

Video Article

Stereo-Electro-Encephalo-Graphy (SEEG) With Robotic Assistance in the Presurgical Evaluation of Medical Refractory Epilepsy: A Technical Note

Jeffrey P. Mullin¹, Saksith Smithason¹, Jorge Gonzalez-Martinez¹

¹Department of Neurosurgery, Cleveland Clinic

Correspondence to: Jorge Gonzalez-Martinez at gonzalj1@ccf.org

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Abstract

SEEG is a method and technique which is used for accurate, invasive recording of seizure activity via three dimensional recordings. In epilepsy patients who are deemed appropriate candidates for invasive recordings, the decision to monitor is made between the subdural grids versus SEEG. Invasive neuromonitoring for epilepsy is pursued in patients with complex, medically refractory epilepsy. The goal of invasive monitoring is to offer resective surgery with the hope of allowing seizure freedom. SEEG's advantages include access to deep cortical structures, an ability to localize the epileptogenic zone (EZ) when subdural grids have failed to do so, and in patients with non-lesional extra-temporal epilepsies. In this manuscript, we present a succinct historical overview of the SEEG and report on our experience with frameless stereotaxy under robotic. An imperative step of SEEG insertion is planning the electrode trajectories. In order to most effectively record ictal activity via SEEG trajectories should be planned based upon a hypothesis of where the seizure activity originates the presumed epileptogenic zone (EZ). The EZ hypothesis is based on a standardized preoperative workup including video-EEG monitoring, MRI (magnetic resonance imaging), PET (positron emission tomography), ictal SPECT (Single-photon emission computed tomography), and neuropsychological assessment. Using a suspected EZ, SEEG electrodes can be placed minimally invasively yet maintain accuracy and precision. Clinical results showed the ability to localize the EZ in 78% of difficult to localize epileptic patients.¹

Video Link

The video component of this article can be found at <https://www.jove.com/video/53206/>

Introduction

In medically refractory epilepsy there are many non-invasive pre-surgical tools (scalp EEG., magnetic resonance imaging (MRI), functional MRI, single photon emission computed tomography, positron emission topography, and magnetoencephalography). If these non-invasive evaluations fail to sufficiently localize or define the epileptic zone (EZ) then invasive recording may be indicated. Currently, subdural grids or Stereo-electro-encephalo-graphy (SEEG) are the two most prevalent methods of invasive monitoring. SEEG was originally developed in France in the 1950's by Jean Talairach and Jean Bancaud; recently it has mostly been used for invasive monitoring of refractory epilepsy patients in France.²⁻⁴ SEEG is the consists of stereotactically inserting intracerebral electrodes into the brain parenchyma to record brain electrical activity for an extended period of time. With the intracerebral electrical recordings many patients are able to have their EZ defined to allow for surgical resection.

Despite this long history of success SEEG remains relatively rarely used for invasive recording in America. However, SEEG does offer several significant advantages; SEEG allows for 1) recording of deep structures, 2) bihemispheric recordings, 3) another recording option if subdural grids failed, and 4) mapping of epileptic networks in three dimensions, mainly in patients where non-lesional extra-temporal epilepsy is suspected.⁵⁻⁷ All of these benefits are achieved without requiring a large craniotomy. A recent technologic advance in SEEG surgery is the used of robotic guidance. This sophisticated development allows for improved operative times but safer and more accurate surgical implantation of electrodes. Recently published literature reviews the results of using two different techniques for SEEG insertion; a more traditional method utilizing stereotactic frames and a newer technique using robotic assistance for SEEG insertion.^{1, 8, 15} the results were similarly successful with each method.

With the advent of improved robotic assistance, the SEEG insertion technique has resulted in improved operative times. The robotic system is classified as a supervisory controlled system which means the surgeon plans the operation off line and implicitly specifies the motion the robot must follow to perform the operation.⁹ The robotic assist results in expedient transitions from one trajectory to the next for the placement of each intracranial electrode.

