Computer-Integrated Surgery: Applications in Neurosurgery

Jose “Tito” Porras, MD
Masaru Ishii, MD, PhD
September 15, 2022
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
Outline

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

College
- 4-5 years
- MCAT

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

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

- Neuro-Oncology
- Skull Base
- Open Vascular
- Endovascular

Subspecialties (Fellowships)
- Tumor
- Spine
- Peripheral Nerve
- Vascular
- Pediatrics
- Functional

Neurosurgery
Comprehensive management of brain tumors.

- Awake surgery
- Electrophysiological mapping
- Laser-induced thermal therapy
- Gamma Knife radiosurgery
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
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
Emphasis on restoring quality of life/neurological function

- Cognitive & neuropsychiatric
- Epilepsy
- Movement disorders
- Pain
Outline

- Neurosurgery: An Overview
- History of Neurosurgery at Johns Hopkins
- Computer Integration to Modernize Neurosurgery
- Computer Integration to Improve Surgical Training
1889 – Johns Hopkins Hospital founded
Harvey Cushing

1896 – Surgical assistant to William Halsted
1900-1901 - **Cushing** spends one year in Europe observing others and studying blood pressure in the context of brain compression.
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.
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
Outline

- Neurosurgery: An Overview
- History of Neurosurgery at Johns Hopkins
- Computer Integration to Modernize Neurosurgery
- Computer Integration to Improve Surgical Training
If you needed to get to center of head for an operation, how would you get there?
Open Approach: Pterional Craniotomy
Open Approach: Pterional Craniotomy
Open Approach: Pterional Craniotomy
Open Approach: Pterional Craniotomy
Open Approach: Pterional Craniotomy
Open Approach: Pterional Craniotomy
Drawbacks of Open Surgery

Wound healing, infection, neurological damage, etc.
Alternative to an open approach?
Endoscopic Endonasal Approach
Endonasal endoscopic removal of pituitary macroadenoma is shown. The initial portion of the procedure involves removing bone at the
Endoscopic Endonasal Approach

- Tuberculum sellae
- Planum sphenoidale
- pSLCA
- Middle Clin. (rem.)
- Periosteal layer
- Middle Clin.
Kerrison biting comes at the risk of poor visualization of neurovascular structures.
How then is surgery safely performed around such high-stakes anatomy?
IGS Components

- Camera
- Computer
- Pointer
- Reference frame
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 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.
These matching pairs are then used to estimate the camera motion using a robust estimator we have developed.
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)

<table>
<thead>
<tr>
<th>TRE₁</th>
<th>Metric for evaluating pointer-based methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRE₂</td>
<td>Metric for evaluating tracker-based and video-based methods</td>
</tr>
<tr>
<td>NGE</td>
<td>Same as TRE₂, however, the target is not visible in the endoscope image.</td>
</tr>
</tbody>
</table>

\[
TRE₁ = \left\| p_{CT} - \left( CT T_{Navigation} \right) p_{pointer} \right\|
\]

\[
TRE₂ = \left\| p_{CT} - \left( t + r \left( \frac{r \cdot (p_{CT} - t)}{r \cdot r} \right) \right) \right\| \quad \text{where} \quad r = RK^{-1} q_{image} - t
\]
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.
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.
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**.
Surgical training translates to

- prolonged operative times,
- increased resource usage,
- and therefore, higher operating room costs.¹
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.
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.
The **Objective Structured Assessment of Technical Skills (OSATS)** is a proposed solution for bias.\(^6\)

<table>
<thead>
<tr>
<th>Time and motion</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Highly tentative, unsure of movements</td>
<td>Efficient, but somewhat tentative, with some unnecessary moves</td>
<td>Clear economy of movements and maximum efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Needle Insertion and bite sizes</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Inappropriate needle positioning and bite sizes resulting in poor suture placement</td>
<td>Generally appropriate techniques with some room for correction</td>
<td>Appropriate needle angle and size and distance of bites every time</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- The OSATS is dependent on the presence of examiners, and thus **prone to subjectivity**.\(^7\)
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.\textsuperscript{10-12}
AI can assess skill level in surgical video with overall accuracy between 92.75 and 100% depending on the observed task.\textsuperscript{13,14}

ML algorithms can also match human expertise in providing objective assessments of surgical skill.\textsuperscript{10,15–18}

- AI may also be used to predict surgical resident performance to help tailor training for at-risk residents.\textsuperscript{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.
**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.
Aim 1: Define a “gold standard” for craniotomy performance through review of intraoperative point-of-view video.

POV craniotomy video recorded from residents and attendings
Aim 1: Define a “gold standard” for craniotomy performance through review of intraoperative point-of-view video.
**Aim 1:** Define a “gold standard” for craniotomy performance through review of intraoperative point-of-view video.

- **POV craniotomy video recorded from residents and attendings**
- **Iterative ranking of craniotomy videos by an institutional panel**
- **Structured interviews to provide in-depth description of craniotomy performance**

**Deliverables**
- Curated, labeled, institutional database of craniotomy video
- Craniotomy assessment rubric
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.
**Aim 2:** Develop a deep learning algorithm that compares trainee to attending performance during a craniotomy.

**Institutional craniotomy video database** → **ML Algorithm Development** → **Final ML Algorithm**

- **ML Algorithm Development**:
  - **Algorithm**
  - **Performance Measurements**
  - **Validation & Testing**

**Novel Measures of Skill**

- **Pupillometry/Gaze**
  - Cognitive workload
- **Instrument Tracking**
  - Task completion time
  - Motion smoothness
  - Positioning/angling
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.
Aim 3: Assess the impact of real-time feedback on trainee performance in a cadaveric model of craniotomy.

Neurosurgery resident performs a cadaveric craniotomy

Raw data streamed to computer

Algorithm Analysis of Raw Data

Comparison of new user data to expert behavior

Anticipated Benefits

- Earlier time to resident independence
- More time learning operative nuances
- Improved intraoperative safety
- Improved intraoperative efficiency

Realtime Audio/Visual Feedback

- Recommendations for next best step
- Negative behavior corrections
**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 self, attending, and AI feedback on resident performance.
Aim 4: Prospectively compare the impact of and bias within resident, attending, and AI feedback on resident performance.

Resident and attending complete a craniotomy

Craniotomy assessment completed via Qualtrics
- Resident
- Attending of Record
- Blinded Attending

Craniotomy assessment completed by ML algorithm

Anticipated Benefits
- Evaluate bias in feedback
- Individualized feedback
- Assess new methods for defining and tracking resident competency

Online Resident Feedback Platform
- Prospective monitoring of performance
- Individualized feedback
- Estimated training level
- Estimated competence in craniotomy components

Raw video data
Mentorship/Collaboration

Gary Gallia, MD, PhD
Masaru Ishii, MD, PhD
Mathias Unberath, PhD
Judy Huang, MD
Henry Brem, MD
Russell Taylor, PhD


