X

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



Sinus Reconstruction



Outline

- Neurosurgery: An Overview
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Historical Perspective - PUMA

- First reported use was the PUMA system in 1985 for stereotactic, CT-guided brain biopsy.

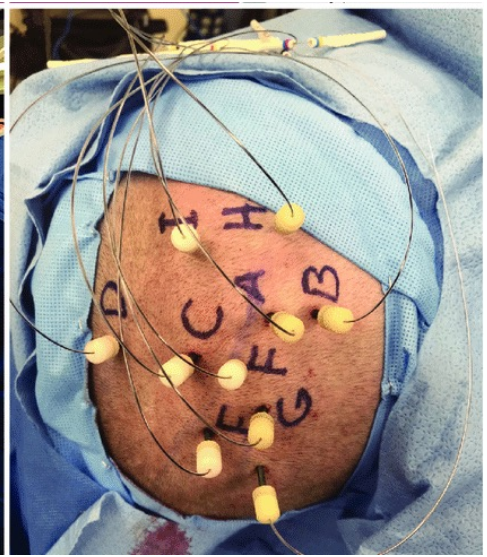
- Quickly abandoned over safety issues

Historical Perspective - Neuromate

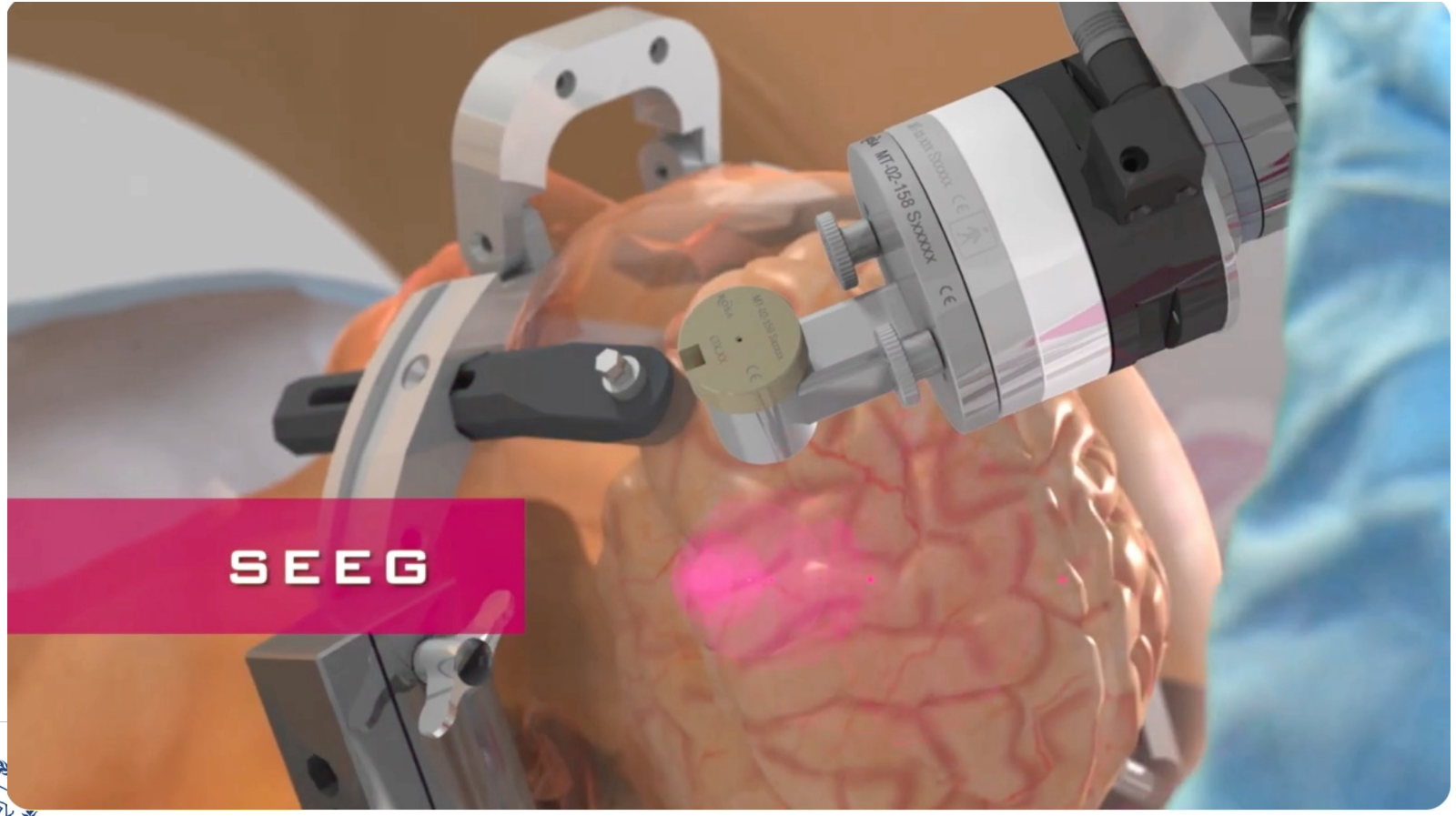
- Neuromate for brain electrode implantation
- Neuromate is still available on the market