Protocol

Ethical statement: Our protocol follows the guidelines established by our institutional human research ethics committee.

1. Identification of Medically Refractory Epilepsy Patients

1. Prior to invasive monitoring, evaluate all patients with noninvasive techniques, such as video-EEG monitoring, MRI, PET, ictal SPECT, and neuropsychological studies as described in ¹. After discussion in multi-disciplinary meeting the decision whether or not to pursue invasive monitoring with SEEG must be made. ^{1,6,7,11,14}
2. Form a hypothesis regarding the location of the EZ. Develop a pre-implantation hypothesis of the presumed EZ incorporating the ictal onset zone and regions of early (*i.e.*, rapid) spread of epileptic (ictal) activity prior to intervention.
NOTE: This step can be done in conjunction with the multi-disciplinary meeting when the decision is made to pursue invasive monitoring.
NOTE: SEEG vs subdural grids—Based on the EZ hypothesis, decide between SEEG and subdural grid monitoring. Criteria to consider might include 1) possible deep seated EZ; 2) previous unsuccessful subdural grids monitoring; 3) indications for bilateral monitoring; 4) When non-lesional extra-temporal epilepsy is suspected. It should also be noted that additional benefit of SEEG over subdural grids includes SEEG's ability to record and stimulate critical subcortical areas when an eloquent region is hypothesized to be near the EZ.
3. Develop an individually tailored implantation strategy based upon hypothesized EZ (**Figure 1**). ^{1,7,8}
NOTE: Adequate implantation strategy must evaluate 1) an anatomical lesion (if present); 2) structure(s) most likely to participate in ictal onset; and/or 3) possible pathway(s) of seizure propagation within a functional network. In addition to anatomic considerations, logistical considerations must also be considered. For this reason, orthogonal trajectories are in general preferential in order to facilitate implantation and, later on, interpretation of the electrode positions.
4. After developing an implantation strategy based upon the hypothesized EZ, create a plan using the robotic assistance. First, create a new encounter, by selecting "new patient", then click on "create trajectory", then select appropriate "entry point" and "end point" which correspond with the desired trajectory.
NOTE: Depending on the pre-implantation hypothesis, the number of electrodes is typically between eight and twelve. The trajectories and points of interest are typically planned using contrasted MRI or rotational angiography. These images which show not only the brain matter but the cerebral vessels allow for trajectory plans in avascular corridors to avoid vascular injury and hemorrhage.

2. Operative Procedure

1. The day before surgery, obtain a contrasted, volumetric T1-weighted MRI sequence as described in by Kuzniecky *et al.* ¹⁴
NOTE: This image is to be used for registration with robotic assistance and must have 1 mm slices. Then transfer the images to the stereotactic neuro-navigation software, where trajectories are planned based on previously discussed implantation strategies as described by Kuzniecky *et al.* ¹⁴
2. Once in the operating room, place the patient on the surgical table in the supine position. Then obtain general anesthesia with endotracheal intubation as per anesthesiologists' protocol.
NOTE: It is imperative that they are under general intravenous anesthesia and complete pharmacologic paralysis. Then shave the patient's head, prep the skin with an antibiotic surgical application and then place the patient's head in a head neurosurgical head holder. General anesthesia differs from patient to patient.
3. After completing the positioning attach the robotic system to the frame and complete registration. On the robotic assistance device select "register" and follow the prompts to complete the registration process. Complete registration using surface landmark registration based on facial features or implanted fiducial markers.
4. Insertion (**Figure 2**)
 1. Use a 2.5-mm drill bit to drill the skull with guidance assistance from the robotic stereotactic system. Insert the monopolar coagulator probe to open the dura mater. Screw the implantation bolt into the skull, also guided by the robotic stereotactic system.
 2. Calculate the final depth distance for the electrode (D3) using the following measurements: $[(\text{Target-Dura Distance}) + (D1 - D2) = D3]$. Measure the target-dura distance using the navigation system.
NOTE: D1 is measured as the length of the guidance system to the dura, D2 is measured as the length of the guidance system to the end of the bolt. The D1 - D2 difference is the length of the bolt. The sum of the length of the bolt and the target-dura distance is the length of the electrode depth.
 3. Create the initial trajectory by inserting a stylette probe, guided by the implanted bolt. Then insert the electrode and secure it into the bolt. This prevents further displacement and cerebrospinal fluid (CSF) leaks.
 4. After placing and connecting all electrodes, place iodine solution soaked gauze around the bolt caps. And, then wrap the head.

