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Technical Note

Techniques for placement of grid and strip electrodes for intracranial epilepsy surgery monitoring: Pearls and pitfalls

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Abstract

Background: Placement of intracranial strip and grid electrodes for recording cortical electrocorticography is important as part of the workup of patients who are being considered for resective epilepsy surgery. In recent decades, the indications and techniques for intracranial epilepsy monitoring have been refined.

Methods: In this article, the authors describe the techniques for intraoperative placement of grid and strip electrodes for extraoperative study of a seizure focus.

Results: Methods to enhance the efficacy of this technique while minimizing complications are reviewed.

Conclusions: Intracranial epilepsy monitoring with grid and strip electrodes is a useful tool for the planning of resective epilepsy surgery. Techniques to advance the safety and minimize complications will lead to improved outcomes.

Key Words: Electrocorticography, electrodes, neurosurgical procedures, seizures

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INTRODUCTION

Placement of intracranial strip and grid electrodes for recording cortical electrocorticography (ECOG) has become an important component in the workup of patients who are considered for resective epilepsy surgery. Foerster and Altenburger[4] reported the first use of this form of invasive monitoring in 1935. Penfield and Jasper[5,16] made major contributions to advance this modality. In recent decades, the indications and techniques for intracranial epilepsy monitoring have been refined, defined, and expanded. Currently, available intracranial electrodes include various sizes of silastic grid and strip electrodes, depth electrodes, and reusable wire electrodes, sometimes called ECOG surface electrodes.[6,13,19,20] The purpose of this report is to describe the techniques for intraoperative placement of grid and strip electrodes for extraoperative study of a seizure focus (this process is hence defined as an "intracranial study"). In this article, we focus on methods to enhance the efficacy of this technique while minimizing complications.

INDICATIONS

The main indication for an intracranial study is for the work up of medically refractory partial epilepsy. Any patient considered for this study must have exhausted all noninvasive diagnostic options for localization of their epileptogenic zone. The noninvasive workup entails a detailed history and physical exam, magnetic resonance imaging (MRI), positron emission tomography (PET), single photon emission computed tomography (SPECT), magnetoencephalography (MEG), and long-term video electroencephalography (EEG).[12,22]

Several clinical scenarios are likely to necessitate an intracranial study. Patients who harbor dual pathology, nonlesional epilepsy, extratemporal epilepsy, and lateral temporal lobe epilepsy often require an intracranial study to map the seizure focus using ECOG and the adjacent functional cortex using cortical stimulation.[3] The presence of bilateral independent temporal lobe spikes or bilateral medial sclerosis often requires an intracranial study to lateralize the dominant epileptogenic temporal lobe and guide the chance of postoperative seizure freedom.[7] In addition, patients whose noninvasive tests are discordant or inconclusive may be served well by placement of intracranial electrodes to definitively evaluate the presence of a defined epileptogenic zone.[21] Younger patients who are unable to tolerate awake cortical mapping for resection of their tumor may undergo extraoperative mapping using these electrodes.

ELECTRODE DESCRIPTION

Grid and strip electrodes consist of silver, platinum, or stainless steel disks embedded in a teflon or silastic sheath. These electrodes are commercially available in multiple configurations. Strips are configured as small as 1 × 4 electrodes or as large as 2 × 8 electrodes. Grids are configured from 4 × 4 up to 8 × 8 electrodes for a total of 16 to 64 contacts, respectively. The contacts are typically spaced 5-10 mm apart.[13,19]

Preoperative preparation

Patients should receive clear instructions regarding the importance of cooperative behavior during their extraoperative monitoring. Violent patients or those with postictal violent behavior may not be candidates for an intracranial study. Serum levels of anticonvulsant medications should be checked 24 hours before the operation to assure therapeutic levels and prevent excessive seizures in the immediate postoperative period. Consideration may be given to double the dose of such medications the night before the operation. There is often as anticipated loss of drugs due to shift of body fluids during the operation.

