Stereoelectroencephalography and stereotactic laser ablation in infants and toddlers: Case series and technical nuances

Jeffrey S. Raskin, Kathryn Wagner, Virendra R. Desai, Rachel Yanowitch, Howard L. Weiner, Sandi Lam, Daniel J. Curry

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Conflicts of interest

• No financial disclosures
“The value of experience is not in seeing much, but in seeing wisely.”

— Sir William Osler
Minimally invasive surgical epilepsy

- Stereoelectroencephalography (sEEG) followed by stereotactic laser ablation (SLA) is an innovative, minimally invasive strategy to treat refractory epilepsy.

- This approach is feasible for deep targets with high surgical access corridor-associated morbidity, or multifocal targets.
Minimally invasive surgical epilepsy

- The technique relies on skull bolts and cranial fixation; thus, the incompletely ossified cranium of young children poses significant challenge.

- This represents the first safety assessment of this surgical technique in infants and toddlers undergoing SLA for epilepsy; this also represents the largest SLA series ever reported in this young population.
Figure 1: Representative SLA case. A) Cranial fixation by CRW frame B) 3.2mm burr hole via stereotactic trajectory C) Placement of skull bolt D) Visualase laser through skull bolt to target (pictures courtesy of TCH).
Figure 2: Representative sEEG case. A) T2 axial demonstrating tuber burden B) Planned trajectories C) Mayfield cranial fixation D) ROSA attached E) Post-op 3D CT F) Seizure onset zone electrodes in red G) coronal with lasers, sagittal and axial post contrast demonstrating ablation zones.
We defined *dynamic sEEG*

- *Dynamic sEEG* describes the intentional placement of DE along trajectories which are chosen based on cumulative preoperative clinical, radiographic, functional, and electrophysiologic data.

- Based on all Phase I data, dynamic sEEG DE are placed along a trajectory that optimizes the subsequent laser ablation of that SOZ.

- Currently, no unified naming convention exists to encode the data elements of each trajectory.
3-D reconstruction of main seizure focus

The 3-D brain model obtained from Curry™ is then utilized to examine the location of the 1st EEG change for the main EEG pattern of interest for surgical planning. The figures below show the onset (red) and spread (pink) of main EEG pattern #1, representing the "big seizures causing falls".

Using Curry™ neuroimaging software, the brain MRI images with the integrated electrodes are used to examine the onset and spread of the EEG pattern of interest. The MRI with integrated electrodes from Curry™ software below show that the 1st EEG change (white circle) of the main EEG pattern #1 at RC 4-6 is inferior to a prominent right frontal tuber.
Planning trajectories on ROSA™ computer

Naming electrode trajectories

There is a need for a naming convention for Stereo EEG electrodes placed during Phase II Epilepsy evaluation for tracking individual cases and for research purposes. A 3 component naming system for naming sequential electrodes is proposed: 1. Numerical; 2. Location; 3. Technology.

2. Location: Anterior temporal (AT), mid temporal (MT), occipital temporal (OccT), parietal temporal (ParT), middle temporal gyrus (MTG), etc.
3. Technology:
   A – Anatomy
   B – Brain electrical source analysis (BESA)
   D – DTI
   E – EEG
   M – MEG
   Mc – MEG cluster
   P – PET
   Pi – PET ictal
   R – RsfMRI
   S – Semiology
   Sp – SPECT

Examples:
1. First electrode, placed in anterior temporal lobe, based on SPECT: 1AT Sp
2. Second electrode, placed in occipital lobe, based on DTI: 2Occ D
3. Third electrode, placed in the fronto-temporal confluence, passed on MEG: 3FT M

Rule set

I. Each trajectory begins with an integer.

II. Capital L or R designates lateralization and follows the integer; then a space is inserted.

III. A capital letter or short moniker identifies the anatomical entry point.
   i. If entry points are similar anatomically and close together, use m (mesial) and l (lateral) preceding the entry point (e.g. mMFG)

IV. A capital letter or moniker identifies the anatomical target point; then a space is inserted.
   i. If the target point and entry point are in the same lobe, only one designation is necessary (orthogonal short middle frontal gyrus, MFG)

V. Phase 1 modalities are listed consecutively and alphabetically in lower case (unless specified, e.g. Mc).
   - 1R AntT Sp
   - 2L Occ ad
   - 3R MFG aMcp
   - 4R OccT asp
   - 5L mPostcav aMc
Stereotactic electroencephalography (sEEG) Planning Form

