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Operative Technique and Nuances for the Stereoelectroencephalographic (SEEG) Methodology Utilizing a Robotic Stereotactic Guidance System

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TITLE:

Operative Technique and Nuances for the Stereoelectroencephalographic (SEEG) Methodology Utilizing a Robotic Stereotactic Guidance System.

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KEYWORDS:

Stereoelectroencephalography, SEEG, Surgical Technique, Implantation, Epilepsy, MRE, Robotic Surgery

SUMMARY:

The SEEG methodology is simplified and made faster with a stereotactic robot. Careful attention must be paid to the registration of the preoperative volumetric MRI to the patient prior to use of the robot in the OR. The robot streamlines the procedure, leading to decreased operative times and accurate implantations.

ABSTRACT:

The SEEG methodology has gained favor in North America over the last decade as a means of localizing the epileptogenic zone (EZ) prior to epilepsy surgery. Recently, the application of a robotic stereotactic guidance system for implantation of SEEG electrodes has become more popular in many epilepsy centers. The technique for the use of the robot requires extreme precision in the pre-surgical planning phase and then the technique is streamlined during the operative portion of the methodology, as the robot and surgeon work in concert to implant the electrodes. Herein is detailed precise operative methodology of using the robot to guide implantation of SEEG electrodes. A major limitation of the procedure, namely its heavy reliance on the ability to register the patient to a preoperative volumetric magnetic resonance image (MRI), is also discussed. Overall, this procedure has been shown to have a low morbidity rate and an extremely low mortality rate. The use of a robotic stereotactic guidance system for the implantation of SEEG electrodes is an efficient, fast, safe, and accurate alternative to conventional manual implantation strategies.

INTRODUCTION:

Medically refractory epilepsy (MRE) is estimated to afflict fifteen million people world-wide[1]. Many of these patients, therefore, may well be treated with surgery. Epilepsy surgery relies on the precise localization of the theorized epileptogenic zone (EZ) in order to guide surgical resections. Jean Tailarach and Jean Bancaud developed the stereoelectroencephalography (SEEG) methodology in the 1950s as a method for more accurately localizing the EZ based on the *in situ* electrophysiology of the epileptic brain in both cortical and deep structures[2,3]. However, only recently has the SEEG methodology started to gain favor across North America[4].

Various techniques and technologies are used throughout the world as part of the SEEG methodology, based on the clinical experience of different professionals and epilepsy centers[5-7]. Recently, however, there has been an evolution of the surgical techniques used to implant SEEG electrodes, beyond the classical use manual headframe based strategies. Specifically, the use of robotic stereotactic guidance systems has been shown to be an accurate alternative for SEEG implantation[8]. Robotic implantation can be safely and effectively used by those with surgical expertise who are looking for a faster, more automated, approach to electrode implantation.

Herein is discussed the specific steps undertaken when employing the use of a robotic stereotactic guidance system for the implantation of SEEG electrodes. Though the SEEG methodology has previously been described, herein particular attention is given to the surgical technique employed with the use of the robot[9].

PROTOCOL:

All devices used herein are FDA approved and the protocol contained herein constitutes the standard of care at our institution. As such, no IRB approval was needed for the detailing of this protocol.

1. Pre-implantation phase

1.1 Create an anatamo-electro-clinical (AEC) hypothesis.

NOTE: Creation of the AEC hypothesis relies on the coordination of multiple non-invasive techniques for identifying the potential EZ. A team of experts, including epileptologists, radiologists, and epilepsy surgeons will typically convene a meeting to discuss the clinical data for each patient in order to create the AEC hypothesis, which serves as the initial hypothesis for the patient's EZ. The details of how this is accomplished is beyond the scope of this article.

1.2 Identify the best methodology for invasive monitoring depending on the location of the AEC hypothesis. **Table 1** lists the different scenarios for which SEEG is preferred over subdural grids (SDG) with or without depth electrodes for invasive monitoring.

1.3 After a patient is deemed a candidate for SEEG evaluation, create an implantation strategy.

NOTE: The implantation strategy should adequately cover the area identified as a part of the AEC hypothesis as well as the wider epileptogenic network in general and neighboring areas of eloquent cortex. This monitoring aids the surgeon in defining the borders of the resection.

