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
- Computer Integration to Modernize Neurosurgery
- Robotics in Neurosurgery
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  - Computer Integration to Modernize Neurosurgery
  - Robotics in Neurosurgery
1889 – Johns Hopkins Hospital founded
Harvey Cushing

1896 – Surgical assistant to William Halsted
Harvey Cushing – founded modern neurosurgery at Hopkins
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**: 
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/exoscopical 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
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
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If you needed to get to the center of head for an operation, how would you get there?
Open Approach: Pterional Craniotomy
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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

- Carotid-optic recess
- ON
- Tuberculum sellae
- ON
- psICCA
- clivus
- pclICA
- Middle Clin.
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

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.
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.
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.
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>$TRE_1$</th>
<th>Metric for evaluating pointer-based methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TRE_2$</td>
<td>Metric for evaluating tracker-based and video-based methods</td>
</tr>
<tr>
<td>$NGE$</td>
<td>Same as $TRE_2$, however, the target is not visible in the endoscope image.</td>
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\[
TRE_1 = \left\| p_{CT} - \left( CT T_{Navigation} \right) p_{pointer} \right\|
\]

\[
TRE_2 = \left\| p_{CT} - \left( t + r \left( \frac{r \cdot (p_{CT} - t)}{r \cdot r} \right) \right) \right\| \quad \text{where} \quad r = RK^{-1} q_{image} - t,
\]
Key result: TREs using video-CT methods are measurably improved over traditional methods.
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.
Key result: tissue surfaces can be reconstructed in 3D using endoscope video.
Sinus Reconstruction
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- 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
Ventriculosity

Voice of Garni Barkhoudarian, MD
Director, Adult Hydrocephalus Center

in a 64-year-old man, with progressive headaches and hydrocephalus with evidence of obstruction
Thank you!