Surgical techniques for investigating the role of the insula in epilepsy: a review

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Intracranial electroencephalography monitoring of the insula is an important tool in the investigation of the insula in medically intractable epilepsy and has been shown to be safe and reliable. Several methods of placing electrodes for insular coverage have been reported and include open craniotomy as well as stereotactic orthogonal and stereotactic anterior and posterior oblique trajectories. The authors review each of these techniques with respect to current concepts in insular epilepsy.

Key Words • intracranial electrodes • epilepsy surgery • epilepsy • insula • stereofaxy

Insular epilepsy has been the subject of increasing investigation over the past decade, but the concept of seizures arising within the insula was in fact first proposed over half a century ago on the basis of intraoperative electrocorticographic recordings in patients undergoing epilepsy surgery, findings that went on to be replicated several years later by Wilder Penfield. There followed several decades of anecdotal reports of seizures associated with insular lesions, including tumors and cavernomas, but owing perhaps to hazardous surgical anatomy and often unfavorable outcomes reported with insular resection, there remained little focused investigation of the insula in ictal onset for many years. Recently, however, several groups have reported experiences with the use of recording electrodes in the insula in patients with medically intractable epilepsy. These studies have enabled semiological characterization of seizures that have an insular onset and demonstrated good outcomes with insula resections in patients with insular seizures, illustrating the important role of intracranial insular recording in the effective surgical treatment of insular epilepsy. Furthermore, they have used a number of techniques and trajectories to place recording electrodes into the insula.

Insular seizures confirmed by stereo-EEG are usually simple partial in nature, with common features being laryngeal discomfort, dysphonia, paresthesias, and somatomotor symptoms. They may additionally include hypermotor features mimicking frontal lobe seizures, visceral symptoms, or dysphasia mimicking temporal lobe seizures, and early somatosensory symptoms in the absence of laryngeal constriction mimicking parietal lobe seizures.

With respect to the outcomes after insular resections based on seizure-onset localization with intracranial recording, several groups have reported good outcomes with insula-sparing resections of the frontal and temporal lobes in patients in whom the insula was identified as a site of secondary seizure propagation, as well as in those without insular involvement. In addition, there have been reports of persistence of insular-onset seizures after temporal lobectomy and of insular seizures clinically mimicking those encountered in temporal lobe epilepsy. Furthermore, when patients preselected using clinical seizure characteristics, scalp EEG recordings (with or without video correlation), MRI, SPECT, and PET undergo insular electrode recording, a seizure-onset zone specifically within the insula may be found in approximately 10%–20% of cases. These findings, as well as the functional connectivity of the insula to the orbitofrontal cortex, cingulate cortex, and temporo-limbic structures, mandate consideration of the insula’s role (and potential intracranial EEG recording of the insula) not only in insular epilepsy but also in suspected frontal or temporal lobe epilepsy.

Abbreviation used in this paper: EEG = electroencephalography.
Finally, several methodologies have been described for placement of insular electrodes. Central to understanding the arguments for and against each approach is an informed consideration of the pertinent anatomy of the insula and surrounding structures.

**Surgical Anatomy of the Insula**

The anatomical features of the insula present unique challenges in surgical exposure for electrode coverage. The insula covers the lateral surface of the hemispheric core and has a triangular shape with its apex directed anterior and inferiorly toward the limen insula. The insula is encircled and separated from the frontal, parietal, and temporal opercula by a shallow limiting sulcus, the circular sulcus, which has superior, inferior, and anterior borders. The insula also has radially projecting sulci and gyri (directed superiorly and posteriorly) from the insular apex. The central sulcus is the deepest of these sulci and extends superoposteriorly, dividing the insula into anterior and posterior parts.28 Accessing the insula, therefore, requires dissection of the sylvian fissure, retraction of potentially functional opercular cortex, and further dissection through M2 middle cerebral artery branches on the surface of the insula.32

Human cadaveric and primate studies have demonstrated that the insula receives main afferents from the amygdala, the dorsal thalamus, and different cortical regions, particularly the sensory cortices and the auditory cortex. Most of these afferents terminate in the posterior granular part of the insula, whereas the ventral anterior agranular insula receives predominantly afferents from the limbic cortex, e.g., the entorhinal, perirhinal, posterior, and orbitofrontal cortices and the cingulate gyrus. In addition, the efferents of the ventral anterior insula reciprocate the afferents of the anterior insula, although this is not the case in the posterior insula. Relatively little is understood about the function of the insula, although several investigators have suggested it may play a role in secondary sensory processing, language and motor control, or higher autonomic control and as a component of the limbic system.2,22,14 The anatomical connectivity described above and the seizure characteristics seen in documented insular epilepsy are in keeping with this concept.

