REVIEW ARTICLE

Intraoperative Cortical Mapping for Epilepsy Surgery: Advances, Challenges, and Clinical Insights

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Cortical mapping has revolutionized the field of neurosurgery by enabling the precise identification of functional brain regions responsible for essential motor, sensory, language, and cognitive processes. Initially developed to minimize postoperative deficits in brain surgeries, cortical mapping has become particularly valuable in the treatment of drug-resistant epilepsy—a condition where antiepileptic medications fail to provide adequate seizure control. Being able to identify epileptogenic tissue during the surgery by highlighting and parcellating functional brain region information in preoperative neuronavigation creates a possible new gold standard. Neuromonitoring offers a more cost-effective tool for identification compared to functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI). For such patients, surgical resection of epileptogenic tissue offers a promising path toward improved quality of life, but success hinges on the ability to map functional regions accurately to prevent unintended damage to functional areas. Epilepsy affects millions globally, with many patients experiencing debilitating seizures that impair daily functioning. A multitude of cortical mapping strategies have been shown to be effective in identifying epileptogenic zones, spasms, and eloquent cortices using single-pulse electrical stimulation, recording of the Bereitschaftspotential, awake craniotomy paired with direct electrical stimulation, and Electrical Corticography (ECoG). Intraoperative cortical mapping can provide real-time insight into changing the surgical resection plan for patients undergoing awake craniotomy. This literature review seeks to examine the current landscape of cortical mapping in epilepsy surgery, analyze the effectiveness of various techniques, and highlight emerging challenges.

INTRODUCTION

Cortical mapping is a critical process in neurosurgery that involves identifying and localizing functional areas of the brain responsible for essential cognitive, motor, language, and sensory functions. Traditionally used in brain surgery to minimize postoperative deficits, cortical mapping has become significant in neurological disorders that require surgical intervention. By delineating eloquent cortex regions, surgeons can operate with greater precision and reduce the risk of impairing vital functions [1].

Cortical mapping has its primary use in identifying epileptogenic zones; however, it has also been observed to benefit patients with epileptic spasms and abnormal cortical discharges that produce involuntary movements. [1]. Epilepsy affects millions of individuals worldwide, and for patients who do not respond to antiepileptic medications, resective surgery offers the potential for long-term seizure control or even cure [2]. However, successful epilepsy surgery depends on accurately localizing both the epileptogenic zone and adjacent functional areas of the brain. Mapping these regions is crucial for distinguishing between areas that can be safely resected and those that must be preserved to maintain neurological function [3].

The challenge in epilepsy surgery lies in balancing maximum seizure control while minimizing functional deficits. Accurately identifying the epileptogenic zone, the area responsible for generating seizures, and differentiating it from the surrounding eloquent cortex remains a complex task. This is particularly challenging in cases of neocortical epilepsy where seizure foci may not be easily localized using noninvasive methods such as magnetic resonance imaging (MRI) or magnetoencephalography (MEG) [4]. As a result, invasive procedures such as the prolonged implantation of subdural electrodes, followed by functional cortical mapping using high-frequency electric stimulation and sensory evoked potentials, become essential tools in presurgical evaluation. However, these techniques are not without limitations [1].

While cortical mapping provides precise localization of functional areas and enhances the success of epilepsy surgery, its implementation still presents several limitations. Although mapping cognitive functions such as sensation, motor capability, and language has become increasingly reliable, other challenges and limitations in functional cortical mapping techniques remain. The variability in individual brain anatomy and the potential for functional plasticity in epileptic patients further complicates the generalizability of these techniques.

This literature review will examine the utility of cortical mapping techniques for epilepsy, assessing their current efficacy, discussing the challenges of their implementation, and highlighting areas for future research to enhance their reliability, accessibility, and broader application in neurosurgical practice. Through an in-depth analysis of invasive and noninvasive methods, this review aims to provide a comprehensive understanding of how intraoperative cortical mapping with a multimodality neurophysiological monitoring approach can be optimized to enhance outcomes in epilepsy surgery.