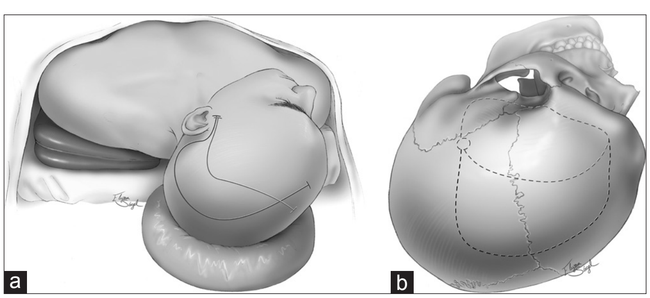

Figure 1: The most commonly used incisions (a) and craniotomies (b) for temporal or extratemporal grid placement. Copyright, IU Health

TECHNIQUE

Craniotomy for placement of electrodes

The techniques for craniotomy and placement of intracranial grid and or strip electrodes is quite straightforward, although the decision as to where to place the electrodes requires considerable planning and collaboration with the epilepsy neurologist. It is neither practical nor safe to cover the entire surface of the brain with electrodes. The preoperative workup must narrow the search for an epileptogenic zone sufficiently to plan targeted placement of the electrodes.

When specific areas of the brain are identified as probable locations for the epileptogenic zone and deemed potentially resectable, a craniotomy can then be tailored based on preoperative epilepsy studies. The entire head is shaved. A skull clamp is used to allow access to large areas of the head to tunnel the electrode wires subcutaneously away from the incision during the later stages of the operation. Typically, a large C-shaped trauma and craniotomy flap is elevated [Figure 1a and b]. Protection of the superficial temporal artery is important to preserve vascularity to the scalp flap. Neuronavigation may be employed, especially if concurrent placement of depth electrodes is contemplated.

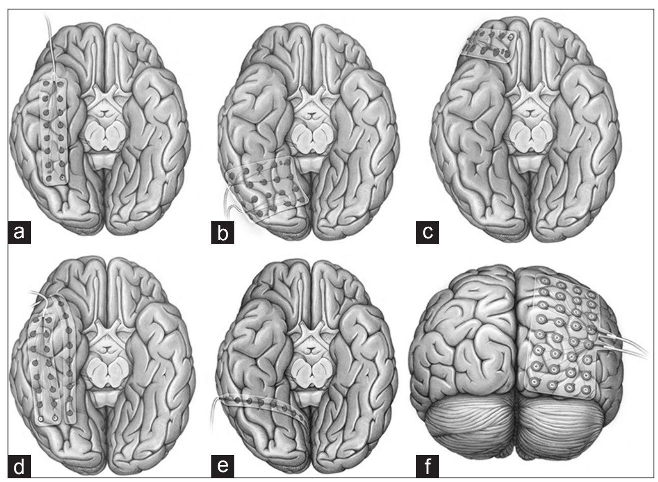

Figure 2: Basal surface of brain showing (a) A 2 × 8 electrode grid placement for evaluation of the inferior temporal lobe epilepsy; (b) A 4 × 5 electrode grid placement on the basal occipital lobe as part of the evaluation for occipital lobe epilepsy; (c) A 2 × 8 electrode grid that has been slid down the sphenoid ridge and subfrontal to evaluate the orbitofrontal cortex during evaluation for frontal lobe epilepsy; (d) A combination of a 2 × 8 electrode grid and a 1 × 10 electrode strip for evaluation of temporal lobe epilepsy. The 1 × 10 electrode allows adequate recording from the medial temporal lobe structures and may obviate the need for hippocampal depth electrodes; (e) A 1 × 10 electrode strip sampling the basal surface of the posterior temporal lobe, basal and interhemispheric occipital lobe. Placement of this electrode along the posterior temporal lobe and its gentle subdural advancement invariably places the electrode within the occipital interhemispheric space and allows for medial occipital recording or stimulation for visual cortex. (f) A 4 × 8 electrode grid has been placed over the parietal occipital region to assess for posterior hemispheric epilepsy. Copyright, IU Health