Patient Name: ___________________________ DOB: ____________ Gender: M / F

Surgeon: ________________________________
Assistant: ________________________________
Diagnosis: ______________________________

Designate neocortical area

Semiology ________________________________

Electroclinical seizures: ______________________

Previous epilepsy surgery: ________________________

High Risk Lesions:

- Calcified lesions: ________________________
- Enhancing lesions: ________________________

Studies
- □ CT
- □ CTA
- □ SPECT
- □ FLAIR
- □ T1+
- □ T2
- □ BESA
- □ MEG
- □ rsfMRI
- □ PET
- □ sLORETA
- □ WADA

Electrodes:

0. Ground = 4 contact

1. ________________________________
2. ________________________________
3. ________________________________
4. ________________________________
5. ________________________________
6. ________________________________
7. ________________________________
8. ________________________________
9. ________________________________
10. ________________________________
11. ________________________________
12. ________________________________
13. ________________________________
14. ________________________________
15. ________________________________
16. ________________________________

Planning trajectories on ROSA® computer

Naming electrode trajectories:

- There is a need for a naming convention for Stereo EEG electrodes placed during Phase II epilepsy evaluation for tracking individual cases and for research purposes. A 3 component naming system for naming sequential electrodes is proposed: 1. Numerical; 2. Location; 3. Technology.

- 2. Location: Anterior temporal (AT), mid temporal (MT), posterior temporal (PostT), parietal temporal (ParT), middle temporal gyrus (MTG), etc.
- 3. Modality:
  - A = Anatomy
  - B = Brain electrical source analysis (BESA)
  - C = Calcified
  - D = DTI
  - E = EEG
  - G = goodinium enhanced
  - M = MEG
  - Mc = MEG cluster
  - P = PET
  - Pr = PET (resolution)
  - PrMRI = PET/MRI
  - S = Semiology
  - Sp = SPECT

- Examples:
  1. First electrode, placed in anterior temporal lobe, based on SPECT: 1AT Sp
  2. Second electrode, placed in occipital lobe, based on DTI: 2OcT 1
  3. Third electrode, placed in the frontal-temporal confluence, passed on MEG: 3FT M

Planning tips:

- Use 3mm cylinders to evaluate vascular corridor, 10mm cylinders to evaluate bolt conflicts.
- Use “view along” to identify nearby vessels.
- Save frequently.
**Stereotaxy**

- **CRW Frame (Integra)**
  - 1. Localizer in OR
  - 2. CT scan
  - 3. Back to OR for planning of trajectory, placement of cath/fiber

- **ROSA (Zimmer)**
  - 1. In-bone fiducials in OR then CT scan vs. laser registration only
  - 2. Back to OR for planning of trajectory, placement of cath/fiber

- **Clearpoint (MRI Interventions)**
  - All done in MRI suite

- **Curve Navigation (Brainlab)**
  - In OR for registration, planning of trajectory, placement of cath/fiber. Scans are done pre-op.

- **Stealth Navigation (Medtronic)**
  - In OR for registration, planning of trajectory, placement of cath/fiber. Scans are done pre-op.

**Location**

- **Surgery type**
  - **Laser Fibers/ Ablation in MRI**
    - 1. Visualase
    - 2. Monteris
  - **Cyst/shunt catheter placement in MRI/OR**
  - **Biopsy in MRI/OR**
  - **SEEG**
  - **Navigation for open cranis, spines in OR**
1. In-bone fiducials in OR then CT scan vs. laser registration only
2. Back to OR for planning of trajectory, placement of cath/fiber

