Robotic image-guided depth electrode implantation in the evaluation of medically intractable epilepsy

Technical note

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Object. The authors describe their experience with a technique for robotic implantation of depth electrodes in patients concurrently undergoing craniotomy and placement of subdural monitoring electrodes for the evaluation of intractable epilepsy.

Methods. Patients included in this study underwent evaluation in the Dartmouth Surgical Epilepsy Program and were recommended for invasive seizure monitoring with depth electrodes between 2006 and the present. In all cases an image-guided robotic system was used during craniotomy for concurrent subdural grid electrode placement. A total of 7 electrodes were placed in 4 patients within the time period.

Results. Three of 4 patients had successful localization of seizure onset, and 2 underwent subsequent resection. Of the patients who underwent resection, 1 is now seizure free, and the second has only auras. There was 1 complication after subpial grid placement but no complications related to the depth electrodes.

Conclusions. Robotic image-guided placement of depth electrodes with concurrent craniotomy is feasible, and the technique is safe, accurate, and efficient. (DOI: 10.3171/FOC/2008/25/9/E19)

Key Words • depth electrode • epilepsy surgery • image guidance • robotic system

MEDICALLY intractable epilepsy, defined as having 1 or more seizures per year, affects ~ 2–3 individuals per 1000 in the general population, and 17,000 new cases are added each year to the ~ 700,000 existing cases. Surgical treatment of intractable epilepsy, particularly in the absence of a structural lesion on imaging, often relies on intensive electroencephalographic studies for the localization of seizure onset. A valuable component of preoperative seizure localization is intracranial electrode recording using a variety of electrodes, including subdural strip electrodes, subdural grid electrodes, and depth electrodes. Although depth electrodes have been placed by freehand technique, the development of coregistration methodology and advanced neuroimaging has led to the wide adaptation of such stereotactic techniques today. Placement of electrodes using a stereotactic frame is a common and expeditious procedure. When combined with craniotomy for placing of subdural grid electrodes, however, it can become cumbersome, inefficient, and limiting. The use of frameless stereotaxy avoids these constraints and offers additional benefits. In this technical note we describe the use of a robotic frameless stereotactic system for the implantation of depth electrodes.

Methods

A review of the Dartmouth epilepsy monitoring database revealed 4 patients who underwent robotic depth electrode implantation between January 2006 and December 2007 (Table1). These patients included all patients in whom depth electrodes were inserted through a craniotomy performed for placement of additional subdural grid electrodes. All patients had undergone evaluation by the Dartmouth multidisciplinary epilepsy team. Patients who underwent depth electrode placement at the time of craniotomy for subdural grid electrode placement were selected at the discretion of the surgeon (D.W.R.) for use of the robotic system. Preoperative MR imaging studies with scalp-based fiducial markers were performed in all patients, and the images were loaded onto the SurgiScope (ISIS Intelligent Surgical Instrument and Systems) workstation. Depth electrode targeting and trajectory determination were performed on the SurgiScope workstation, with the electrode entry site coordinated with the targeted location of the subdural electrodes and the planned craniotomy. The planned depth electrode path was reviewed to verify that no vessels or other important structures would be at risk.
risk for injury, and modified if necessary. Three-point pin fixation secured the patient’s head, and scalp fiducials were registered using the SurgiScope handheld probe. The time required for loading imaging studies, defining the electrode trajectory, and registering the patient was typically 25 minutes. Preparation of the sterile field, draping, craniotomy, and dural opening were performed using the standard surgical technique. An arm attachment (ISIS Intelligent Surgical Instruments and Systems) was affixed to the draped SurgiScope operating microscope, enabling the robotic instrument to function primarily as an instrument holder (Fig. 1 right). The probe carrier from a Leksell Model G stereotactic frame (Elekta AB) was attached to the arm. The robotic arm and stereotactic guide were brought by the surgeon to the predetermined position for electrode placement using a microterminal covered by a transparent sterile drape. Through the bushings of the robotically positioned stereotactic guide, the insertion needle with central stylet was advanced by hand to the predetermined depth as established by the guide (Fig. 1). Prior to insertion, the dura or pia mater (depending on the trajectory’s location with respect to any subdural grids) was coagulated to avoid bleeding. Once at target depth, the central stylet was removed and an electrode (Adtech) marked at the appropriate length with indelible ink and/or a silk tie was inserted. During the time of robot positioning and actual electrode positioning, the operating table was locked and all table movements were prohibited by disabling of its controls. In cases in which a subdural electrode grid was to be placed over the depth electrode site, the electrode was bent at a 90° angle at the level of the cortical surface to facilitate grid contact with the cortex. The electrode was secured in place either with the 90° bend and an overlying grid, or with a suture anchored to the dura. The distal end was then tunneled to a skin opening separate from the incision using an angiocatheter needle. The electrode was then secured to the skin with an 0-gauge silk suture (Ethicon). The electrodes were appropriately labeled, and a chart and schematic were made immediately after each case to illustrate the location of all electrodes. The bone flap was prepared and kept in the operating room freezer, and the wound was closed in the standard fashion using interrupted 3-0 Vicryl sutures (Ethicon) to reapproximate the galea, and a running 4-0 nylon suture (Ethicon) for the skin. The incision site was dressed with antibiotic ointment and covered with a sterile dressing and multilayered wrap. Patients recovered in the postanesthesia care unit and were then transferred to a monitoring unit equipped with video electroencephalography. Patients were monitored until sufficient data were acquired to localize seizure origin or until it was concluded that localization would not be possible. The epilepsy team used the data