METHODOLOGY

Exclusion Criteria and Study Selection

To curate the mass amount of literature we had gathered, we built exclusion criteria to narrow down our selection. Our exclusion criteria set guidelines for voiding the use of book chapters, publications not available in English, and non-peer reviewed studies lacking scientific rigor; as well as publications published before the year of 2000 unless they provide foundational or seminal evidence directly informing key concepts relevant to the objectives of this review, and publications that only focus on non-invasive monitoring methods such as MEG and functional magnetic resonance imaging (fMRI) which offer no significance to cortical mapping. All publications were gathered through PubMed, Google Scholar, and the UT Dallas Library. The search terms included: cortical mapping, brain mapping, electrocorticography, somatosensory evoked potentials, intraoperative mapping, high-frequency cortical stimulation, neurophysiological monitoring, and epilepsy surgery. After the search, sources were imported to the Zotero database to assess selection and exclusion. Seven sources were deemed relevant out of the 34.

Inclusion Criteria

This review included peer-reviewed studies published after 2000 that examined the role of cortical mapping in epilepsy surgery. Furthermore, only studies with invasive mapping techniques were included. ECoG, SSEPs, and HFCS were all considered invasive mapping techniques. Only studies that considered the efficacy and challenges of cortical mapping in epilepsy surgery were included. All studies used were required to be accessible through institutional access to open-access databases to ensure reliability and validity.

Parameter	Value
Low Cut Filter	1 Hz
High Cut Filter	70 Hz
Notch Filter	Off
Dynamic Range (Input Gain)	20 μV/div
Sensitivity	100 μV/div
Sweep	500 ms/div
Electrode Impendence	> 5 kΩ

Table 1. Electrocorticography (ECoG) Recording Parameters.

Electrocorticography (ECoG)

Electrocorticography is recorded by placing subdural grid electrodes directly onto the surface of the brain (Table 1). Due to the electrodes being in direct contact with the cortex, ECoG provides significantly higher temporal and spatial resolution than electroencephalography (EEG). It also results in a better signal-to-noise ratio than a scalp EEG. ECoG is used for the precise identification of epileptogenic zones and functional cortical areas. Its real-time feedback is essential for guiding surgical boundaries and optimizing outcomes.

Somatosensory Evoked Potentials (SSEP)

Somatosensory Evoked potentials are employed to assess the integrity of the somatosensory pathways and assist in identifying functional cortical regions during epilepsy surgery. Peripheral nerves are stimulated in both upper and lower extremities. For the upper extremities, the median, ulnar, and radial nerves are commonly used. Stimulation sites for the lower extremities are often the posterior tibial, peroneal, and femoral nerves (Table 2). Baseline responses are established before any cortical manipulation and are monitored throughout a procedure. The stability of characteristic waveforms confirms functional integrity of the sensory pathways, while any reduction in amplitude or increase in latency indicates potential cortical or subcortical disruption.

	Upper Extremity	**Lower Extremity**
Sensitivity	1 – 5 µV /div	1 – 5 µV /div
Low Frequency Filter	30 Hz	30 Hz
High Frequency Filter	500 Hz	500 Hz
Sweep	50 ms	100 ms
Stim Intensity	10 – 35 mA	40 – 100 mA
Stim Duration	300 µsec	300 µsec
Stim Rate	2.66 - 4.79 / sec	2.66 - 4.79 / sec
Sweeps	200 – 300	200 - 300

Table 2. Somatosensory Evoked Potential Parameters.

High Frequency Cortical Stimulation (HFCS)

High-frequency cortical Stimulation is used for cortical mapping to identify eloquent motor, sensory, and language regions. The stimulation was delivered with strip electrodes and subdural grids on the cortical surface. The stimulation consists of a 50 Hz train of 0.3 ms square pulses with alternating polarity, applied for 2–5 seconds per site (Table 3). The current gradually increased up to a maximum of 15 mA or until a positive cortical response or after-discharges were observed. Positive response sites were used as a guide in surgical resection to ensure maximal removal of the epileptogenic zone.