1.3.1 Obtain a pre-operative volumetric MRI and CTA.

1.3.2 Transfer the images in DICOM format to the stereotactic robot's native planning software and perform imaging fusion (T1+Gadolinium MRI fused with CTA).

NOTE: Imaging fusion is performed automatically by the robot's software. One need only select the studies that need to be fused.

1.3.3 Plan the trajectory of each individual electrode array within the 3D reconstruction of the MRI-CTA fusion, making sure to maximize sampling from a multitude of areas, including superficial, intermediate, and deep cortical and subcortical areas within the AEC hypothesis.

1.3.3.1 Define each trajectory by manually selecting the surface entry point and deep target point for each electrode.

NOTE: Generally, it is best to initially use a working distance of 150 mm from the drilling platform to the deep target point and then adjust the depth to maximally reduce the working distance in order to improve implantation accuracy.

1.3.4 Verify each implantation trajectory.

1.3.4.1 Review each electrode in the 3D MRI-CTA fusion reconstruction individually to make sure that the trajectory does not compromise any vascular structures, adjusting any trajectories as needed.

1.3.5 Review the overall implantation schema in the 3D MRI reconstruction, assessing for any trajectory collisions.

1.3.6 Verify that the surface entry points are all at least 1.5 cm apart on the skin surface, as anything closer than this would be prohibitive to implantation later.

2. **Operative technique**

2.1 In the OR, prepare the patient and place them supine while preparing the stereotactic robot for surgery.

2.1.1 Intubate under general anesthesia according to the recommendations of the anesthesiologist. Use propofol for sufficient anesthesia and verify by adequate electrophysiological recordings as certified by a clinical epileptologist.

2.1.2 Fix the patient's head using a three-point fixation head holder.

NOTE: This is a standard 4-point Lexell frame. Occasionally one of the front posts will be removed in order to facilitate registration of the robot to the patient, as described later. Therefore, the fixation is referred to as 3-point.

2.1.3 Position the robot at the head of the patient, such that the distance between the base of the robotic arm and the midpoint of the cranium is 70 cm. Lock the robot into position and secure the three-point head-holder to the robot.

NOTE: Do not make any more adjustments to the position of the patient or the robot after this time. Any further adjustment after this point will potentially result in implantation inaccuracies.

2.1.4 Use the semi-automatic laser based facial recognition system to register the preoperative volumetric MRI with the patient, following all prompts given by the robot.

2.1.4.1 Calibrate the laser using the set distance calibration tool.

2.1.4.2 Select the preset anatomical facial landmarks manually with the laser. Registration is then completed as the robot automatically scans the facial surface.

2.1.4.3 Confirm the accuracy of the registration by correlating additional independent surface landmarks with the registered MRI.

NOTE: The planned trajectories are then automatically verified by the robot software.

2.1.5 Prepare and drape the patient in standard sterile fashion.

2.1.6 Drape the robotic working arm using sterile plastic.

2.1.7 Attach the drilling platform, with a 2.5 mm working cannula, to the robotic arm.

2.2 Implant the bolts along their designated trajectories.

2.2.1 Select the desired trajectory on the touch screen of the robot.

2.2.2 Step on the robot pedal to initiate movement of the robotic arm to the correct trajectory. When the correct position is reached, the arm is automatically locked by the robot.

2.2.3 Insert a 2 mm drill through the working cannula and use it to create a pinhole through the entire thickness of the skull.

2.2.4 Open the dura with an insulated dural perforator using monopolar cautery at a low setting.

NOTE: Opening the dura can be particularly challenging in small children. Because the dura is not completely adherent to the internal layers of the skull, it is very easy to displace rather than open the dura without noticing.

2.2.5 Screw guide bolt firmly into each pin hole.

2.2.6 Measure the distance from the drilling platform to the guide bolt using a sterile ruler.

NOTE: This is a fixed distance related to the length of the drilling adapter.

2.2.6.1 Subtract this measured distance from the value of the distance “platform to target” used in planning the trajectory.

NOTE: Remember that the recommendation is to always use the standard 150 mm platform to target distance unless a need arises to change this distance. Using this standard will simplify this step in the OR.

2.2.6.2 Record and note the result as it will be used later as the final length of the implanted electrode.

2.2.7 Measure and note the final length of the electrode and ensure that it matches the newly calculated length for the bolt. Ensure the electrode and bolt have matching labels to prevent confusion later during electrode implantation.