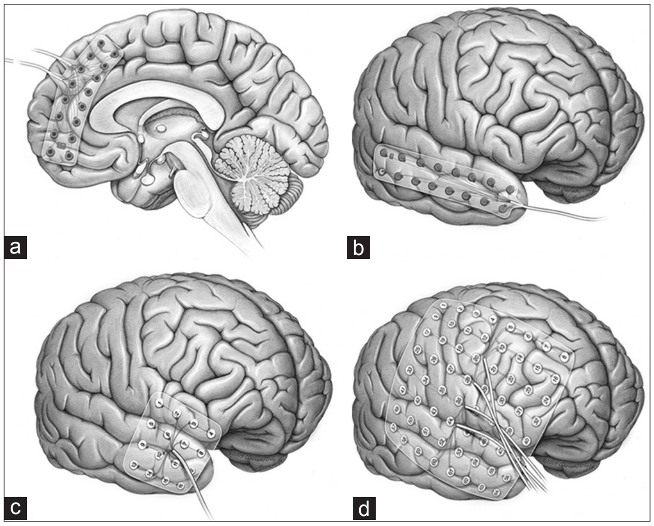

Figure 3: (a) A 2 × 8 electrode grid has been placed within the interhemispheric space to investigate frontal lobe epilepsy. The presence of recording electrode contacts on both sides of the grid facilitates bilateral medial frontal lobe monitoring. (b) A 2 × 8 electrode grid has been placed over the lateral surface of the temporal lobe as part of the evaluation for cortical temporal lobe epilepsy. (c) A 4 × 4 electrode grid has been placed over the anterior temporal lobe and inferior frontal lobe as part of the evaluation for frontotemporal epilepsy. (d) An 8 × 8 electrode grid has been placed to sample large regions of the frontal and temporal lobes as part of the evaluation for frontotemporal epilepsy. Copyright, IU Health

Large areas of the fontal, temporal, parietal, or occipital convexities can be covered with appropriately sized grids and strip electrodes within the subdural space [Figures 2-4]. While sliding the strip electrode underneath the edges of the craniotomy, we gently inject irrigation fluid underneath the strip and over the brain surface to make the strip "glide over water" to its final destination, rather than forcing the strip within the tight subdural space. Any resistance may indicate the presence of a bridging vein, especially in the parasagittal regions. Under special circumstances, the grid arrays may be cut or trimmed to further conform to the cortical surface and stay clear of the parasaggital bridging veins. This technique will avoid buckling of the grid edges. Careful record keeping is required to account for missing contacts during extraoperative monitoring. In addition, slits may be made in the rows at the periphery of the grid to taper the edges and allow a good fit along the boundaries of dural opening.

BASAL AND INTERHEMISPHERIC ELECTRODES

To place special double-sided grid electrodes (contact electrodes on both sides of the grid) within the interhemispheric space [Figure 3a], we remove the bone over the superior sagittal sinus and carefully respect the bridging veins upon opening the dura. Blind forced insertion of these electrodes should be avoided since there are numerous bridging veins in the area and their injury is consequential.

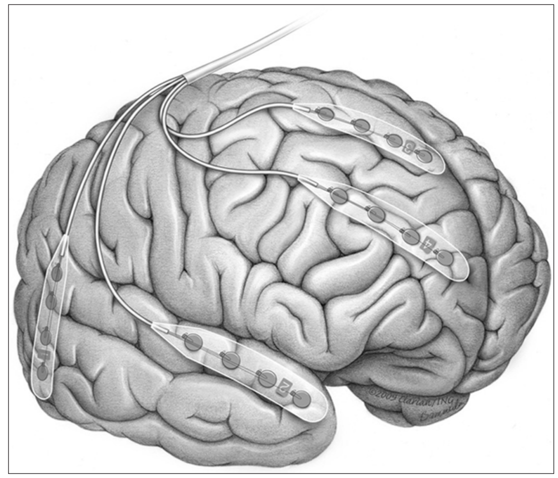

Figure 4: Four 1 × 4 electrode strips have been placed over the right frontal and temporal lobes. These electrodes are placed through burr holes and may also cover the occipital lobe. Such an intracranial study may be bilateral and will prepare the patient for another operation when a craniotomy is performed to delineate the focus in more detail. This technique carries the advantage of allowing bedside removal of these electrodes in select patients. Copyright, IU Health

To record from the hippocampus and parahippocampal areas, a 1 × 10 strip electrode is advanced parallel and over the superior temporal gyrus wrapping along the anterior temporal lobe medially. Upon its final placement, this electrode invariably covers the parahippocampus to the level of the tectal plate and allows adequate recording from the medial temporal lobe structures and may obviate the need for hippocampal depth electrodes [Figure 2d].[2] Similarly, a 1 × 10 electrode may be placed along the posterior temporal lobe and gently advanced in the posteromedial direction. The surrounding dural structures including tentorium invariably guide the electrode within the occipital interhemispheric space. This electrode allows for medial occipital recording or cortical stimulation of the visual cortices. In addition, this strip samples the basal surface of the posterior temporal and occipital lobes [Figure 2e].