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>No. of Depth Electrodes, Location</th>
<th>Other Electrodes</th>
<th>Seizure Localization</th>
<th>Resection Location</th>
<th>Outcome After Resection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47, M</td>
<td>2, rt occip, lat occip 4 × 8, suboccip 4 × 5, &amp; medial occip 4 × 5</td>
<td>rt occip cortex, no seizures observed</td>
<td>not performed</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20, F</td>
<td>2, rt frontal, 3 × 8 IH subdural grid, 1 × 4 ant IH subdural strip, 4 × 5 orbital frontal grid, &amp; 4 × 8 subdural grid over rt frontal lat convexity</td>
<td>rt frontal</td>
<td>rt frontal</td>
<td>seizure free</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>21, M</td>
<td>2, rt frontal, 3 × 8 IH, 4 × 8 medial frontal convexity grid, &amp; 1 × 8 medial frontal polar subdural electrode</td>
<td>rt occip &amp; hippocampus</td>
<td>occip focus &amp; hippocampectomy</td>
<td>continued auras</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>42, M</td>
<td>1, occip lobe to hippocampus, 4 × 8 occipitotemporal subdural, 4 × 5 medial occip, &amp; 4 × 5 suboccip grids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ant = anterior; IH = intrahemispheric; lat = lateral; lt = left; NA = not applicable; occip = occipital; rt = right.

Fig. 1. Left: Photograph of the SurgiScope with biopsy arm. Right: Intraoperative photograph of the SurgiScope biopsy arm with Leksell model G insertion guide. An insertion canula has been inserted, through which the depth electrode will be deployed.
compiled from monitoring and cortical mapping to determine a treatment plan.

Illustrative Cases

Case 1

This 47-year-old man presented with medically intractable epilepsy which had begun when he was 4 years of age. He had previously undergone a right temporal lobectomy without significant improvement in his seizures. The results of evaluation by the epilepsy team suggested a right occipital seizure focus, and the patient was recommended for an intracranial electrode study. Preoperative imaging revealed an area of dysplasia around the right atrium and 2 depth electrodes were placed in that region (Fig. 2). A $4 \times 8$ grid and $2 \times 4 \times 5$ electrode grids were also implanted, covering the lateral and inferior surfaces of the right occipital lobe. In this case the depth electrodes were placed prior to opening of the dura and placement of the subdural grids. The depth electrodes were anchored to the dura with 4-0 Vicryl sutures and tunneled as described above. Seizures were localized in this patient to a large area of occipital cortex, and given the risk to his visual fields, the patient declined to undergo resection.