- Laser Fibers/ Ablation in MRI
  1. Visualase
  2. Monteris

SEEG
### Stereotactic Implantation of Depth Electrodes with ROSA

<table>
<thead>
<tr>
<th>ELECTRODE</th>
<th>RECORDING LENGTH</th>
<th>DISTANCE TO TARGET</th>
<th>SKULL THICKNESS</th>
<th>SKULL/SKIN THICKNESS</th>
<th>NUMBER OF CONTACTS</th>
<th>COLOR/NUMBER CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. LMFG n ascpb</td>
<td>29.0</td>
<td>168.88</td>
<td>4.5</td>
<td>7.8</td>
<td>6</td>
<td>🟠 Rad 22</td>
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<tr>
<td>2. LSEP ab</td>
<td>33.1</td>
<td>121.22</td>
<td>5.1</td>
<td>9.8</td>
<td>8</td>
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<tr>
<td>3. LPAN am</td>
<td>36.0</td>
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<td>12.16</td>
<td>10</td>
<td>🟦 Brown 5</td>
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<tr>
<td>4. LOT sp</td>
<td>97.3</td>
<td>185.32</td>
<td>4.47</td>
<td>7.6</td>
<td>12</td>
<td>🟦 Brown 26</td>
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<td>5. RPOSTCAV apm</td>
<td>26.3</td>
<td>120.46</td>
<td>4.1</td>
<td>9.4</td>
<td>6</td>
<td>🟠 Red 7</td>
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<td>6. RS2 ames</td>
<td>27.0</td>
<td>127.88</td>
<td>6.49</td>
<td>11.32</td>
<td>6</td>
<td>🟦 Green 32</td>
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<td>7. RMFG arsm</td>
<td>46.4</td>
<td>140.41</td>
<td>5.39</td>
<td>10.23</td>
<td>10</td>
<td>🟦 Yellow 12</td>
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<td>8. FOPR abp</td>
<td>34.5</td>
<td>189.23</td>
<td>3.6</td>
<td>5.7</td>
<td>8</td>
<td>🟦 Orange 00</td>
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<tr>
<td>9. ROT sp</td>
<td>90.4</td>
<td>185.97</td>
<td>6.8</td>
<td>11.0</td>
<td>12</td>
<td>🟦 Orange 98</td>
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<td>10. LMFG, ascpb</td>
<td>20.5</td>
<td>137.60</td>
<td>5.12</td>
<td>7.4</td>
<td>4</td>
<td>🟦 Brown 93</td>
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<td>5.0</td>
<td>4.0</td>
<td>6</td>
<td>🟦 Orange 16</td>
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<tr>
<td>12. LPOS am</td>
<td>30.7</td>
<td>135.5</td>
<td>5.9</td>
<td>9.3</td>
<td>6</td>
<td>🟦 Blue 9</td>
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<tr>
<td>13. LEOPR am</td>
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<td></td>
<td>2.0</td>
<td>3.9</td>
<td>8</td>
<td></td>
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<tr>
<td>14. RT asr</td>
<td>40.5</td>
<td>132.0</td>
<td>3.8</td>
<td>6.16</td>
<td>8</td>
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<td>15. LI asr</td>
<td>42.2</td>
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<td>7.4</td>
<td>8</td>
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<td>16. LSMA asg</td>
<td>26.8</td>
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<td>5.2</td>
<td>10.1</td>
<td>8</td>
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<td>25.8</td>
<td>171.24</td>
<td>6.7</td>
<td>12.6</td>
<td>12</td>
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</table>
Minimally invasive surgical epilepsy

Standard work tools

Case series

Technical nuances
Methods

• A retrospective chart review for patients <36 months old undergoing sEEG or SLA at TCH from 2013-2016.

• Demographics, medical history, and surgical outcomes were recorded.

• Perioperative events and technical nuances of SLA surgery for effective execution and for complication avoidance in these children were noted.
<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Age (months)</th>
<th>Sex (m/f)</th>
<th>Cranial fixation</th>
<th>Surgery</th>
<th>Outcome</th>
<th># Stereotactic Trajectories</th>
<th># Complications</th>
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<tr>
<td>HH</td>
<td>5.3</td>
<td>m</td>
<td>Sugita, Horseshoe, Sugita</td>
<td>SLA, 1 Visualase laser</td>
<td>Repeat SLA X 2, then diminished frequency</td>
<td>3</td>
<td>0</td>
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<tr>
<td></td>
<td>6.1</td>
<td>m</td>
<td>Sugita</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
<td>1</td>
<td>0</td>
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<td></td>
<td>9.9</td>
<td>m</td>
<td>Sugita, Sugita</td>
<td>SLA, 1 Visualase laser</td>
<td>Repeat SLA X 1 (Monteris laser); retreatment pending</td>
<td>2</td>
<td>1</td>
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<tr>
<td></td>
<td>18.4</td>
<td>m</td>
<td>CRW, CRW, CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Revision SLA X 2, then diminished frequency</td>
<td>3</td>
<td>0</td>
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<td></td>
<td>22.1</td>
<td>m</td>
<td>CRW, CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Revision SLA X 1, then seizure free</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
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<td>25.1</td>
<td>m</td>
<td>CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>28.8</td>
<td>f</td>
<td>CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>m</td>
<td>CRW, CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Repeat SLA X 1, continued seizures</td>
<td>2</td>
<td>0</td>
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<tr>
<td></td>
<td>30.0</td>
<td>m</td>
<td>CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>31.0</td>
<td>f</td>
<td>CRW, CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Revision SLA X1, then seizure free</td>
<td>3</td>
<td>0</td>
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<tr>
<td></td>
<td>35.9</td>
<td>m</td>
<td>CRW</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>FCD</td>
<td>6.7</td>
<td>f</td>
<td>Horseshoe</td>
<td>SLA, 1 Visualase laser</td>
<td>Seizure free</td>
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<td>0</td>
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<td>f</td>
<td>Sugita, Horseshoe</td>
<td>sEEG, 4 electrodes</td>
<td>SLA X 2 Visualase lasers, almost seizure free</td>
<td>6</td>
<td>0</td>
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<tr>
<td>TSC</td>
<td>23.6</td>
<td>f</td>
<td>Sugita, Horseshoe</td>
<td>sEEG, 17 electrodes</td>
<td>SLA w/ 2 Visualase lasers, almost seizure free</td>
<td>21</td>
<td>0</td>
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<td>34.7</td>
<td>f</td>
<td>Mayfield, Horseshoe</td>
<td>sEEG, 10 electrodes</td>
<td>SLA X 4 Visualase lasers, seizure free</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>