2.2.8 Repeat steps 2.2.1 – 2.2.7 for every bolt (i.e., implant all bolts) and mark all electrodes accordingly.

2.3 Change surgical gloves and open a new sterile field.

2.4 Implant all electrodes to the target depth via the implanted bolts.

2.4.1 Insert a 2 mm diameter stylet through the guide bolt to the intended depth of the final electrode as calculated after implantation of the bolt previously.

2.4.2 Immediately insert the electrode through the bolt after removing the stylet and screw the electrode into the bolt for fixation.

2.4.3 Ensure that the electrode is appropriately labeled.

2.4.4 Repeat steps 2.4.1 – 2.4.3 for every electrode.

2.5 Connect the electrodes to the clinical electrophysiology hardware.

2.6 Wrap the patient's head using standard head bandaging technique.

REPRESENTATIVE RESULTS:

The absolute indicator of success following use of the SEEG methodology is seizure freedom for the patient, which ultimately follows successful electrode implantations, successful electrophysiological recordings, as well as successful resection of the EZ. Such a case is shown in **Figure 1**. Panels A and B of **Figure 1** show two tests (single positron emission computed tomography (SPECT) and magnetoelectroencephalography (MEG), respectively) that help in the creation of the AEC hypothesis. However, discussion of the identification of the EZ and the completion of the subsequent resection is outside the scope of this article. However, when SEEG evaluation demonstrates that a patient is a poor surgical candidate for any number of reasons (AEC overlaps with eloquent cortex, multifocal epiliptogenicity, etc.) helping a patient to avoid surgery may certainly be classified as a successful study. Here the focus is instead on the successful anatomical placement of the electrodes and the absence of complications as the indicator for success using this methodology. As such, **Figure 1C** demonstrates the positioning of an electrode in the frontal opercular and dorsal insular area. **Figure 1D** shows the resection of the right operculum and insula in a post-operative T1 MRI image.

Figure 2 demonstrates the appropriate OR setup, successful bolt placement, and successful electrode implantation for the SEEG methodology. In a study of 200 patients who underwent a total of 2,663 SEEG electrode implantations at our center only 5 patients experienced complications. The rates of wound infection, hemorrhagic complications, and transient neurological deficit were 0.08%/electrode, 0.08%/electrode, and 0.04%/electrode for a total morbidity rate of 2.5%/patient and a mortality rate of 0%/patient.

FIGURE AND TABLE LEGENDS:

Table 1. Selection criteria for SDG (with or without depth electrodes) vs. SEEG for invasive monitoring of patients with medically refractory focal epilepsy.

Figure 1. Components of the STEREO-ELECTRO-ENCEPHALOGRAPHY methodology. Panels A and B are showing non-invasive pre-implantation localization testings (as ictal SPECT - **A**, and MEG scan - **B**) demonstrating potential epileptogenicity located in the right opercular-insular areas. Panel **C** depicts the location of the R electrode, in the frontal opercular and dorsal insular area, from which epileptic activity was demonstrated by local field potentials. Panel **D** depicts post-operative T1 MRI image (sagittal view), demonstrating right opercular and insula resection.

Figure 2. STEREO-ELECTRO-ENCEPHALOGRAPHY robotic method. The figure represents an intra-operative digital picture of the robotic technique, during the drilling phase. The robotic arm precisely guides the drilling step, allowing (after opening the dura and the position of the guiding bolt) the final implantation of the depth electrode. The robotic arm is equipped with a 2.55 mm adapter, which allows precise alignment of the 2.5 mm drill bit.

DISCUSSION:

Meticulously defining of the AEC hypothesis coupled with particularly detailed attention to the design of the implantation strategy is ultimately what will determine the success of the SEEG methodology for each individual patient. As such, careful pre-surgical planning of the procedure is critical and makes for a relatively simple, low-risk surgery. Generally it is best to orient the trajectories orthogonally to the sagittal midline, thereby facilitating an easier anatomo-electrophysiological correlation in the future and also obtaining higher precision during implantation. However, in some cases oblique trajectories can be used. Specifically, when an oblique trajectory allows for the sampling of multiple targets within the AEC hypothesis, this may be preferable as it will reduce the total number of electrodes that must be implanted for adequate sampling. The implantation strategy should therefore account for the three-dimensional, dynamic, multidirectional spatiotemporal organization of epileptic activity and the pathways it follows.