**Intracranial EEG Investigation of the Insula**

The use of intracranial EEG to investigate seizure onset in patients with medically intractable epilepsy is well established,2,21 and the role of the insula in seizure onset has received increasing interest over the past decade.1,5,7,11-13,15,16.24,26,34 Several groups have published reports of intracranial monitoring electrodes implanted into the insula using a variety of methods (Table 1).1,5,7,11-13,15,16,24 Broadly speaking, the electrodes may be intracerebral depth electrodes (located within the insula) or subdural strip electrodes (located on the insula surface), and may be placed stereotactically, with or without the use of a stereotactic frame, or under direct visualization. The techniques of electrode placement within or onto the insula may be categorized as follows: 1) craniotomy and direct visualization method, with or without frameless stereotactic neuronavigation; 2) stereotactic orthogonal method; 3) stereotactic posterior oblique electrode method; 4) stereotactic anterior oblique electrode method; and 5) combined stereotactic anterior and posterior oblique electrode method.

These approaches have been extensively described and each has potential advantages and disadvantages, which will be discussed.

**Techniques of Electrode Placement**

**Craniotomy and Direct Visualization Method**

The first strategy to be considered involves the placement of a depth electrode within the insula, or a strip electrode onto its surface, after craniotomy and dissection of the sylvian fissure, as described by several groups.13,30 When this method is used, placement of the depth electrode within the insula may also be accompanied by stereotactic guidance.15,30

The advantages of this approach are that it allows the insular electrode placement to be efficiently combined with temporal and frontal convexity subdural grid placement if required. This is a relatively common scenario, and this technique enables concomitant electrode coverage of these regions and the opercular surface, for recording and for functional mapping. Furthermore, insular coverage by a depth electrode can provide coverage of both the medial and lateral portions of the insula, which may be difficult to achieve with parasagittal oblique trajectories. Finally, in cases eventually requiring surgery, the subpial depth electrodes can be used as surgical landmarks for insular resection.17

This strategy, on the other hand, can have important drawbacks and may not always be preferred. If subdural grid electrodes necessitating an ipsilateral craniotomy are not required, then performing a craniotomy to place insular electrodes alone is less efficient than other techniques. This method also carries an increased risk of vascular injury to the middle cerebral artery during dissection, as well as the risk of morbidity from frontal lobe retraction.30 Insular coverage provided by a typical depth electrode placed in this manner is essentially orthogonal, with 2 contacts expected to reside within the insula per electrode.30 This “contact-to-electrode” ratio is lower than that achievable via oblique trajectories and therefore necessitates placement of a greater number of electrodes to get a broad sampling of the insula.

This technique can be efficiently complemented with frameless stereotactic guidance17,30 and potentially with robotic placement.30 The use of stereotactic neuronavigation, while potentially increasing operative duration and cost, provides assistance with electrode trajectory to maximize contacts within the insula and neighboring regions, if desired, and avoidance of deeper structures such as the internal capsule. Some groups have reported placing subdural strip electrodes over the insular cortex without neuronavigation after craniotomy and splitting of the sylvian fissure.13 This strategy necessitates stable placement of the strip elec-
### TABLE 1: Major studies describing techniques for placement of insular recording electrodes