3. Monitoring/Recording

1. Before finishing the case, connect the electrodes to the EEG recording machine to ensure proper functioning. The last step in the OR is intraoperative imaging (**Figure 3**). Perform Intraoperative x-rays or fluoroscopic imaging in the lateral and anterior-posterior skull.
NOTE: Obtain these to ensure appropriate trajectories of the electrodes. These images are not obtained to ensure stereotactic placement, rather they ensure the general correct trajectory and placement of the electrodes.
2. After surgery, transfer the patients to the epilepsy monitoring unit. Monitor the patient for seizure activity both clinically and electrographically via the SEEG electrode recording.
NOTE: Length of stay varies, depending on the number, quality, and ictal and interictal patterns of recordings. While monitored patients may have minor pain, treat this with acetaminophen. Typically, the length of stay is 7 days (range 3 - 28 days).
3. Before removal of electrodes, discuss regarding the patient in a multi-disciplinary conference to review recordings and hypothesis.
4. After recording sufficient ictal data (step 3.2) and the patient has been discussed in conference, restart the patients' prior anti-epileptic medications while waiting OR for removal of electrodes.

4. Return to OR for Removal

1. After recording sufficient ictal data, return the patient to the operating room for removal of the SEEG electrodes. Perform this under conscious sedation; typically 2 mg midazolam IV is sufficient.
 2. After anesthesia obtain sufficient sedation (typically with midazolam [defer dosing to anesthesiologist]), remove patients head wrap and cut the electrode wires. Monitor Patient's sedation clinically by the reported pain levels with electrode removal or suture insertion. Then prep the remaining bolt and tail of the electrode using iodinated gel.
 3. Individually, remove each bolt cap by twisting it off, followed by the electrode and lastly remove the bolt. Remove the electrodes by gently pulling them out along the axis of their insertion. Then remove the bolt by twisting it out, typically do this using fingers.
 4. Before moving on to the next electrode, close the defect left by the bolt with one stitch of nylon suture. Repeat these steps for each electrode. After removing all the electrodes, cover the stitch areas with antibiotic ointment and a loose head wrap.
 5. After removal, obtain further imaging either CT or A/P and lateral x-rays to ensure no residual hardware.
- NOTE: Possible resection-If a surgical resection was believed to be of benefit to the patient's epilepsy then plan for a craniotomy and resection roughly 6 weeks after removal. This delay is due to infectious concerns of operating during the same hospitalization as the monitoring period.

Representative Results

Recent results indicate that in one consecutive series of 78 patients who underwent SEEG insertion via robotic assistance had successful localization of the EZ in 76.2% of patients.¹ That same study showed of the patients who went on to have surgical resection of EZ had grade 1 Engel seizure freedom in 67.8% of patients (**Figure 4**). Morbidity rate is 2.5%. Permanent morbidity was noticed in 1 patient (1.2%). Per electrode, it was shown to have a wound infection and intracranial hematoma rate of 0.08%, each.