Stereoelectroencephalography

- aka sEEG
- Recording of brain activity to determine sources of seizures
- Robotics have increased the accuracy and safety
- Robots don’t suffer from fatigue or tremor

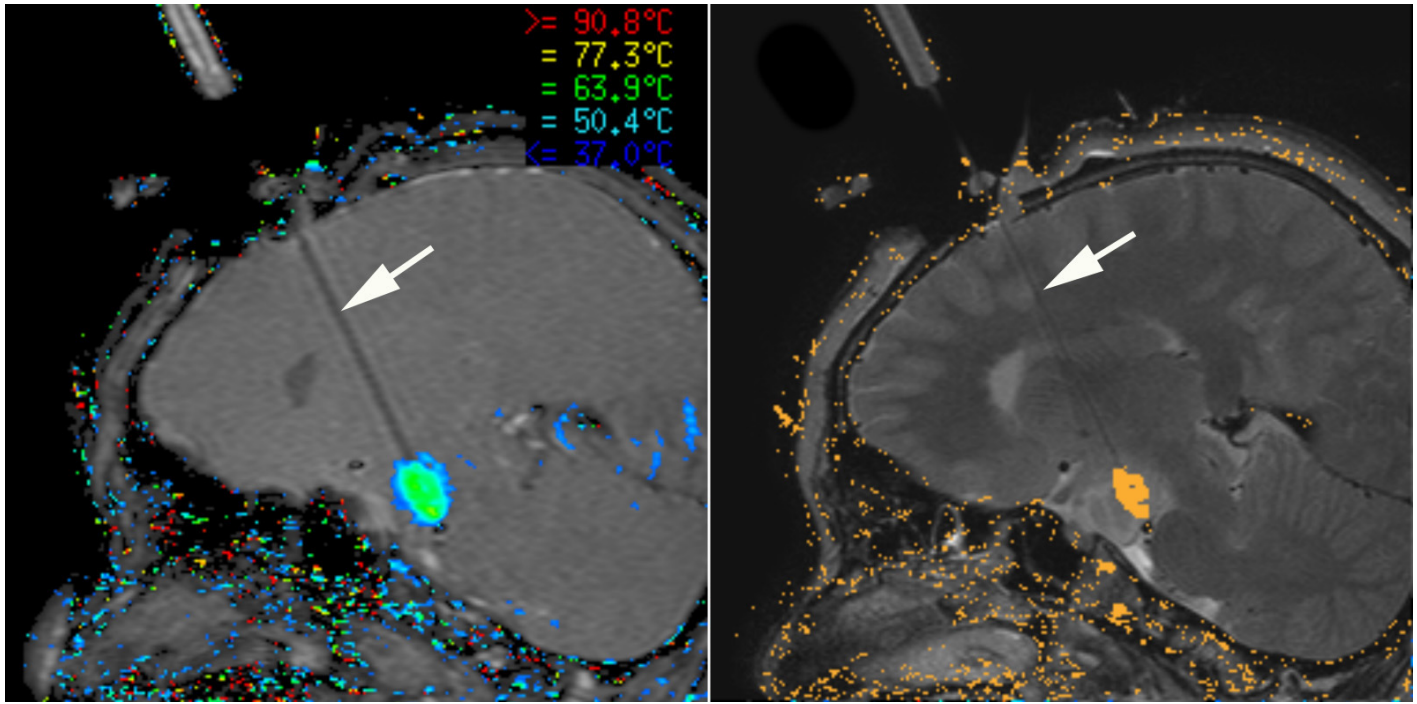