* SLA, Stereotactic laser ablation; HH, Hypothalamic Hamartoma; FCD, Focal Cortical Dysplasia; TSC, Tuberous Sclerosis Complex

n = 62
n = 1
Results

• N=15, 9 M and 6 F,

• Average age 23 months underwent 26 procedures

• Diagnoses included hypothalamic hamartoma (n=11), focal cortical dysplasia (n=2), and tuberous sclerosis complex (n=2).

• Cranial fixation strategies included 6/26 (23%) in Sugita headframe, 15/26 (58%) in Mayfield CRW frame, and 5/26 (19%) horseshoe headholder.

• There was only one perioperative complication out of 33 electrode and 29 laser ablations (1.6%): a clinically insignificant intracranial tract hemorrhage with no resultant intervention.

• Hypothalamic hamartoma pathology was retreated subsequently in 6/11 (55%) cases and a third stage in 1/11 (9%).
Results

• We demonstrate safety of our nuanced cranial fixation methods for sEEG and SLA as applied to children less than 3 years of age, who have incompletely ossified and thin skull bone.

• More than half of hypothalamic hamartoma patients had subsequent SLA surgery in staged fashion, underscoring the iterative approach to this minimally invasive surgical technique.
Minimally invasive surgical epilepsy

Standard work tools

Case series

Technical nuances
Stereoelectroencephalography and stereotactic laser ablation in infants and toddlers: Case series and technical nuances

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Workflow: Placing dynamic sEEG electrodes using bone fiducials and ROSA™

Placing dynamic sEEG electrodes using bone fiducials and ROSA™

The workflow for placing dynamic sEEG electrodes at TCH includes intraoperative fiducial placement, extracerebral volumetric CT, cranial fixation and registration using ROSA™, and surgical placement using ROSA™ (Figure Infographic).

Anesthesia and preparation

The patient undergoes general anesthesia using total intravenous anesthesia (TIVA; e.g. Precedex, Remi, Sufentanil). Benzodiazepines and propofol are strictly avoided. Large bore IV access and bladder decompression by indwelling catheter are obtained. Beat to beat monitoring is not necessary for surgery, although an arterial line may be indicated by patient physiology. The patient’s head is positioned on a horseshoe and the scalp is prepared with 70% isopropyl alcohol. A surgical team pause occurs and prophylactic antibiotics is administered.

Procedure start and placing intraosseous fiducials

On a dedicated mayo table, betadine sponges, suture, local and disposable Osteomed driver (450-0600) and bone fiducials (FM-4010) with the DBS screw driver set are placed. The procedure begins with identification of target trajectories which have been uploaded to ROSA™ (TIP 1-3). Hair is not clipped; the intended placement is swiped with betadine, injected with lidocaine 0.5%/bupivacaine 0.5%/1,200,000 Epinephrine (local mix). A stab wound with 15 blade scalpel allows for passage of a fiducial into bone, with perpendicular orientation. The fiducial should have adequate purchase to prevent wobble, but also one must guard against over-penetration (TIP 4). A stitch is placed around the base to control bleeding. The operator then accompanies transport of the patient to CT for zero-gantry stereotactic protocol CT head without contrast, and return to the operating room (OR) for planning and depth electrode placement (TIP 5).