Parameter	Value
Stimulation Frequency	50 Hz
Pulse Type	Square Pulse
Pulse Duration	0.2-0.5 ms
Stimulation Duration	2 – 5 seconds
Stimulus Intensity	Gradually increased to 15 mA.

Table 3. High Frequency Cortical Stimulation Parameters.

RESULTS

Our systematic review was conducted in direct compliance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines (Table 4). We compiled publications from Google Scholar, PubMed, and the University of Texas at Dallas online database. Our goal was to identify studies that included cortical mapping in the context of epileptic surgeries (Table 5). There was a focus on Electrocorticography (ECoG), with further mention of Somatosensory Evoked Potentials (SSEPs) and High-Frequency Cortical Stimulation (HFCS).

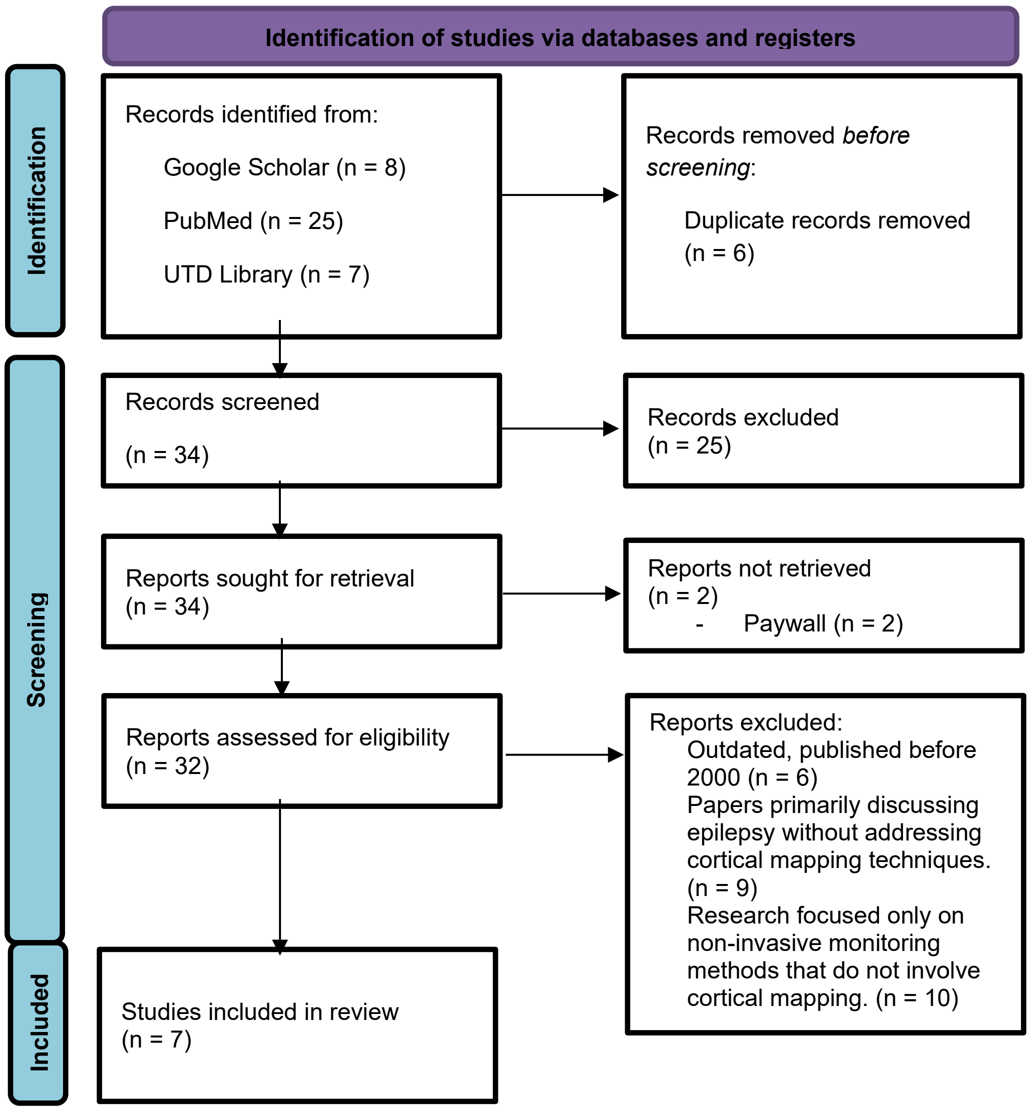

Table 4. PRISMA flow chart.

Literature Analysis

Ikeda et al. emphasized the importance of implanting a subdural electrode during presurgical evaluation to identify and target epileptogenic zones, as well as to establish eloquent cortices that are located at or near the epileptogenic zone. Single-pulse electrical cortical stimulation, in tandem with high-frequency cortical electrical stimulation, is an effective method for recording motor potentials and mapping out primary and premotor cortices, particularly in the context of slow cortical potentials known as the bereitschaftspotential (BP), which are involved in voluntary motor movements. BP offers a significantly safer clinical benefit compared to high-frequency stimulation, as it is a safe and more versatile method for identifying primary and supplementary motor areas, with a lower likelihood of invoking seizures [1]. This involves a technique for eliciting motor evoked potentials (MEPs) to map primary motor and premotor cortices. Ikeda and the authors also noted that the difference between high-frequency stimulation and single-pulse electrical cortical stimulation lies in the latter's ability to reveal excitatory and inhibitory mechanisms, offering more insight into silent periods and epileptic adverse motor events.

Research also investigates awake craniotomy (AC) with direct electrical stimulation (DES) in patients with drug-resistant epilepsy caused by focal cortical dysplasia (FCD) affecting eloquent brain areas. Minkin and colleagues sought to determine whether awake surgery can enhance the accuracy of functional mapping to identify epileptogenic zones and minimize postoperative deficits. Note that AC was done by the asleep-awake-asleep method [5]. The paper