What is Epilepsy Surgery

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What causes epilepsy?

- Unknown: 65%
- Vascular: 10%
- Congenital: 8%
- Trauma: 6%
- Tumor: 4%
- Degenerative: 4%
- Infection: 3%

Who gets epilepsy surgery?

“A skilful healer does not howl incantations when a wound is crying for the knife.”

Sophocles Ajax: 582.

Patients with intractable epilepsy

Epilepticus sic curabitur
Sloane Manuscript, ~1190 A.D.
Intractable Epilepsy

Statement of the Problem

It is estimated that 15-35% of patients with seizure disorders are considered medically refractory.

Inca ruler Capac Yupanqui's wife having an epileptic seizure (~1500).
The Argument for Epilepsy Surgery

Jan Sanders van Hemessen (~1500-1575): "The stone-cutter"
Medically Refractory Epilepsy

Brodie et al. Neurology 2002;58:S2-8

470 newly diagnosed, untreated

- Seizure-free on 1st medication  N=222 (47%)
- Seizure-free on 2nd medication  N=61 (13%)
- Seizure-free on 3rd medication  N=6 (1%)
PARTIAL EPILEPSY
seizure-free on medications

Partial Epilepsy: 55%
Temporal Lobe Epilepsy: 35%
Lesional Pathology: 10%
Mesial Temporal Sclerosis: 10%
Pediatric Epilepsy Surgical Procedures

Resective Surgical Procedures

“remove epileptic brain”

Disconnective Surgery

“disconnect epileptic brain from normal brain”

Stimulation Procedures

“disrupt epileptic network with electrical stimulation”
Epilepsy Surgery: Resective

- Removal of a portion of the brain from which seizures arise

- Need to document:
  - Seizures are medically intractable and disabling
  - Seizures arise only from the region to be resected
  - The area can be resected without causing significant disability to the child

- Child needs careful evaluation to see if this is an option which includes:
  - MRI
  - Video-EEG study in hospital to record typical seizures
  - Neuropsychology evaluation
  - May need other tests – SISCOM, PET, MEG, TMS, fMRI
Resective Surgical Procedures
“remove epileptic brain”

• Diagnostic surgery (Phase I)
  • Intracranial monitoring - subdural grids and strip electrodes
  • Stereoencephalography (SEEG)

• Therapeutic Surgery
  • Image-guided resection
  • Electrocorticography (ECoG) guided resection
The location of seizure onset and spread is determined by the type of symptoms or behavior that occur during the seizure.
ECS

SSEP

Increase hgEEG

fMRI
Limitations of Subdural Grid Monitoring

- Inadequate coverage of intrasulcal, deep brain, and interhemispheric regions
- Difficulty of multilobar sampling
- Inadequate functional network sampling
- Large craniotomy – swelling, hematoma
- Wound complications and infection
- Difficult re-operation with subdural-cortical adhesions
SEEG - Stereoelectroencephalography
SEEG

Commissural & White Matter Connections
- Internal Capsule
- Extreme Capsule
- Anterior commissure
- Corpus Callosum

Frontal
- Anterior Cingulate
- Orbito-frontal
- Inferior Frontal / Opercular

Temporal
- Temporal pole
- Superior Temporal Plane
- Operculum
  (Auditory, AI-All)
- Rhinal/entorhinal
- AMYGDA

Parietal
- Somatosensory (SI, SII)
- Inferior & Superior Parietal lobule
- Operculum

Other
- Striatum, Claustrum, Corticospinal/bulbar
- Hypothalamus, Zona incerta
- Peripenduncular nucleus, N. Basalis
- Pontine-mesencephalic reticular formation
- Raphe, N. Coeruleus, N. parabrachialis

Thalamus
- VM
- VA
- CM (intra-laminar)
- VPI / VPL
- N. Parafascicularis
- N. Dorsalis Orbis
- N. Limitans
- N. Supragniculate limitans
- Pulvinar & Reticularis