Because the use of the stereotactic robot is so critical to the entire operative technique outlined herein, it is recommended that a surgeon gain hands-on experience in working with one of these intraoperative robots before using it in the OR. Familiarity with the workings of the hardware and software associated with the stereotactic guidance system will not only improve patient safety, but also increase the speed of the procedure and facilitates a streamlined operative experience. Furthermore, as detailed in the protocol, it is important that the surgeon and all assistants change surgical gloves and open a new sterile field following the implantation of all bolts and prior to the implantation of the electrodes. This is done to prevent infection.

A caution to this methodology is the importance of accurately registering the patient to 3D reconstruction of the preoperative MRI. Any variance in the registration, or deviation therefrom, will manifest in decreased implantation accuracy for each electrode. It is therefore crucial that the registration be meticulously checked throughout the implantation procedure to make sure it starts off correct and remains as such. Any concern of an inaccurate implantation should be met with verification of the registration and, if necessary, reregistration.

Ultimately, there are many ways of completing the stereotactic implantation of these depth electrodes, but in the experience of the authors, the use of the stereotactic robot provides a much preferable (efficient and precise) operative experience, as well as a very low morbidity rate and an extremely low mortality rate. Additionally, a previous study of the implantation accuracy achieved with this protocol has shown high levels of implantation accuracy[10]. The results and conclusions herein are congruent with previously published literature regarding the morbidity of the SEEG methodology[11-15].

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The authors have no acknowledgements.

DISCLOSURES:

The authors have nothing to disclose.

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Updated Figure 1

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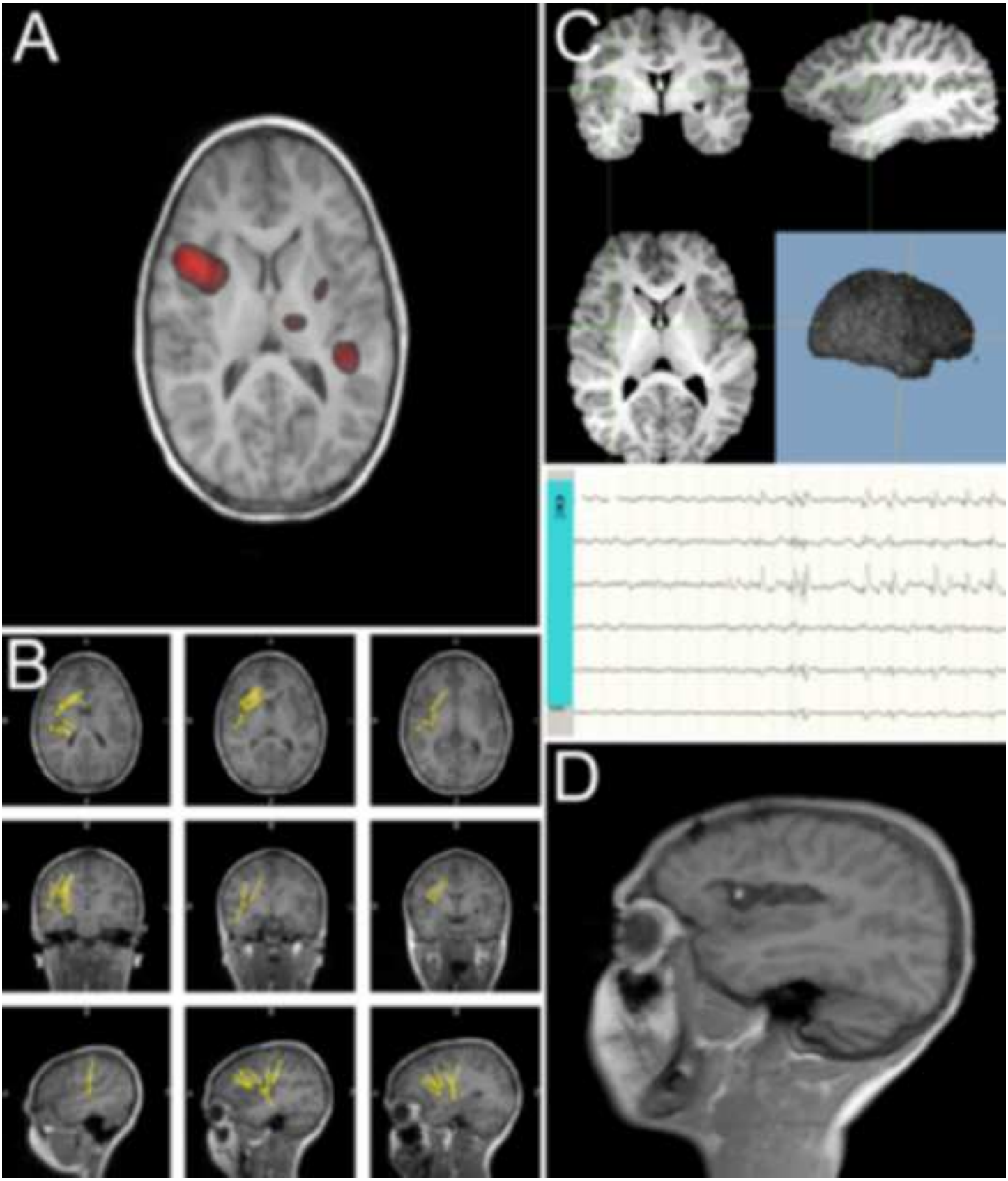