consisted of a retrospective analysis of 95 patients who underwent surgery for FCD between 2009 and 2018. Among the patients with AC and DES, language mapping was the primary indication in 71% of cases. [5]. Intraoperative brain mapping altered the surgical resection plan in 6 of 14 awake patients (43%) based on real-time feedback regarding functional areas [5]. Minkin found no significant difference in seizure outcomes across groups. AC & DES achieved Engel Class I seizure freedom in 71.4% of cases. At the same time, transient neurologic deficits were more common in the AC and GA with IONM groups; no patients experienced permanent deficits. Intraoperative seizures occurred in 29% of AC patients but were manageable with cold saline irrigation [5].

Lehtinen et al. conducted a comparative study between navigated transcranial magnetic stimulation (nTMS) and extraoperative direct cortical stimulation (DCS) for pre-surgical language mapping in epilepsy patients, including a majority of pediatric cases [3]. The results showed that nTMS had a sensitivity of 68% and specificity of 76% compared to DCS in a cohort of 20 patients. While nTMS was less specific and had a lower positive predictive value, its high negative predictive value and noninvasive nature make it a valuable screening tool. Significantly, no seizures were induced during nTMS sessions, supporting its safety even in pediatric and cognitively impaired populations. This study examines the application of navigated transcranial magnetic stimulation (nTMS) for preoperative language mapping in patients undergoing epilepsy surgery, encompassing both children and adults. The authors compared nTMS language mapping with the gold standard method of direct cortical stimulation (DCS) in 20 patients. The study also found that age, location of the ictal-onset zone, and severity of cognitive deficits did not significantly affect the validity of nTMS mapping [3]. Significantly, no seizures were induced by nTMS in any of the patients [3]. The results also provide substantial evidence for the clinical utility and safety of nTMS in epilepsy surgery patients, including children and those with cognitive dysfunction [3]. It suggests that nTMS can be a valuable tool for preoperative language mapping in this population, particularly for identifying potential language sites. However, the authors also highlight the limitations of nTMS, including its less-than-perfect sensitivity and specificity, and emphasize the need for verification of nTMS results with other methods.