Case 2

Preoperative evaluation of this 20-year-old woman with medically intractable epilepsy suggested a left frontal lobe seizure focus. At surgery, 2 depth electrodes were implanted in the right frontal lobe after the dura was opened. Additional electrodes included 2 strips over the frontal convexity, a $3 \times 8$ interhemispheric subdural grid, a $1 \times 4$ anterior interhemispheric subdural strip, a $4 \times 5$ orbital frontal grid, and a $4 \times 8$ subdural grid over the left frontal lateral convexity (Fig. 3). The postoperative course was complicated by left leg weakness caused by a subpial right interhemispheric grid. The patient returned to the operating room on the same day for grid revision, and recovered full strength prior to discharge. Unfortunately no seizures were recorded during her monitoring, and the electrodes were removed without successful localization.

Case 3

This 21-year-old man with medically intractable seizures localized to the right frontal lobe was recommended for invasive monitoring. He underwent placement of 2 right frontal depth electrodes, placed after opening the dura mater. Additionally, a $3 \times 8$ double-sided interhemispheric grid, a $4 \times 8$ medial frontal convexity grid, and a $1 \times 8$ medial frontal polar subdural electrode were placed (Fig. 4). The patient subsequently underwent a tailored right
medial frontal resection and has been seizure free for 1 year since surgery.

Case 4

This 42-year-old man presented with a medically intractable seizure disorder which started after a bout with mycoplasma encephalitis. Preoperative seizure localization suggested a right occipital origin. A single depth electrode extending from the occipital cortical surface to the hippocampus and a 4 × 8 occipitotemporal subdural grid, a 4 × 5 medial occipital grid, and 4 × 5 grid covering the inferior surface of the occipital lobe were placed (Fig. 5). The patient’s seizures were localized to 2 regions, the right hippocampus and the right occipital cortex, and a tailored resection encompassing both foci was undertaken. The patient experienced seizure improvement postoperatively but continues to have auras consisting of nausea and feelings of warmth. He was also noted postoperatively to have some inattention in his left visual field, specifically with movement.

Discussion

The usefulness and safety of depth electrodes for localization of the epileptogenic zone prior to resection has been well-established. Freehand placement techniques have progressively been replaced with stereotactic and image-guided methods for improved accuracy and safety. Although the methods of frame-based stereotaxy are safe and well-established, in the setting of concurrent depth and grid placement requiring a craniotomy, the frame can obstruct the surgical field. In the present study we describe the use of the SurgiScope robotic frameless image guidance system, which has been shown to be safe and accurate in the placement of ventricular catheters in the setting of small ventricles. This system allows the safe and accurate placement of depth electrodes in an efficient manner while obviating the need to reposition the patient, remove the frame, or reprepare and redrape the patient. The efficiency of this frameless and noniterative guide positioning is especially appreciated with multiple depth electrode placement. An additional benefit of the robotic arm is the stability of the arm and guide. The main disadvantage of the current system is its initial cost. The system’s primary utilization is for routine craniotomy for tumor resection, and in this setting, the marginal cost for its additional deployment on these cases is relatively low. A second disadvantage or inconvenience is that its ceiling mounting renders the instrument not portable.

Conclusions

Robotic image-guided placement of depth electrodes is feasible, accurate, safe, and efficient. The system we describe combines the benefits of frame-based and frameless systems. It is efficient, requires few adjustments during the procedure, and is removable from the operating field as necessary. This system also offers the advantages of being stable and eliminating the risk of microtrauma that is present with freehand techniques.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References

Robotic image-guided depth electrode implantation


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