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Pts</th>
<th>Electrode Placement</th>
<th>Electrodes in Insula</th>
<th>Contacts in Insula</th>
<th>Complications</th>
<th>Localization of Seizure/Onset to Insula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isnard et al., 2004</td>
<td>50</td>
<td>frame-based stereotactic orthogonal trajectory w/ teleangiography</td>
<td>mean 2.9/pt</td>
<td>not reported</td>
<td>not reported</td>
<td>6 (12%) of 50; onset solely in insula in 5 (10%) of 50</td>
</tr>
<tr>
<td>Ryvlin et al., 2006</td>
<td>26</td>
<td>frame-based stereotactic orthogonal trajectory w/ teleangiography; 2 w/ stereotactic ant oblique trajectory</td>
<td>1/pt</td>
<td>mean 5, range 2–7</td>
<td>not reported</td>
<td>Larger cohort undergoing monitoring; onset not reported</td>
</tr>
<tr>
<td>Afif et al., 2008</td>
<td>30</td>
<td>frame-based stereotactic ant &amp;/or pst oblique trajectories</td>
<td>mean 1.2/pt</td>
<td>mean 7.5</td>
<td>none reported</td>
<td>5 (18%) of 30; onset solely w/in insula in 2 (6.7%) of 30</td>
</tr>
<tr>
<td>Malak et al., 2009</td>
<td>7</td>
<td>w/ orthogonal, frame-base stereotactic trajectory w/ teleangiography; 6 w/ depth electrodes placed under direct visualization</td>
<td>2/pt in most cases</td>
<td>2</td>
<td>1 pt w/ transient leg weakness</td>
<td>Larger cohort undergoing recording; not reported</td>
</tr>
<tr>
<td>Park et al., 2009</td>
<td>6</td>
<td>strip electrode placed under direct visualization; 2 depth electrodes placed w/ frame-based stereotactic pst oblique trajectories; 3 depth electrodes (direct visualization w/ aid of image guidance)</td>
<td>3/pt under direct visualization; 1/pt placed stereotactically</td>
<td>strip electrode w/ 2 contacts; depth electrodes (2 for stereotactic, 4 for direct visualization)</td>
<td>none reported</td>
<td>Larger cohort undergoing recording; not reported</td>
</tr>
<tr>
<td>Robles et al., 2009</td>
<td>9</td>
<td>frame-based stereotactic pst oblique trajectory</td>
<td>1/pt</td>
<td>&gt;4 in all cases</td>
<td>none reported</td>
<td>Larger cohort undergoing op; not reported</td>
</tr>
<tr>
<td>Desai et al., 2011</td>
<td>20</td>
<td>frame-based stereotactic oblique ant trajectory</td>
<td>mean 1.45/pt</td>
<td>mean 5.2/pt</td>
<td>none reported</td>
<td>2 (10%) of 20</td>
</tr>
<tr>
<td>Surbeck et al., 2011</td>
<td>19</td>
<td>16 w/ depth electrode placement under direct visualization; 3 w/ frame-based stereotactic, transfrontal, &amp; transparietal trajectories</td>
<td>direct visualization: 1–3; stereotactic placement: 2</td>
<td>direct visualization: mean 3.5 (range 1–6); stereotactic placement: overall mean 8, 2–4 w/ transfrontal trajectory, 5–7 w/ transparietal trajectory</td>
<td>1 foot-drop due to migration of electrode; 1 dysphasia from opercular retraction</td>
<td>7 (37%) of 19</td>
</tr>
</tbody>
</table>

trodes within a relatively narrow space, which is hindered by surrounding vasculature. Our own group at one time made recordings from the insula using strip electrodes, but we were not satisfied with the coverage and electrode stability and have since ceased using this strategy.

**Stereotactic Orthogonal Approach**

The stereotactic orthogonal, or transopercular, approach was originally described by Talairach and Bancaud and has since been frequently used in various insular applications. Of the stereotactic approaches to the insula, the orthogonal approach is historically the most well established. It involves the placement of multiple ipsilateral axially oriented electrodes into the insula using frame-based coordinates and has traditionally been facilitated by teleangiography, or newer 3D methods of angiography, to avoid middle cerebral artery branches.

The advantages of this approach include its relatively established use as a safe and efficacious method of accessing the insula and the ability to sample medial and lateral portions of the insula, as well as neighboring frontal and temporal opercula. The use of teleangiography meanwhile does not require computer-based registration. The relative disadvantages include an inherent trajectory through a region of potentially eloquent cortex and numerous vascular structures; as such, the procedure requires accurate visualization of the middle cerebral artery, sylvian fissure, and sulcal vasculature. Although this can be achieved using either teleangiography or stereotactically coregistered vascular imaging, this may be more time consuming than other stereotactic approaches and some surgeons consider it cumbersome. In addition, the orthogonal trajectory and the shape of the insula in this technique, like the above-mentioned open approach, result in relatively fewer contacts (n = 2) per electrode within the insula, leading to a greater number of electrodes needing to be placed for sufficient insular coverage and further decreasing the technique’s potential efficiency. Like all implantation methodologies, confirmation of contact localization on postoperative imaging (MRI or CT) is essential.

**Stereotactic Posterior Oblique Approach**

Several groups have described placing depth electrodes stereotactically using image-guided, frame-based, stereotactic oblique trajectories planned to minimize pial violations. These oblique approaches have been facilitated by advances in stereotactic planning, visualization, and trajectory determination. These oblique trajectories may be posterior (transparietal) or anterior (transfrontal), and can potentially be performed with additional robotic assistance.