Stereoelectroencephalography



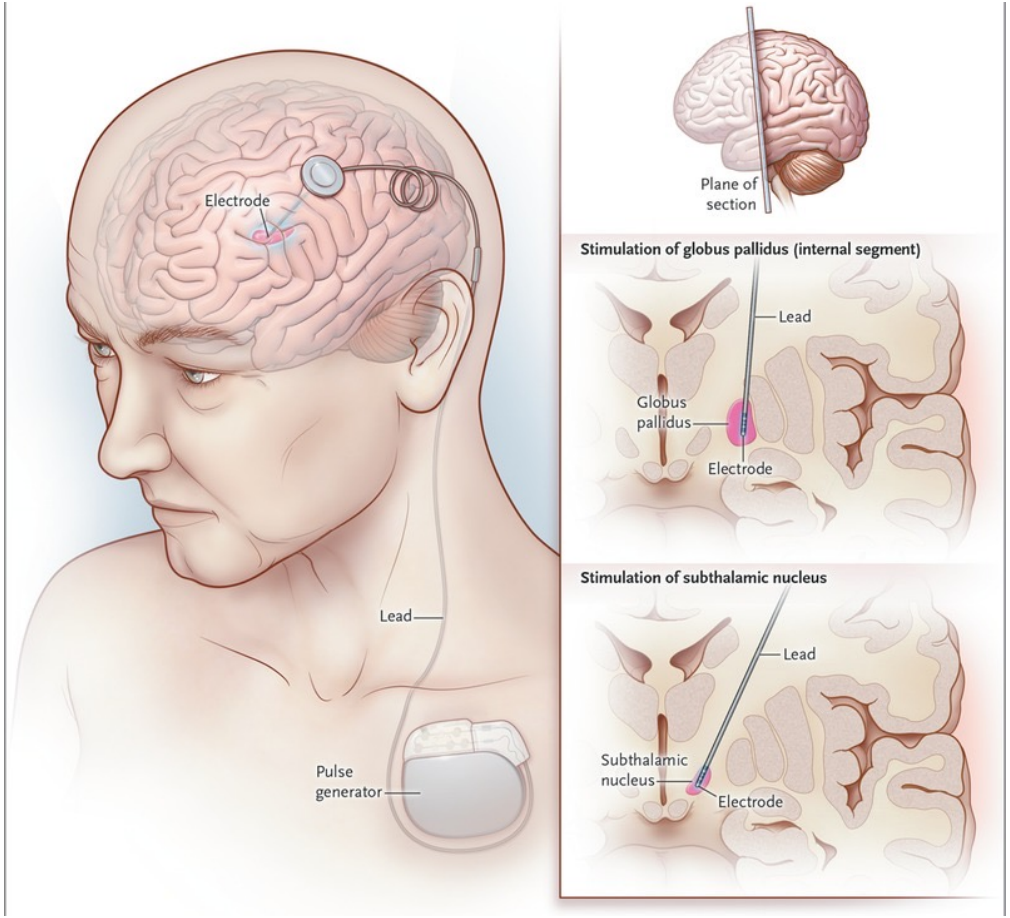
RF-THC and LiTT

- Radio-Frequency Thermocoagulation and Laser Interstitial Thermal Therapy (LiTT)
- Used for drug-resistant epilepsy
- Enables ablation before removing the SEEG electrodes