**TIPS**

1. Place a minimum of 5 fiducials, spaced widely and asymmetrically to maximize accuracy.
2. Identify 3D ROSA™ trajectories and place fiducials where they will not interfere.
3. Bilateral parasagittal Mohawk fiducial placement ensures they will be out of the way of trajectories and accessible to ROSA™.
4. Beware, the fiducials will not torque limit, the anchoring thread measures 5mm and may prolute deeper than the skull depth.
5. Any fiducial movement will eliminate accurate registration.

Placing dynamic sEEG trajectories using the ROSA™

Patient planning folder from ROSA™ software and stereotactic CT with fiducials are uploaded to the ROSA™ robot. Prior to cranial fixation, it is useful to circumferentially block the scalp using local mix. The patient is placed in appropriate cranial fixation (TIP 1-2). Position the patient such that the majority of trajectories are dependent, minimizing skiving error, and that flexion of the neck facilitates venous drainage (TIP 3). The scalp is prepared with 3-step prep using Betadine scrub/paint and chlorhexidine. ROSA™ is draped using the disposable ROSA™ arm drape along with the patient head using towels, stapler, loban, and a dana sheet. For very small children, a sterile registration is performed at this point to minimize any time spent in cranial fixation. Registration in this manner using bone fiducials results in submillimeter prediction accuracy.

First, a 4 contact ground electrode is placed midline in a subcutaneous pocket from parietal vertex towards bregma using the passing needle, with tail emanating posteriorly and sewn at exit and in four point circle restraints (TIP 4). The ROSA™ instrument holder is attached. The operator drives ROSA™ to the first trajectory (TIP 5), fixes the 1.8mm PEEK instrument reducer and passes a sharp obturator to mark the injection site. After local injection, a 15-blade stab wound is created, the 1.8mm reducer is removed and 3.2mm metal reducer for drilling is placed. The caliper is set to the skull thickness measurement and the depth stop is adjusted appropriately.

Incrementally, the operator drills using the 3.2mm bit, while the assistant uses forceps to clear the drill path of hair (TIP 6). Then, the 3.2mm adaptor is removed and the wench guide is placed, using the T-handle wrench with anchor bolt and cap removed (TIP 7-8). The wench guide is then removed and replaced with the 1.8mm plastic adaptor. The sharp obturator is passed to depth (calculated on ROSA™ software) using a stereotactic ruler and marker (TIP 9). After some dwell time, the obturator is removed, the anchor bolt cap is placed (TIP 10), and then the depth electrode is placed to measured depth (TIP 11). A 3-0 prolene skin stitch is tied at the base of the electrode, securing the depth electrode in situ. The operator must be sure the cables match the number and color of electrodes on the field! When opening electrodes, we typically take note of the color and number and write it on a board and on a map sheet for the epilepsy monitoring unit (EMU). We write the following on the white board (columns): depth name, recording length, skull thickness, contacts, and codes (Figure). Once the final electrode is placed, electrocorticography proceeds to ensure electrode integrity. When complete, dores are carefully removed, the electrodes gathered at the scalp convexity, and the head wrapped with Kerlix dressing.

**TIPS**

1. This patient population retains diastatic sagittal suture and posterior fontanelle, great care must be taken not to transgress the calvarium.
2. The Sugita frame requires placement of the star adapter prior to fixation, or repositioning will be necessary.
3. Avoid neck flexion or excessive head rotation which may impede venous return, causing the intracranial vessels to become more conspicuous targets during stereotactic placement.
4. Take great care in the midline if the sagittal or coronal sutures remain diastatic.
5. Using the vigilance device, ensure that the ROSA™ arm does not contact itself or the patient.
6. Keep hair and skin clear using forceps, especially when the hair is long as the 3M movement can cause significant scalp injury or move the patient in pins.
7. For sEEG which may become ablation tracts, use Ad-tech electrodes and PHT anchor bolts and caps (which are large bore enough for lasers).
Workflow: Placing dynamic sEEG electrodes using bone fiducials and ROSA™