Updated Figure 2

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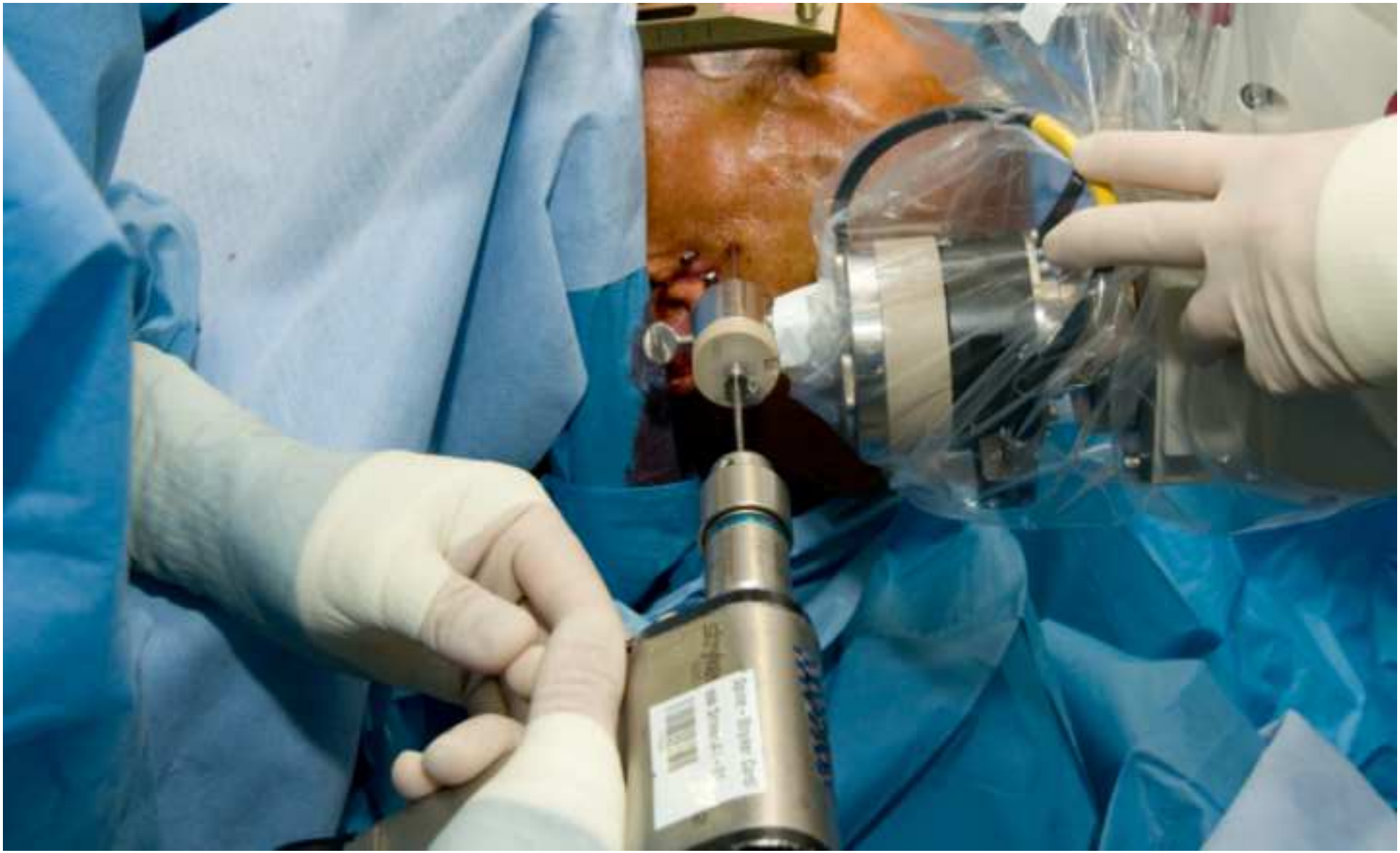