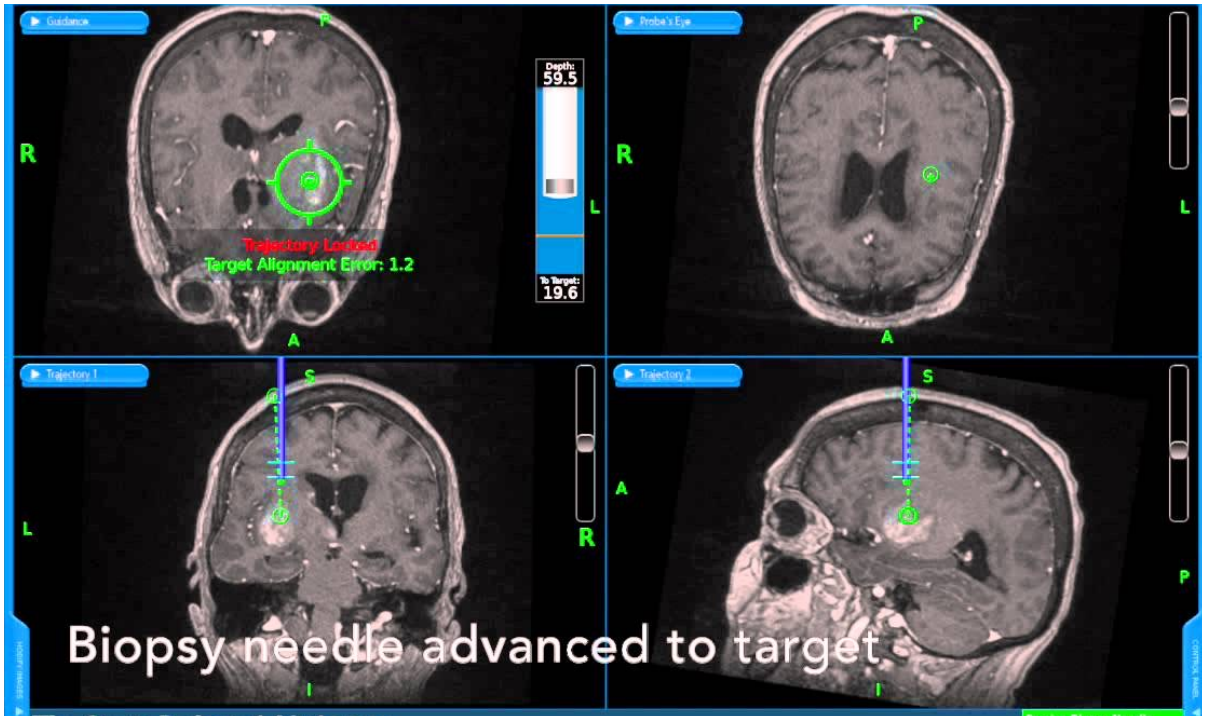
Deep Brain Stimulation

- Used to treat movement disorders and drug-resistant epilepsy.
    - e.g. Parkinson's disease