Year	Author	Title	Techniques Used	Key Findings	Limitation
2002	Ikeda et al.	Cortical motor mapping in epilepsy patients: information from subdural electrodes in presurgical evaluation	High Frequency Stimulation, single-pulse electrical cortical stimulation, and the Bereitschaftspotential recording.	Established the value of a multi-modal approach, demonstrating that combining High-Frequency Stimulation (HFS), single-pulse stimulation, and Bereitschaftspotential (BP) provides more comprehensive functional data than any single technique alone.	High-frequency stimulation can induce seizures.
2024	Palao-Duarte et al.	Electrical stimulation guides an individualized surgical approach in an epilepsy-associated tumor with language representing cortex	Invasive subdural electroencephalogram (iEEG) & Electrical Stimulation Mapping (ESM)	iEEG & ESM were valuable methods in creating a highly individualized surgical plan to remove a tumor in eloquent tissue while minimizing any damage to other structures.	Potential lack of generalizability due to focus on a single case
2018	Lehtinen et al.	Language mapping with navigated transcranial magnetic stimulation in pediatric and adult patients undergoing epilepsy surgery	Navigated Transcranial Magnetic Stimulation (nTMS), Direct Cortical Stimulation (DCS)	nTMS showed substantial negative predictive value for language areas, validating its use as a noninvasive adjunct to DCS	Lower specificity and positive predictive value than DCS; not a complete replacement for invasive mapping
2017	Nowell et al.	Resection planning in extratemporal epilepsy surgery using 3D multimodality imaging and intraoperative MRI.	Stereo-EEG (SEEG), 3D Multimodal Imaging with EpiNav™, Intraoperative MRI	EpiNav™ enabled precise resection planning in non-lesional extratemporal epilepsy with confirmation via intraoperative MRI	Technical complexity and limited availability may hinder widespread adoption.
2021	Minkin et al.	Awake epilepsy surgery in patients with focal cortical dysplasia	Awake Craniotomy & Direct Electrical Stimulation	AC with DES in patients with FCD involving eloquent areas allowed real-time adjustment of surgical plans, achieved high rates of seizure control (71% Engel Class I)	A small sample size of awake craniotomy patients (n = 14) may reduce the generalizability of the findings.
2018	Okanishi et al.	Resective surgery for Double Epileptic Foci Overlapping Anterior and Posterior Language Areas: A Case of Epilepsy with Tuberous Complex	Extraoperative and intraoperative electrical cortical stimulation (ECS), stepwise resection planning.	Stepwise resection with functional mapping enabled seizure freedom and full language recovery despite overlapping with eloquent cortex.	Case Study: single patient limits generalizability to the general population
2014	de la Vaissière et al.	Cortical involvement in focal epilepsies with epileptic spasms	Intracerebral EEG (IcEEG) and the Epileptogenicity Index (EI)	Epileptic spasms in children with drug-resistant epilepsy often originate from focal cortical regions, in the temporal and frontal lobes, supporting a cortical rather than subcortical origin	Surgical efficacy may be lower due to abnormalities in epileptogenic networks

Table 5. Comparison of Modalities, Findings, and Limitations.