Table

Clinical Scenario	Method of Choice	Second Option
Lesional MRI: Potential epileptogenic lesion is superficially located, near or in the proximity of eloquent cortex. -OR- Non-lesional MRI: Hypothetical EZ located in proximity of eloquent cortex	SBG	SEEG
Lesional MRI: Potential epileptogenic lesion is located in deep cortical and subcortical areas. -OR- Non-lesional MRI: Hypothetical EZ is deeply located or located in non-eloquent areas.	SEEG	SBG with depths
Need for bilateral e	SEEG	SBG with depths
After subdural grids	SEEG	SBG with depths
When the AEC hypo	SEEG	SBG with depths
Suspected frontal lo	SEEG	SEEG

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
2 mm drill bit	DIXI	KIP-ACS-510	For opening the cranium
Coagulation Electrode Dura	DIXI	KIP-ACS-600	for opening and coagulating the dura
Cordless driver	Stryker	4405-000-000	to drive the drill bit
Leksell Coordinate Frame G	Elekta	14611	For head fixation
Microdeep Depth Electrode	DIXI	D08-**AM	SEEG electrodes that are implanted, complete with: guide bolt and st
ROSA	Medtech	n/a	stereotactic guidance system with robotic arm, complete with: roboti
Stylet	DIXI	ACS-770S-10	for creating a path through the parenchyma for the electrode

ylet, as described in manuscript.
c arm, calibration tool, registration laser, head frame attachment, and software, as described in the manuscript.

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Signature:	 Date: 11/28/18

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Dear Editor(s) and Reviewers,

Thank you for your thoughtful comments re: our paper entitled “Operative Technique and Nuances for the Stereoelectroencephalographic (SEEG) Methodology Utilizing a Robotic Stereotactic Guidance System.” We have addressed each of your concerns directly as detailed below. Your comments are in black and our responses are in red. Revisions were made to the manuscript using the “track changes” function in Word. We believe your comments have improved the quality of this manuscript and we thank you for your interest in this work.

Editorial comments:

Changes to be made by the Author(s):

1. Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammar issues. The JoVE editor will not copy-edit your manuscript and any errors in the submitted revision may be present in the published version.

Done.

2. Please expand your Introduction to include the advantages over alternative techniques with applicable references to previous studies and Information that can help readers to determine if the method is appropriate for their application.

Added sentence (with reference) to introduction indicating the safety and efficacy of robotically assisted SEEG implantations. Also indicated practical reasons one surgeon may choose to switch from other methods to the described methodology.

3. Please include an ethics statement before the numbered protocol steps, indicating that the protocol follows the guidelines of your institution’s human research ethics committee.

This protocol constitutes the standard of care at our institution and is not considered research in any way. As such, no IRB or ethics committee approval is necessary.

4. Please revise the protocol to contain only action items that direct the reader to do something (e.g., “Do this,” “Ensure that,” etc.). The actions should be described in the imperative tense in complete sentences wherever possible. Avoid usage of phrases such as “could be,” “should be,” and “would be” throughout the Protocol. Any text that cannot be written in the imperative tense may be added as a “Note.” Please include all safety procedures and use of hoods, etc. However, notes should be used sparingly and actions should be described in the imperative tense wherever possible. Please move the discussion about the protocol to the Discussion.

Done.