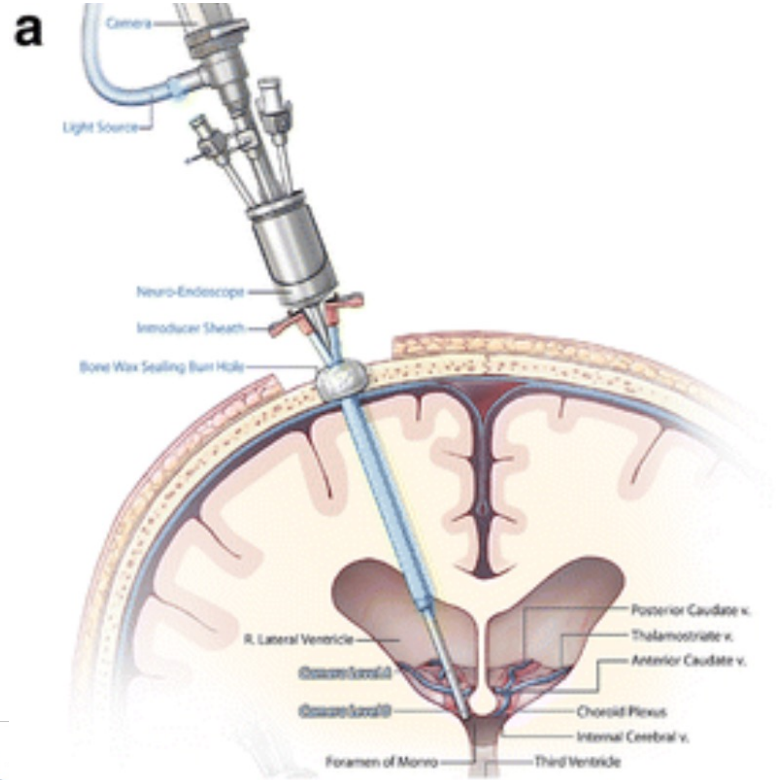
Biopsy

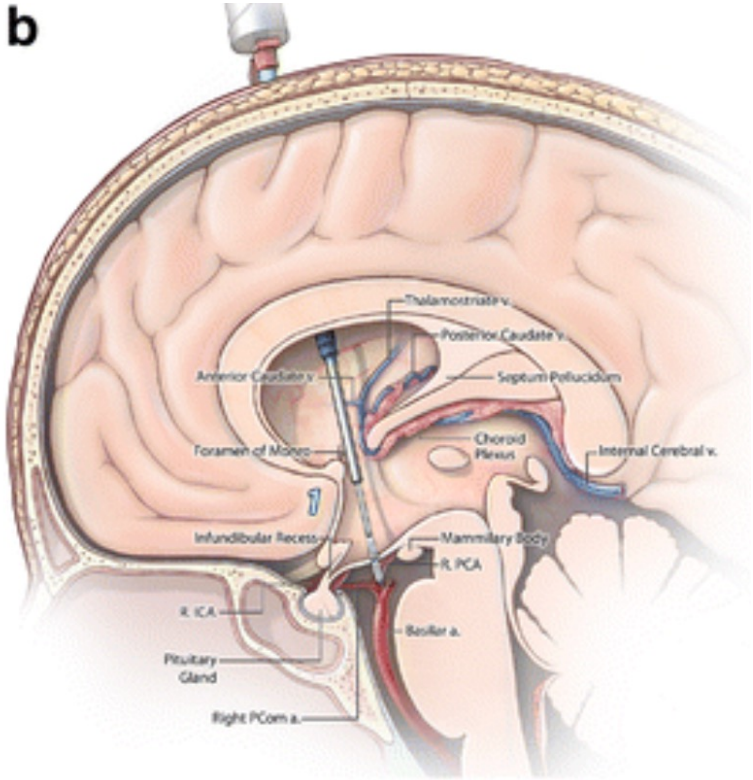
- Allows sampling of lesions to determine identity and behavior
- For multi-bite biopsy, the robot arm allows precise advancement in small steps for sampling different zones of tissue