<table>
<thead>
<tr>
<th>TIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. This patient population retains diastatic sagittal suture and posterior fontanelle; great care must be taken not to transgress the calvarium.</td>
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</tr>
<tr>
<td>8. Use low torque when placing or removing the anchor bolts as they can break or cause skull fractures.</td>
</tr>
<tr>
<td>9. The PMT anchor bolt is 25mm long. It is helpful to place the obturator to 25mm depth, and apply monopolar electrocautery to the obturator with slow pressure until dura is penetrated. Open dura obviates this step.</td>
</tr>
<tr>
<td>10. The anchor bolt cap should have a blue gasket inside; check before placing or spinal fluid will leak indefinitely.</td>
</tr>
<tr>
<td>11. Ad Tech electrode recording length is selected based on intracranial length, calculated on stereotactic software (e.g. 30-40mm recording length = 8 contact; 40-50 recording length = 10 contact).</td>
</tr>
</tbody>
</table>
## TIPS

1. Check stability of all bolts prior to preparing the scalp for laser placement; if unstable, see “Salvage Techniques” for placement of trajectory.

2. Be careful as excessive torque can cause skull fractures in thin skulls or break titanium in thick skulls with good purchase.

3. Whenever placing the PMT bolts and caps, check that the cap has a blue gasket internally. If not, it will not form a seal and will leak CSF throughout the case.

4. There should be minimal or no resistance as dura and bone is all open. Stop if any resistance is felt.

5. If bone is too thin or craniectomized, see “Salvage Techniques” for placement of trajectory.
CRW frame: Cranial fixation

TIPS

1. If the head size exceeds the CRW gantry, remove the posterior Luminant panel.

2. See proper placement in figure below. If patient will be lateral or significantly head turned (e.g. to avoid previous craniotomy), attachment of the frame to the table will require the off-set Mayfield attachment.

3. Avoid any obliquity in angle, all orthogonal with nose straight in frame and frame straight in CT.

4. Use a “level” app on the frame within the CT scanner to assure the head is orthogonal to couch, and therefore orthogonal to gantry (Bubble Level from Lemonado is free online).

5. When tomahawk approach or lateral positioning, one must use the offset U-connector from Mayfield to CRW frame, or the frame will be limited intra-operatively, requiring undraping and Mayfield disconnection.

CRW frame: Achieving trajectories

TIPS

1. Vernier scale: An engraved accessory scale which allows 0.1-mm accuracy; for the CRW frame it represents the decimal of the intended coordinate. For example, to find 45.6, place the 0 mark of the Vernier scale between the 45 and 46 and then orient the 6 on Vernier scale in confluence with 51 (45+6).

2. There are two fasteners: anterior and posterior. Any incomplete docking will lead to massive error.

3. Bone thickness is best identified on volumetric CT head. Drilling is optimized by orthogonal forces. Any angle can induce ‘skiving’ error, which may be prevented by hovering the drill bit to create a divot before continuing a burr hole or serial drilling with variable bit sizes.

4. After coordinates have been secured, the target centered frame makes the top of the frame 160mm to target. We use a reducing block which adds 10mm (170mm to target) and then another 50mm reducing tube (220mm to target). This allows for unobstructed view from the top of the frame to the entry point.

5. If CSF egresses, we typically place a finger or gentle bone wax over the lumen. Any resistance of electrode passage indicates a problem, and the obturator may need to be reused for dural penetration. If excessive bleeding comes from the trajectory, judgment needs to be used regarding open craniotomy, removal of bolt, placement of electrode, or irrigation.

6. If bone is too thin or craniectomized, see “Salvage Techniques” (below) for placement of trajectory.
## Stereotactic placement using Clearpoint

<table>
<thead>
<tr>
<th>Tips</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. We ensure the tennis racket shaped send/receive coils are placed between scalp and pins prior to pinning (pins through tennis racket holes).</td>
</tr>
<tr>
<td>2. Positioning is optimized when the drilling angle is as dependent as possible and the laser trajectory is straight out of the MRI gantry. A trajectory too high or lateral will be impeded by the roof/walls of the gantry. An inferior projecting laser will allow air to enter the cavity and laser, causing artifact.</td>
</tr>
<tr>
<td>3. We avoid using towels to drape as they bunch under the final drape obscuring the operative field; however, staples are acceptable as they as will not cause bad artifact.</td>
</tr>
<tr>
<td>4. We place a tegaderm on the proprietary drape to allow removal of the Clearpoint grid.</td>
</tr>
</tbody>
</table>
Conclusions

• Stereotaxy in children less than age three is complicated by the morbidity of cranial fixation and the accumulation of error.

• Careful surgical technique maximizes safe placement of sEEG electrodes and laser cannula.

• Multiplicitous workflows for achieving laser ablation in children exist and are safe.
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