5. 1.3.3: The Protocol should be made up almost entirely of discrete steps without large paragraphs of text between sections. Please simplify the Protocol so that individual steps contain only 2-3 actions per step and a maximum of 4 sentences per step. Use sub-steps as necessary. Please move the discussion about the protocol to the Discussion.

1.3.3: Everything beyond the first imperative sentence was moved to the first paragraph of the discussion section.

1.3.3.1 was divided into instruction and "note."

1.3.4 was divided into multiple sub-steps.

6. 1.3.2: How to perform imaging fusion?

Imaging fusion is performed automatically by the stereotactic robot's software. This has been indicated in a note within the protocol.

7. 2.1.1: Please specify the anesthesia method and mention how adequate anesthesia is confirmed.

Propofol sedation confirmed by electrophysiological recordings, as now indicated in the protocol.

8. 2.2.6: How to measure the distance from the drilling platform to the guide bolt?

This is accomplished manually by the surgeon using a sterile ruler. It is also a fixed distance related to the drilling adapter that is used. Verbiage added to the protocol.

9. Please add more details to your protocol steps. There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol. Please ensure you answer the "how" question, i.e., how is the step performed? Alternatively, add references to published material specifying how to perform the protocol action. See examples below.

Changes have been made to increase clarity of procedural steps.

10. After you have made all the recommended changes to your protocol (listed above), please highlight 2.75 pages or less of the Protocol (including headings and spacing) that identifies the essential steps of the protocol for the video, i.e., the steps that should be visualized to tell the most cohesive story of the Protocol.

Operative technique highlighted in full.

11. Please highlight complete sentences (not parts of sentences). Please ensure that the highlighted part of the step includes at least one action that is written in imperative tense. Notes cannot usually be filmed and should be excluded from the highlighting. Please do not highlight any steps describing anesthetization and euthanasia.

Done.

12. Please include all relevant details that are required to perform the step in the highlighting. For example: If step 2.5 is highlighted for filming and the details of how to perform the step are given in steps 2.5.1 and 2.5.2, then the sub-steps where the details are provided must be highlighted.

Done.

13. Representative Results: Please reference the different panels of Figures 1 and 2.

14. Figure 1: Please define the scale bars in the appropriate figure legend.

Figure 1 has been changed entirely. All panels referenced appropriately in representative results.

15. Is Figure 2 reprinted from a previous publication? If so, please obtain explicit copyright permission to reuse any figures from a previous publication. Explicit permission can be expressed in the form of a letter from the editor or a link to the editorial policy that allows re-prints. Please upload this information as a .doc or .docx file to your Editorial Manager account. The Figure must be cited appropriately in the Figure Legend, i.e. “This figure has been modified from [citation].” If Figure 2 is not reprinted, please rephrase the figure legend to avoid previously published text.

A new figure 2 has been created to mitigate the above issues.

16. Table of Materials: Please revise the Table of Materials to include the name, company, and catalog number of all relevant supplies, reagents, equipment and software in separate columns in an xls/xlsx file, and sort the items in alphabetical order according to the name of material/equipment.

Done.

Reviewers' comments:

Reviewer #1:

Manuscript Summary:

Manuscript summarizes one robotic method of SEEG implantation using the ROSA robot. Accurately describes the indications for SEEG vs subdural grid +/- depth electrode placement and provides a systematic surgical workflow. This will be beneficial for surgeons switching from frame / frameless methods to using a robot.

Major Concerns:

Nil

Minor Concerns:

Line 75 - SBG is not qualified as an abbreviation. SubDural Grid (SDG) is more commonly used in the literature.

The change has been made. Thank you for catching this.

Line 78 - Error is sentence construction

Corrected.

Line 79 - SEEG targeting should also include the wider epileptogenic network, not just the hypothesized EZ. Further, using SEEG to define resection margins in neighboring structures is critical to tailoring the resection.

Absolutely. Manuscript updated to reflect this.

Line 82 - Only MR and CTA vascular imaging are mentioned. Does MR refer to T1+Gad or MRV/A or both? I recommend commenting in the discussion section regarding the use of DSA, which may would consider the gold-standard.

Line 99 - 'for' should be replaced with 'by'.

Done.

Line 105 - Is a MIP (maximum intensity projection) used?

No MIP is used in our protocol.