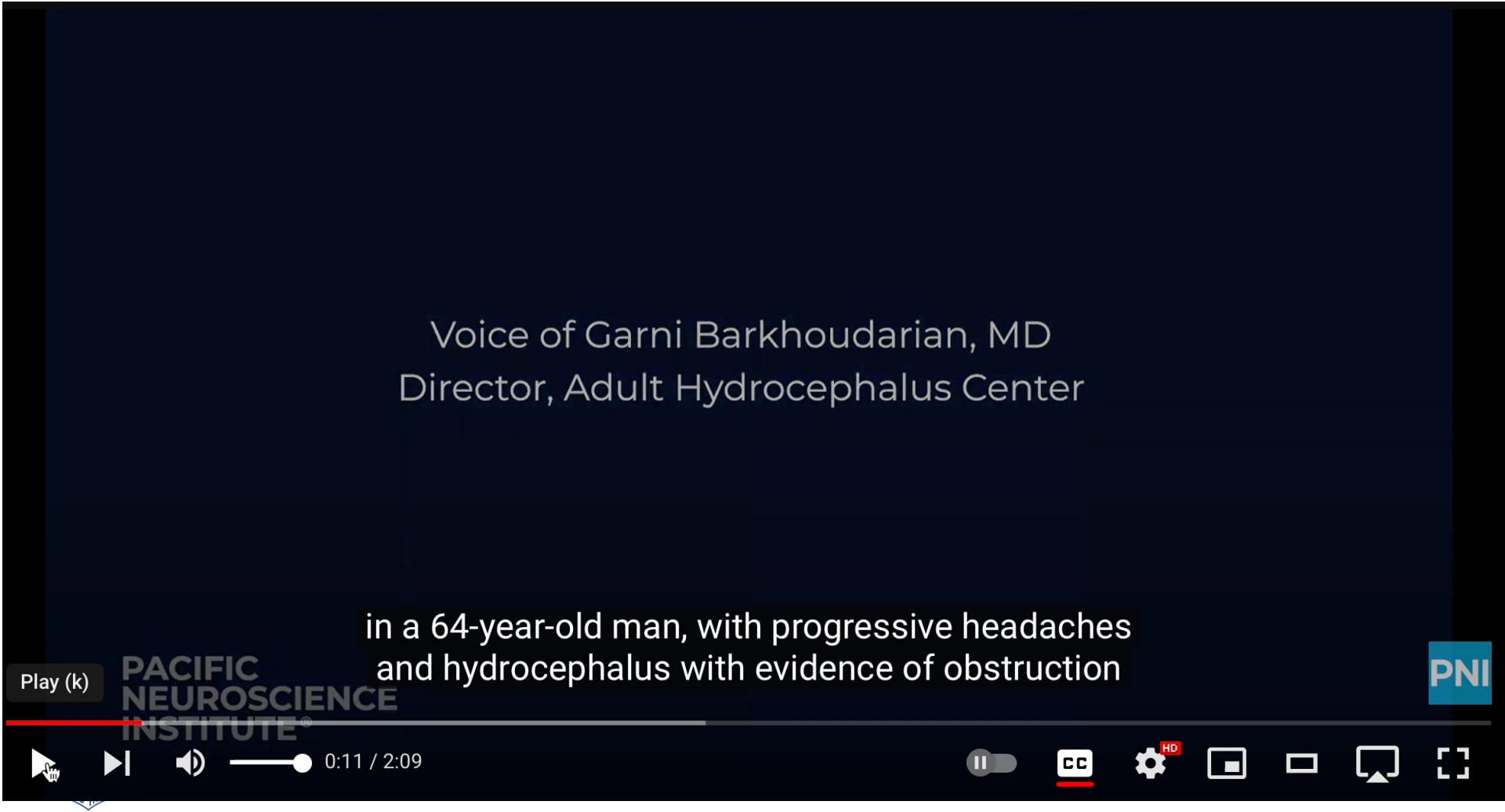
Ventriculoscopy

- Passing of an endoscope into the ventricles for diagnosis, treatment, etc





Ventriculoscopy



Spine Surgery

Spine Surgery

Thank you!

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