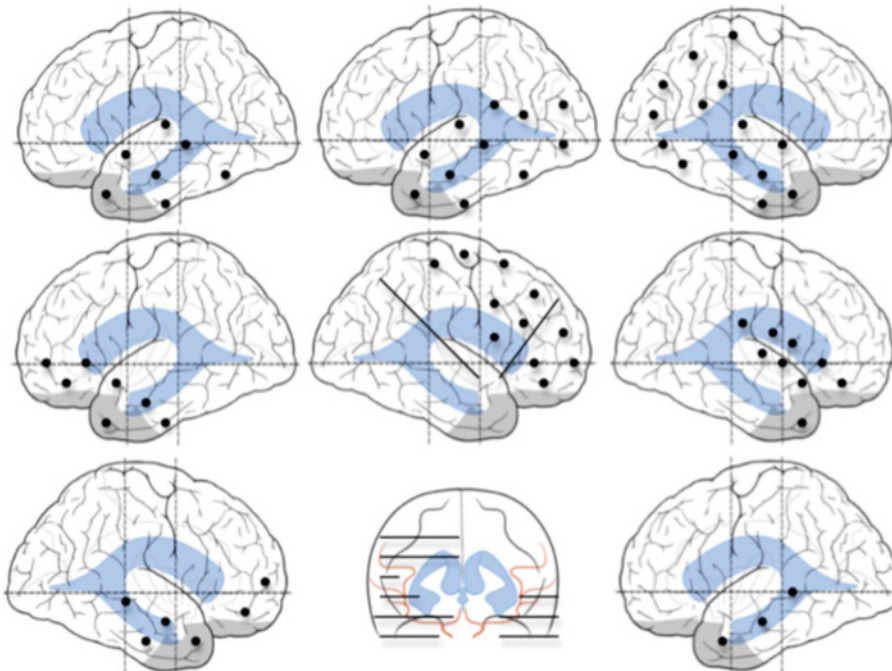


Figure 1. Examples of Patterns of SEEG Implantations. All Insertions are Individual Customized Based on the Patient's Proposed Hypothesis. In these examples we show (from top to bottom, left to right) temporal, temporal-occipital, temporal-parietal-occipital, fronto-temporal, fronto-parietal-insular, perisylvian, and frontal and bitemporal insertion plans. Black dots represent entry points of SEEG electrodes, implanted in orthogonal fashion. Black lines represent electrode trajectories. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography. Copyright 2011 - 2013. All rights reserved. [Please click here to view a larger version of this figure.](#)