The posterior approach, in which depth electrodes targeting the insula are placed through a parietal entry point, is the more commonly reported oblique trajectory. This approach carries the relative advantage of a trajectory through a relatively safe, usually noneloquent corridor. Unlike the open approach to electrode placement, this approach avoids the need for craniotomy, sylvian fissure dissection, and opercular retraction. Furthermore, in contrast to the stereotactic orthogonal approach, it does not require passing the electrodes through potentially eloquent cortex or through the dense vasculature of the sylvian fissure and the insular surface. A posterior trajectory also allows more proximal electrode contacts to be placed in the parietal lobe, which may be of use where there is concern of parietal involvement in seizure onset. The posterior trajectory also appears well tailored to the 3D shape of the insula, and the trajectory can almost approximate the long axis of the insula. This subsequently increases the number of contacts per electrode residing within the insula, using this trajectory, and potentially makes this a very efficient technique.

The posterior oblique trajectory also has some potential drawbacks. It is necessarily performed stereotactically and requires sophisticated computerized registration, usually with stereotactic head frame placement. Using this trajectory also makes it difficult for coverage to span the entire mediolateral width of the insula, unlike the case with the orthogonal or open approach. Furthermore, several authors consider the approach to offer relatively limited coverage of the anterior insula. Similar to other stereotactic approaches, this technique also carries the potential disadvantage of reliance on postoperative imaging to confirm correct electrode placement.

**Stereotactic Anterior Oblique Approach**

An alternative oblique trajectory is the transfrontal approach in which the depth electrode is placed through an anterior frontal entry point (Fig. 2). This approach has been described by several groups recently, including our own. Advantages of this technique include a relatively safe trajectory through usually noneloquent anterior frontal
Role of the insula in epilepsy

cortex. In addition, the trajectory passes through the insula in a posteriorly angulated, approximately parasagittal plane, potentially allowing several contacts of a given electrode to reside within the insula. An additional advantage of this trajectory is that it provides added frontal coverage with more proximal contacts. This can be particularly useful in the relatively common scenario of ambiguity on the roles of both the insula and the frontal lobe in seizure onset.

Disadvantages of this technique, similar to the transparietal trajectory, include the relative reduction in mediolateral electrode contact coverage that can be achieved within the insula. Furthermore, like the transparietal trajectory, this technique requires computer-based registration, the placement of a stereotactic head frame, and is associated with concerns about the reliability of postoperative imaging in contact localization. Our own experience is that the latter has not proved problematic when postoperative high-resolution head CT scans are fused with preoperative MR images for reconstructions. One further disadvantage of this trajectory, compared with the transparietal technique, is that the latter appears to facilitate greater contact coverage of the insula. Surbeck et al. found that their use of the transfrontal trajectory resulted in 2–4 lead contacts being positioned within the insula whereas electrodes placed in the transparietal approach had a range of 5–7 contacts within the insula. Furthermore, a study by Afif et al. documented a mean of 7.5 contacts per electrode within the insula when using either a transfrontal or transparietal trajectory (or both in some cases), whereas our own group’s experience in using a transfrontal trajectory resulted in only 5.2 contacts within the insula per electrode. The triangular shape of the insula and its essentially anteroposteriorly directed long axis may account for this, since the study by the aforementioned Grenoble group used a significant number of transparietal electrodes, compared with our own group, which used a transfrontal trajectory only. A prospective quantitative analysis of insular contacts achievable by each trajectory, however, remains to be performed. This technique may also provide reduced coverage of the posterior insula relative to the parietal approach, although its anterior insular coverage is likely superior.

Combined Stereotactic Anterior and Posterior Oblique Approaches

Several groups have used a frame-based stereotactic approach and incorporated both transfrontal and transparietal oblique trajectories. This strategy has the advantage of combining 2 relatively efficient, low-risk methods of electrode placement to enhance contact coverage within the insula and intervening frontal and parietal regions.

The disadvantages of this method include the incrementally increased risk (for example, of hemorrhage and infection) associated with additional invasive subpial electrodes, in addition to the aforementioned drawbacks of oblique trajectories, namely a relative lack of mediolateral coverage, the requirement for computer-based registration and stereotactic frame placement, and potentially ambiguous postoperative imaging.

Conclusions

Intracranial EEG monitoring of the insula is an important tool in the clarification of the insula in medically intractable epilepsy and has been shown to be safe and reliable. Several methods of placing electrodes for insular coverage have been used, with subpial depth electrodes being the most common. These can be inserted during craniotomy and under direct visualization, with or without neuronavigation, or stereotactically using orthogonal or oblique trajectories. Each method has potential advantages and disadvantages and should be chosen accordingly.

Disclosure

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

Author contributions to the study and manuscript preparation include the following. Conception and design: Desai. Acquisition of data: Darcey. Analysis and interpretation of data: Desai. Drafting the article: Desai, Bekelis. Critically revising the article: Desai, Bekelis, Roberts. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Desai.

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