Piriform (Olfactory)
## Insular Anatomy and Physiology

Table 8.1 Clinical Correlates for Seizure Origin in Insular Cortex

<table>
<thead>
<tr>
<th>Semiology</th>
<th>Classic Frontal Lobe Localization</th>
<th>Classic Temporal Lobe Localization</th>
<th>Possible Insular Correlate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal rising sensation</td>
<td>No</td>
<td>Amygdala</td>
<td>Anteroventral</td>
</tr>
<tr>
<td>Abdominal pain</td>
<td>No</td>
<td>Amygdala</td>
<td>Anterodorsal</td>
</tr>
<tr>
<td>Throat sensation</td>
<td>No</td>
<td>(Amygdala)</td>
<td>Anterodorsal</td>
</tr>
<tr>
<td>Orofacial somatosensory</td>
<td>No</td>
<td>Parietal operculum</td>
<td>Anterior and posterior</td>
</tr>
<tr>
<td>Painful somatosensory</td>
<td>No</td>
<td>No</td>
<td>Anterior and posterior</td>
</tr>
<tr>
<td>Dysarthria</td>
<td>Motor/premotor/supplementary motor</td>
<td>No</td>
<td>Anterior and posterior</td>
</tr>
<tr>
<td>Hypermotor seizures (+/− nocturnal)</td>
<td>Orbito- and mesiofrontal</td>
<td>No</td>
<td>Anterior and posterior</td>
</tr>
</tbody>
</table>
Many electrodes that have targeted the insula during SEEG investigations have been placed using a standard orthogonal “Talairach” approach. MRIs with electrodes in position are usually not obtained in this situation (Marc Guénot, personal communication). An alternative oblique strategy of depth electrode placement is illustrated in this figure. (Courtesy of Santiago Gil Robles and Philippe Coubes.) Upper three images: (a) occipitoinsular electrode, (b–d) frontal electrodes; lower three images: (a, b) hippocampal electrodes, (c) right inferior insular electrode; (d) right superior insular electrode, (e) left inferior insular electrode.
Engel Classification

- **Group A**
  - Class I: Seizure-free
  - Class II: Rare, nondisabling Seizures

- **Group B**
  - Class III: Improvement in seizure frequency (≥ 80%)
  - Class IV: No significant improvement in seizure frequency
Mayo Surgical Results
N=491

- Group A: 356 patients (72%)
- Group B: 135 patients (28%)
- Most seizures occurred the first year following surgery
- If there is mesial temporal lobe sclerosis and EEG concordance-94% have an excellent outcome (Engel Class I and II)
- Excellent durability
- Major operative M+M 1%
### Complications of Epilepsy Surgery

25 Centers/1,911 Patients

<table>
<thead>
<tr>
<th>Complication</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>9</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Hemiparesis</td>
<td>28</td>
<td>1.5</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>Speech impairment</td>
<td>7</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Hemianopia</td>
<td>11</td>
<td>0.6</td>
</tr>
<tr>
<td>Memory problems</td>
<td>7</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>
Disconnective Surgery
“disconnect epileptic brain from normal brain”

- Corpus callosotomy
- Hemispherotomy
- Posterior Quadrant Disconnection
- MR-guided Laser Interstitial Thermal Therapy (LITT)
  - Visualase
Corpus Callosotomy
Corpus Callosotomy
Fig. 4  

a Sagittal T2 from b=0 image demonstrating the regions of interest outlining the five segments (I to V) of the corpus callosum based on Witelson’s classification. 

b Segment I: The anterior third of the corpus callosum contains fibers to the prefrontal, premotor, and supplementary motor; 

c Segment II: The anterior midbody contains the motor fibers; 

d Segment III: The posterior midbody contains fibers to sensory and posterior parietal region. 

e, f Segment IV and V: The isthmus and splenium contain fibers to the posterior parietal, temporal, and occipital lobes.
Hemisphere Disconnection Surgery
Peri-insular Hemispherotomy