Nowell et al. detail a novel approach to surgical planning for nonlesional extratemporal epilepsy, which traditionally presents challenges due to the lack of clear anatomical landmarks and frequent seizure onset in deep cortical regions such as the insula and cingulate gyrus [4]. In their technical report, the authors describe EpiNav. This 3D multimodal image integration platform combines structural MRI, CT electrode localization, and stereoEEG (SEEG) data to construct a resection model guiding surgical intervention. The study involves a case of a 30-year-old male with hyperkinetic seizures and no visible MRI abnormalities. Using EpiNav™, a 3D resection model was built, excluding the eloquent cortex mapped preoperatively and including seizure onset and propagation zones defined through SEEG [4]. During surgery, the model was imported into the BrainLab iPlan neuronavigation system [BrainLab, (Munich, Germany)] and updated intraoperatively via MRI coregistration, allowing surgeons to confirm the completeness of the resection in real time. The intraoperative MRI confirmed that the resection covered the intended seizure zones while preserving critical structures [4]. This technique enhances precision and communication between the surgical and neurophysiology teams, especially in anatomically ambiguous cases, such as those demonstrated in tractography for white matter pathways, including the arcuate and uncinate fasciculi.

A case report by Okanashi et al describes a 21-year-old female with tuberous sclerosis complex (TSC) who had refractory partial seizures originating from two epileptic foci in the left hemisphere that overlapped with anterior and posterior language areas [6]. The patient underwent a comprehensive preoperative assessment, including intracranial EEG monitoring with 92 electrodes covering two cortical tubers in the inferior frontal lobe and inferior parietal lobule [6]. Intracranial video-EEG monitoring captured vital fast activities that started simultaneously but separately in frontal and parietal regions, partially overlapping the identified language areas [6]. The surgical approach involved stepwise resections, beginning from the anterior to the posterior regions, with continuous language assessment during each stage. This strategic approach allowed the surgical team to evaluate language function after each resection and adapt their strategy accordingly [6]. The patient developed transient but significant language deficits postoperatively, including expressive aphasia, comprehension deficits, left-right disorientation, and arithmetic difficulties [6]. However, language function improved dramatically within 5 weeks and completely recovered by 6 months post-surgery [6]. At 9-month follow-up, the patient remained seizure-free [6]. This case highlights the importance of comprehensive functional mapping and strategic surgical planning when epileptic foci overlap with the eloquent cortex. The results indicate that language areas may be altered in patients with epilepsy, particularly those with structural lesions, such as cortical tubers, necessitating individualized mapping rather than relying on anatomical landmarks [6]. The successful outcome demonstrates that with appropriate mapping and stepwise surgical approaches, even multiple epileptic foci overlapping language areas can be successfully treated without permanent language deficits [6].

De la Vaissière et al. investigated the cortical origins of epileptic spasms (ES) in children with pharmacoresistant epilepsy undergoing presurgical evaluation. ES was initially thought to arise from subcortical structures; however, they have recently been proposed to have focal cortical origins based on asymmetric spasms and lateralized EEG patterns. This study aims to determine whether ES can be due to specific cortical regions using Intracerebral EEG (IcEEG) and the Epileptogenicity Index (EI) [7]. De la Vaissière retrospectively reviewed 11 pediatric cases with ES who underwent depth electrode recordings between 2002 and 2012. The seizure onset zone and respective pathways were analyzed using the EI, which quantifies the epileptogenicity of brain regions based on the timing and frequency of discharges. A focal cortical origin was confirmed in 10 of the 11 patients, with maximal EI values found in temporal (n = 5), frontal (n = 4), and parietal (n = 1) lobes. Premotor cortex involvement was mainly observed during spasms, suggesting a shared final common pathway in the motor system regardless of the cortical seizure origin. Good surgical outcomes, as determined by the different Engel classes, were achieved in 7 of the 10 patients who underwent surgery [7]. The study highlights the importance of IcEEG in detecting focal origins of ES, even when traditional EEG and imaging appear inconclusive [7]. However, limitations include the study's retrospective nature and a relatively small sample size. Also, some patients had widespread or complex epileptogenic networks, which may reduce surgical efficacy. Despite these limitations, the findings support the notion that ES often result from cortical discharges and that precise localization can guide effective surgical intervention [7].