Line 121 - This method is only applicable to the ROSA robot and not to other devices. This should be made clear in the abstract and main text.

Reference to ROSA has been added to the abstract and the introduction.

Line 176 - Electrodes are placed one at a time. May be worth mentioning in Discussion why you do this over placing all the bolts in one go and then electrodes at the end?

Thank you for catching this error. Indeed, we place all bolts first, followed by the implantation of the electrodes. A glove change is performed between completion all bolt implantations and the electrode implantations, as well as opening a new sterile field, in the hopes of preventing infection. Verbiage has been changed to reflect this and the reasoning is now mentioned in the discussion.

Line 189 - SEEG is equally successful if it prevents patients from undergoing futile resections (and the associated morbidity of failed surgery).

Agreed and noted in the manuscript.

Line 200 - Are these symptomatic haemorrhages only or all? Was a systematic imaging protocol was used to detect haemorrhage i.e. CT post electrode explantation or only after insertion?

This refers to only symptomatic hemorrhages. There are asymptomatic, small, discrete hemorrhages in up to 20% of implantations. A coming publication from our group highlights this (McGovern et al., 2019, in press). This finding is discussed in full in that publication and is out of the scope of this manuscript.

Line 202 - 2.5% morbidity refers to per patient not electrode? This should be made clear.

You are correct. The manuscript has been made clearer on this point.

Line 202 - Why are EP and TP accuracy measures not provided so that these can be compared with the literature (recent meta-analysis published in Epilepsia comparing accuracies of different systems).#

A previous article by the current authors has addressed this point in great detail. A sentence and the following reference have been added to the discussion. Reference:

Jones, J. C., Alomar, S., McGovern, R. A., Firl, D., Fitzgerald, Z., Gale, J., & Gonzalez-Martinez, J. A. (2018). Techniques for placement of stereotactic electroencephalographic depth electrodes: Comparison of implantation and tracking accuracies in a cadaveric human study. Epilepsia, 59(9), 1667-1675.

Line 235 - Many feel Laser / surface registration is too inaccurate. What minimum registration accuracy do you achieve / is one provided by the system?

Please again see the newly referenced manuscript for details regarding the implantation accuracy of this protocol.

Figure 2 appears to show the patient in a frame, yet the Line 118 refers to 3 point fixation.

Indeed a frame is used but we refer to it as 3-point fixation because one of the posts of the frame is removed in order to facilitate the laser face registration of the robot. A new figure has been created and replaced Figure 2 that will help avoid confusion. Verbiage has been added in the form of a note in the protocol to clarify this point.

Reviewer #2:

Manuscript Summary:

The number of centers are increasing where neurosurgical robots are in routinely used. The topic is important for all the new and old centers. The manuscript has a proper abstract and introduction. The technical steps clearly described step by step.

Major Concerns:

I would recommend to mention the other registration methods as well and give a short comparison between them, because one of the main concern of the article is the accuracy of the laser scanning surface registration. The list of references are satisfactory.

A previous article by the current authors has addressed the accuracy (including the laser scanning surface registration) in great detail. A sentence and the following reference have been added to the discussion to direct the interested reader to this more comprehensive investigation of the subject.

Reference:

Jones, J. C., Alomar, S., McGovern, R. A., Firl, D., Fitzgerald, Z., Gale, J., & Gonzalez-Martinez, J. A. (2018). Techniques for placement of stereotactic electroencephalographic depth electrodes: Comparison of implantation and tracking accuracies in a cadaveric human study. Epilepsia, 59(9), 1667-1675.

Minor Concerns:

On the picture Fig.2. the patient's head is in a Leksell frame. In the methodological description of the surgical procedure in the 118 row(2.1.2) the authors wrote: "Fix the patient's head using a three -point

fixation head holder. On the picture they used Leksell frame. I would recommend to change the picture according to the written method or change the surgical description. It could be confusing for a beginner.

Indeed a frame is used but we refer to it as 3-point fixation because one of the posts of the frame is removed in order to facilitate the laser face registration of the robot. A new figure has been created and replaced Figure 2 that will help avoid confusion. Verbiage has been added in the form of a note in the protocol to further clarify this point.

If the three point fixation system is a Mayfield head holder we know that the Mayfield is not as rigid as the Leksell frame and the accuracy is less.

As above.