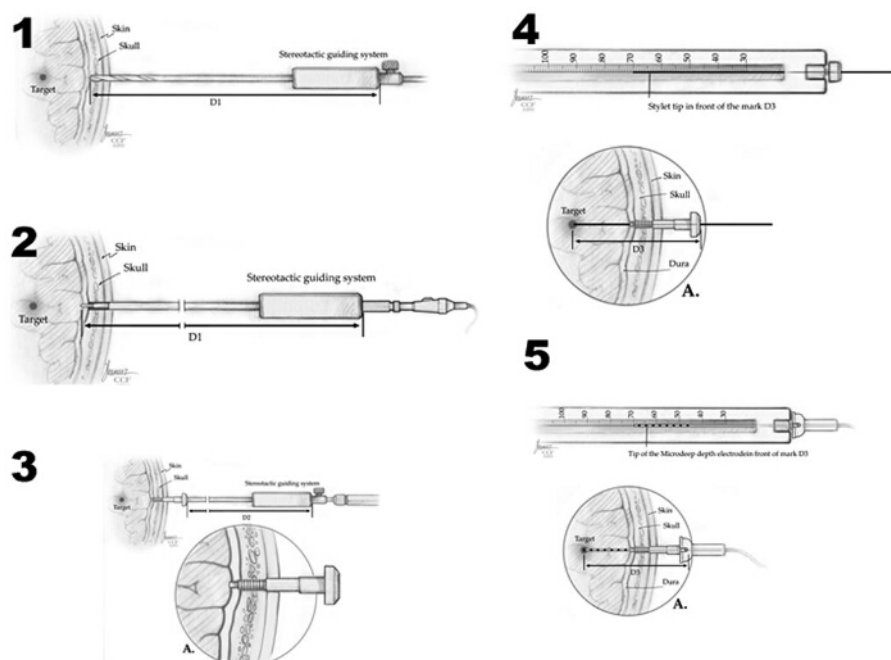


Figure 2. Method of Depth Electrode Implantation. 1) The skull is drilled with a 2.5-mm drill bit, guided by the stereotactic system. 2) The monopolar coagulator probe is inserted and the dura is opened. 3) The implantation bolt is screwed into the skull, also guided by the stereotactic system. 4) The final depth distance for the electrode (D3) is calculated and measured: $[(\text{Target-Dura Distance} + D1) - D2 = D3]$. Initially, the trajectory is created by a stylette probe, guided by the implanted bolt. 5) Final position of the depth electrode, and its fixation into the bolt, preventing displacements and CSF leaks. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography. Copyright 2011-2013. All rights reserved. [Please click here to view a larger version of this figure.](#)

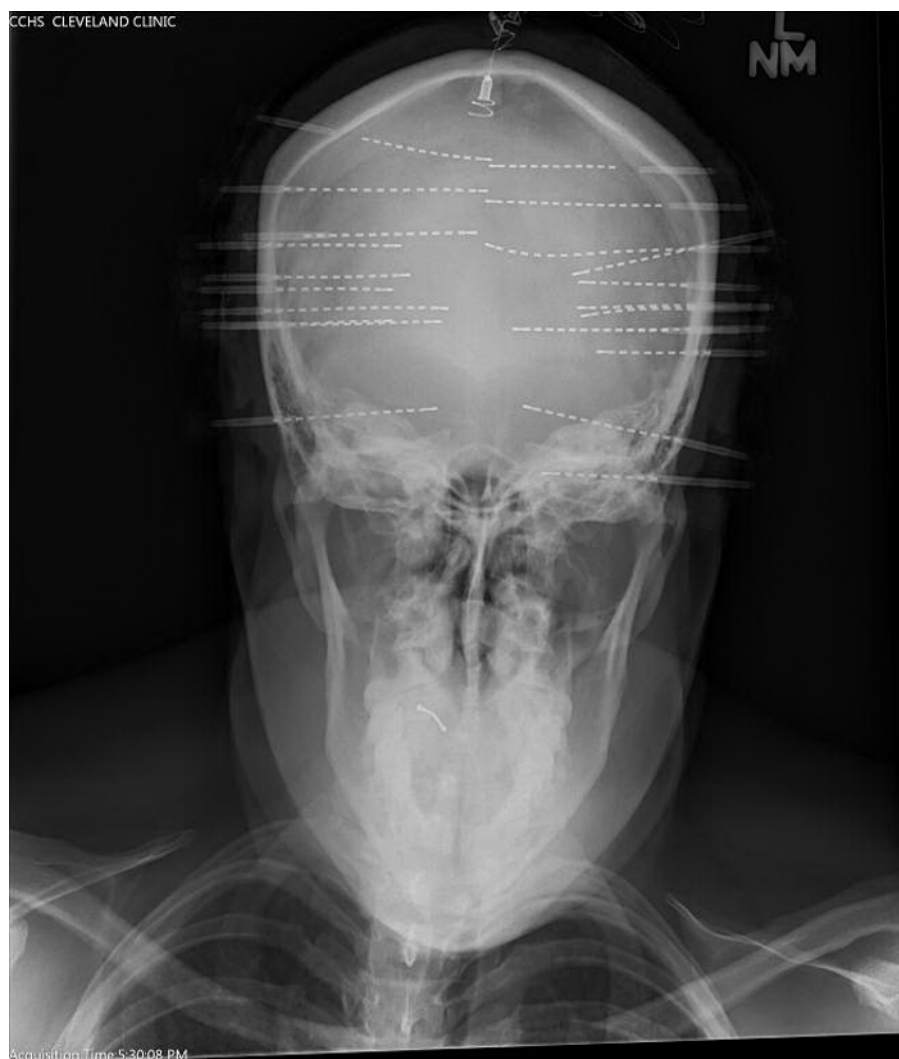


Figure 3. Intraoperative Operative AP Skull X-ray. Obtained to confirm placement of electrodes corresponds with preplanned trajectories. [Please click here to view a larger version of this figure.](#)