29 Hemispherectomy and Hemispherotomy Techniques:
Peri-insular Hemispherotomy
Wetjen, Nicholas M., Kestle, John R. W.

Cataltepe/Jallo
Pediatric Epilepsy Surgery [2010]
browse html / pages
Posterior Disconnection (Posterior Quadrantectomy)
Laser Ablation

• MR-guided Laser Interstitial Thermal Therapy (Visualase Thermal Therapy System)
• Only for lesional epilepsy, often mesial temporal sclerosis
  • Small, well-defined, solitary lesions
  • Good EEG correlate with seizure onset
Placement Of Fiber - Image Confirmation

Sagittal image

Axial image

Target Area

Laser Fiber

Target Area

Laser Fiber

Slide courtesy of Dr. Greg Worrell
Ablation 1

Test Dose
2.75W for 43sec

Laser Doses
10.75W for 163sec

Irreversible Damage Estimate
25mm by 15mm

Animation – not in real-time

Final Images

Axial Visualase images

Treatment Temperature Map

Irreversible Damage Estimate

Slide courtesy of Dr. Greg Worrell
Combined Estimated Irreversible Damage

Axial image

33mm by 15mm

25mm by 15mm

18mm by 14mm

Ablation 1

Ablation 2

33mm by 15mm

Slide courtesy of Dr. Greg Worrell
Procedure Verification - Post-contrast T1

Target Area

Irreversible Damage Estimate

Ablation

Pre-procedure Axial images

Visualase Image

Post-procedure FLAIR

35mm

Slide courtesy of Dr. Greg Worrell
Procedure Verification - Post-contrast FLAIR

Pre-procedure Axial images

Visualase Image

Post-procedure DIFFUSION

Irreversible Damage Estimate

Target Area

Ablation

Slide courtesy of Dr. Greg Worrell
Stimulation Procedures

“disrupt epileptic network with electrical stimulation”

• Vagal nerve stimulation (VNS)

• Deep Brain Stimulation (DBS)
  • anterior nucleus
  • centromedian nucleus
  • hippocampus

• Cortical stimulation (Neuropace)

• Cortical stimulation ± Depth stimulation
  • chronic subthreshold
Vagal Nerve Stimulation

Goals

• Reduce the frequency and severity of seizures, as well as the opportunity to abort a seizure at its onset

Advantages

• The advantages of vagal nerve stimulation (VNS) include the ability to reduce the dose of anticonvulsant medications that may cause sedation, developmental delay, risk of teratogenicity, and other complications.
• VNS also offers the potential for better seizure control.

Indications

• Although VNS is approved by the U.S. Food and Drug Administration (FDA) for the treatment of pharmacologically intractable partial seizures in adolescents and adults, it is often used for other types of seizure and in children.

Contraindications

• Cardiac dysrhythmias and tracheotomy are relative contraindications to VNS.
• Debilitated patients with little subcutaneous fat have a significant risk of skin breakdown, which is considered a relative contraindication to VNS placement.
• Other contraindications also include patients with previous vagotomies (left-sided or bilateral) and patients with significant upper airway, pharyngeal, cardiac, or gastrointestinal problems.
• Caution should be exerted in patients with history of vasovagal syncope or other brain stimulator implantation.
(A) The head is placed in gentle extension and rotated approximately 15 degrees to the right. A left transverse incision is planned in a skin fold at about C5-C6, below the carotid bifurcation. (B) The jugular vein and sternocleidomastoid muscle are retracted laterally revealing the carotid artery and the vagus nerve (elevated by a vessel loop). It is important to differentiate the vagus nerve, which is deep between the carotid artery and jugular vein, from branches of the ansa cervicalis that typically cross the incision superficial to the carotid sheath. 1. Ansa cervicalis branch; 2. carotid artery; 3. vagus nerve (cranial nerve X); 4. jugular vein; 5 sternocleidomastoid muscle.
Steps for implantation of the vagal nerve electrode. The electrode is oriented perpendicular to the nerve and gently stretched by grasping the embedded sutures. The nerve is slid between the loops of the coil. (A) Tensioning both sutures, the electrode is wound around the vagus nerve. (B) The electrode naturally coils around the nerve. (C) Proper electrode configuration and final position in relation to surrounding structures. JV, jugular vein; CC, common carotid artery.
Neurostimulation
Deep Brain Stimulation
Figure 1  Main connections of the anterior nucleus of the thalamus