Mesial temporal lobe structures can also be sampled with depth electrodes. These electrodes can be placed either orthogonally or parasaggital.[20] The orthogonal technique involves multiple depth electrodes placed stereotactically via lateral burr holes and placed strategically to sample the amygdala, hippocampus, and parahippocampus.[19,20] The parasaggital technique involves placing a single electrode stereotactically via a parietoccipital burr hole and choosing a trajectory to sample the mesial temporal lobe structures.[19] Both techniques can be performed unilaterally or bilaterally when indicated.[19,20]

In general, before closure of the dura, color photographs and sketches are prepared to record the location of the electrodes in relation to the major lobes and fissures/sulci. Adequate recording from the implanted electrodes is confirmed before closure. These sketches will be used to mark the hyperactive cortical areas during the ictal and interictal states and extraoperative monitoring.

BURR HOLES FOR PLACEMENT OF STRIP ELECTRODES

The clinician may suspect partial epilepsy based on preoperative studies, but he/she may find it difficult to accurately localize the epileptogenic lobe. Extensive electrode coverage is not safe or feasible. In these situations, burr holes over the suspicious lobes will allow implantation of strip electrodes and may assist with specifying the lobes involved in seizure generation [Figure 4]. Such an intracranial study will prepare the patient for a second operation when a more guided craniotomy is performed to delineate the seizure focus. This technique has the advantage of allowing bedside removal of the strip electrodes in select patients. To decrease the risk of infection, a 6-week period is allotted before a craniotomy with more extensive targeted electrode placement is contemplated.

It is important to note that medial "interhemipheric" epileptogenic foci may not be accurately mapped using burr holes and strip electrodes implanted over the convexity cortices. Specifically, seizure activity originating from a medial frontal focus can propagate quickly to the contralateral frontal lobe through corpus callosum before any ipsilateral convexity cortical hyperactivity is detected, leading the clinician to interpret the results as "nonlateralizing" or falsely lateralizing. As a general rule, the timing of clinically and electrographically detected seizure activity should be carefully analyzed to assure adequate electrode coverage of the cortices involved in epileptogenesis.

Closure

The electrodes are generously sutured along their various borders to the edges of the dura to avoid their displacement during the extraoperative monitoring period. We use segments of previously harvested pericranial autograft to complete a duroplasty and close the dura in a relatively "water-tight" fashion.

We do not replace the bone flap while the electrodes are in place, but reimplant this flap during the second operation when the electrodes are explanted and resection is conducted. Some patients gradually accumulate subdural fluid and blood over the electrodes after the first operation despite immaculate hemostasis. Replacement of the bone flap during the first operation potentially facilitates the delayed mass effect caused by the hematoma and the need for an emergent decompression. Venous congestion, pial inflammation, and cortical pressure from nonpliable portions of the grids contribute to this mass effect. A temporary epidural drain is used to decrease the risk of postoperative fluid collection. The scalp is closed in two layers while nylon sutures are used to approximate the skin. Significant tension on the sutures is prevented to avoid necrosis along the scalp edges.

Tunneling of the electrodes wires

Substantial hair removal is usually necessary to allow sterile tunneling of the electrode wires from the incision site. Multiple angiocaths (10 GA, 3.4 mm, 3 inches), inserted through separate stab incisions some distance (usually an inch) from the skin edge are used to tunnel the wires percutaneously away for the wound. Purse-string stitches around the wires can be an effective way to prevent cerebrospinal fluid (CSF) leak from tracking along the wires. At the time of intraoperative electrode explantation, during the second operation, the purse string stiches are removed prior to prepping, and the exiting electrodes are draped out of the surgical field. This technique allows an assistant to go under the drapes and pull the wires from the sterile field after the intracranial wires are cut. A larger exit site must be planned if there are intentions of removing the strips at the bedside.