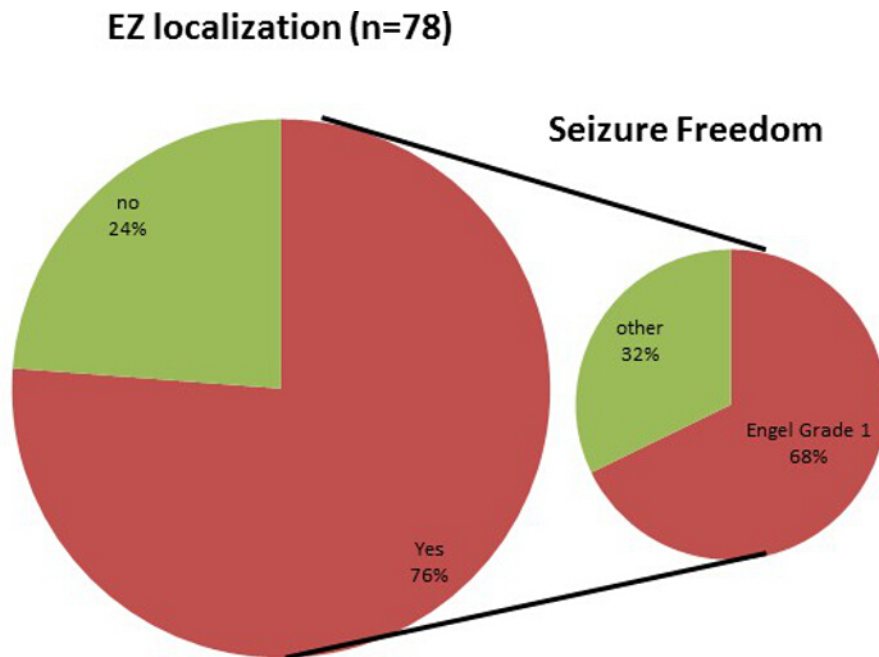


Figure 4. Outcomes of Patients Undergoing SEEG Monitoring. Seventy six patients were able to have their EZ localized; furthermore of those patients undergoing resection after SEEG 67% experienced Engel Grade 1 seizure freedom. [Please click here to view a larger version of this figure.](#)

Discussion

Here is presented the technique of SEEG insertion utilizing robotic stereotactic assistance. While SEEG was originally described using other methods of frame based stereotaxis, robot-assisted SEEG offers not only similar safety but superior accuracy and efficiency. The literature reports success at localizing the EZ in over 76% of cases, which is commiserate with other previous studies using alternative techniques.^{6,13}.

As with any invasive intracranial procedure, SEEG is not without risk. Fortunately, SEEG insertions have reported a very low risk of complication.¹⁵ Most notable, intracranial hemorrhage was the most severe complication^{10,11}. These results are compatible with the current SEEG literature. Utilizing robotic assistance for SEEG is not only safe, but also efficient and accurate, demonstrating to be a promising technique.

While a superior technology, which offers significant improvements on operative time, robotic assistance is not perfect. One limiting factor that must be considered before implementing into one's practice is the initial cost of product acquisition. Depending on individual case numbers this could easily be justified with improvements in OR times alone.

Another crucial step that must not be taken lightly is the critical nature of proper registration prior to placement of the initial depth and all subsequent depths. If a intraoperative concern regarding accuracy arises, the surgery must be halted until accurate registration can be confirmed. The current technique of SEEG insertion not only supplants prior methods but opens up a neurosurgeon's armamentarium to other utilizations. Laser ablation for treatment of epilepsy is a burgeoning field, which has already shown to be amenable to combination with robotic SEEG.¹²

Another technology that we have begun to utilize with robotic SEEG is implantation of Responsive Neuro-Stimulation System (RNS) The ability of SEEG to demonstrate 3-d functional anatomy while allowing precise and accurate placement of electrodes is of clear benefit when implanting RNS.

Disclosures

The authors have nothing to disclose.

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