- Anterior cingulate cortex
- Subicular cortex
- Anterior nucleus of the thalamus (ANT)
- Anterior medial subnucleus (AM)
- Anteroventral subnucleus (AV)
- Anterodorsal subnucleus (AD)

Retrospenial cortex
Formix (postcommissural)
Anterior Thalamic Nucleus
Centromedian Nucleus
Summary

Adults

Seizure reduction:
   At year 1: 41%, at year 5: 69%

Responder rate:
   At year 1: 43%; at year 5: 68%
RNS

Figure 1: Implanted RNS neurostimulator and NeuroPace cortical strip and depth leads

Copyright owned by NeuroPace, Inc; no permissions for use are required.
Summary:

Adults

Disabling focal or GTC seizures/month at baseline: 10.2

Percent seizure reduction:

- year 1: 44%
- year 2: 53%
- years 3-6: 48-66%
Cortical Stimulation

Figure 1.
Image of subdural grid overlying the seizure focus that resides in eloquent cortex, in this case the motor strip.
Epilepsia © ILAE
Chronic subthreshold subdural cortical stimulation for the treatment of focal epilepsy originating from eloquent cortex

*Nicholas D. Child, *Matt Stead, †Elaine C. Wirrell, ‡Katherine C. Nickels, ‡Nicholas M. Wetjen, ‡Kendall H. Lee, and *Bryan T. Klassen

_Epilepsia, 55_(3):e18–e21, 2014
doi: 10.1111/epi.12525

2-100 Hz, pulse width 9-450 μs, amplitude 2-2.5 mA
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**Summary**

Medically refractory epilepsy remains a major medical problem worldwide. Although some patients are eligible for surgical resection of seizure foci, a proportion of patients are ineligible for a variety of reasons. One such reason is that the foci reside in eloquent cortex of the brain and therefore resection would result in significant morbidity. This retrospective study reports our experience with a novel neurostimulation technique for the treatment of these patients. We identified three patients who were ineligible for surgical resection of the intracranially identified seizure focus because it resided in eloquent cortex, who underwent therapeutic trial of focal cortical stimulation delivered through the subdural monitoring grid. All three patients had a significant reduction in seizures, and two went on to permanent implantation, which resulted in long-term reduction in seizure frequency. In conclusion, this small case report provides some evidence of proof of concept of the role of targeted continuous neocortical neurostimulation in the treatment of medically refractory focal epilepsy, and provides support for ongoing investigations into this treatment modality.

**KEY WORDS:** Epilepsy, Seizures, Epilepsy surgery, Deep brain stimulation, Neurostimulation.
Example traces from two patients (upper and lower rows) before and during cortical stimulation. Red dots mark detected interictal discharges (IEDs).
Comparison of the frequency of IEDs per second before and during cortical stimulation with each bar representing six 15-minute blocks of data from a single patient. $P = [0.000, 0.0028, 0.0081, 0.0141, 0.0001, 0.0006]$. 
Subdural subthreshold cortical stimulation

Comparison of all six patients across condition. $P = 0.002$. Error bars represent standard error.
Am I An Epilepsy Surgery Candidate?

• If 2-3 medications fail to stop seizures, surgical options are often considered

• Resective surgery can be a very effective option for medically intractable epilepsy in selected children

• Minimally invasive procedures may reduce risk / discomfort / expense of surgery

• Disconnective and neurostimulation surgical options can also be considered depending on type of epilepsy
Questions & Discussion