An intraoperative skull X-ray photograph at the time of grid placement is useful for verifying that the electrodes have not moved at the time of reoperation for resection of the seizure focus. In addition, if a suspicion of electrode displacement during extraoperative monitoring is raised, another X-ray image can be taken and the original X-ray images can be used as a reference. Frameless stereotactic neuronavigation may be used to guide electrode placement and subsequent resection of a seizure focus. Chamoun *et al*.,[1] described a technique of merging a preimplant MRI with a postimplant head computed tomography (CT) for improved localization of the postimplant electrodes. They drilled four holes at the edge of their craniotomy that can be used as fiducials at the time of reoperation and to realign the original registration.

The exiting wires corresponding to each electrode are carefully tagged and registered to ensure correct identification of the source of data recorded during the extraoperative period. In other words, the wire covering the parahippocampal gyrus is numbered (i, e., 3) and the assistant will record the number and the corresponding location of the strip for later reference. It is important to document adequate intraoperative recordings from the electrodes before closure. ECOG recordings while measuring impedance of the electrodes assure adequate contact with corresponding cortices. Any electrodes that are not in good contact with the cortex or that may overlie large bridging veins have to be repositioned.

Anesthesia considerations

Benzodiazepines, barbiturates and high-dose inhaled halogenated agents interfere with ECOG.[9] Kurita *et al*.,[10] confirmed that 1.5 minimal alveolar concentration (MAC) sevoflurane can be used during ECOG. Oda *et al*.,[14] demonstrated that dexmedetomidine can be used in combination with 1.5 MAC sevoflurane while maintaining ECOG activity. Other reports indicate that less than 50% nitrous oxide or 0.5 MAC isoflurane allow for ECOG.[18]

Alfentanil, sufentanil, remifentanil, fentanyl, and methohexital have all been shown to enhance ECOG activity.[8,9,11,24] Reports on the effect of propofol have been contradictory.[9,17] Remifentanil may prove particularly useful since it can suppress activity in normal cortex, while increasing activity in abnormal cortex.[23]

Postoperative care and additional comments

The epidural drain is removed on the first postoperative day after a head CT is completed. A new head wrap is then applied. For our patients, the longest intracranial study lasted 6 weeks. Typical intracranial monitoring study period lasts 4-10 days. Lengthier studies are associated with increased infection rates. Any sign of infection, including fever, altered mental status, and wound drainage, requires urgent removal of the electrodes and later surgery to complete cortical resection. Removal of the epileptogenic cortex in the face of infection is avoided. We recommend the use of prophylactic antiobiotics during the monitoring period.

Intracranial studies require large scalp flaps, and we therefore recommend shaving the entire head to minimize infection. While seizing, the patient often is confused and may inadvertently pull on his or her electrode wires. This high risk of electrode displacement should be minimized by placement of secure head wraps that have a submandibular sling to decrease the chance of their loosening. Electrode displacement and infection complicate extraoperative monitoring and all measures to minimize their risk should be remembered.

Placement of electrodes alters the normal electrical environment of the brain, potentially leading to temporary cessation of seizures or alternation of patients' habitual seizure semiology. It is important to confirm that the recorded seizures during an intracranial study are similar to or the same as the patient's habitual seizures recorded during preoperative inpatient video-EEG monitoring sessions. In addition, if the epileptogenic zone is on the edges of the electrodes and not completely contained within the areas covered by the electrodes, another intracranial study is necessary to provide more extensive electrode coverage in these areas.

Some surgeons have advocated a multistage intracranial monitoring scheme, especially for pediatric patients. Initial monitoring/resective surgery and/or multiple subpial transections are followed by further intracranial monitoring and additional resection and/or multiple subpial transections.[15] The risk of infection in these operations has to be weighed against its benefits.

CONCLUSIONS

Intracranial epilepsy monitoring with grid and strip electrodes is a useful tool for the planning of resective epilepsy surgery. Techniques to advance the safety and minimize complications will lead to improved outcomes.

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