In a case study presented by Palao-Duarte et al., Electrical Stimulation Mapping (ESM) was used to guide the surgical approach for a young woman with focal epilepsy caused by a low-grade tumor located in the left posterior superior temporal gyrus, an area closely associated with language function. By applying ESM through a subdural grid, clinicians identified specific cortical language areas that overlapped with the tumor. This allowed for a highly individualized surgical plan that prioritized the preservation of language abilities. Despite being unable to remove the entire tumor or seizure onset zone, the surgical team safely resected the majority of the tumor without postoperative deterioration in language performance [2].

DISCUSSION

The literature review demonstrates the efficacy of multimodal cortical mapping techniques in the treatment of epilepsy surgery. These techniques have proven essential for maximizing seizure control while preserving neurological function. Several key themes emerged from the studies analyzed.

Efficacy of Multiple Mapping Techniques

The research highlights the complementary nature of various neurophysiological mapping approaches. Ikeda et al. established the value of combining traditional high-frequency stimulation with the bereitschaftspotential (BP) analysis and single-pulse electrical stimulation. This multi-modal approach provides comprehensive functional data that a single technique cannot offer [1]. The BP technique demonstrates explicitly that it is a safer alternative to high-frequency stimulation, significantly reducing the risk of intraoperative seizures while effectively identifying motor areas [1].

Single-pulse electrical stimulation offers unique insights into both excitatory and inhibitory mechanisms within the cortex, providing crucial information about silent periods and adverse motor events that high-frequency stimulation might miss. This multilayered approach to mapping appears especially valuable when navigating cases of anatomical ambiguity or atypical cortical organization, which are common in epilepsy patients [1].

Real-time Intraoperative Decision Making

Minkin et al.'s study on awake craniotomy highlights one of the most compelling benefits of intraoperative cortical mapping: the ability to alter surgical plans in real-time. The finding that 43% of awake cases underwent modification of the resection plan based on functional feedback underscores the dynamic nature of neurosurgical decision-making [5]. This real-time adaptability represents a significant advancement over static preoperative planning, allowing surgeons to maximize resection while receiving immediate feedback on functional boundaries.

Despite the intuitive appeal of awake procedures with direct electrical stimulation (DES), it is noteworthy that Minkin's study found no significant difference in seizure outcomes between awake and non-awake approaches. For instance, long-term seizure freedom likely depends less on the technique of mapping (awake vs. asleep) and more on factors such as the underlying pathology type (e.g., focal cortical dysplasia vs. a low-grade tumor), the completeness of the resection of the true epileptogenic zone, and careful patient selection to ensure the identified focus is the actual source of the seizures.

Paolo-Duarte et al.'s study further emphasizes the importance of real-time, task-specific mapping that directly informs surgical decision-making. The use of electrical stimulation mapping (ESM) has been found to improve outcomes in epilepsy surgery by enabling neurosurgeons to tailor resections according to individual functional anatomy [2]. Specifically, in patients with tumors or epileptogenic zones in eloquent tissue, ESM continues to serve as the gold standard for preserving quality of life postoperatively, reinforcing its indispensable role in modern epilepsy treatment strategies [2]. These findings suggest that cortical mapping via ESM is effective for delineating functional cortex and optimizing surgical outcomes by reducing the risk of cognitive deficits.

Identifying Epileptic Networks Beyond Classical Epileptogenic Zones

The utility of cortical mapping is also expanding beyond traditional epileptogenic zones to help identify complex epileptic networks. Research on epileptic spasms (ES), for instance, has challenged the view of ES as a primarily subcortical phenomenon. The use of Intracerebral EEG and the Epileptogenicity Index can now identify focal cortical origins for ES in pediatric patients [7].

This is clinically significant because it suggests the existence of shared pathways in the motor system, such as involvement of the premotor cortex, regardless of the original seizure onset zone. This insight could guide new surgical approaches that target specific nodes within an epileptic network rather than simply resecting an isolated seizure focus [7].

Challenges and Limitations

Despite the promising results, significant challenges persist in implementing cortical mapping techniques. Literature acknowledges several important limitations:

1. Technical Complexity: The accurate interpretation of cortical mapping data requires substantial expertise and experience. This creates barriers to widespread adoption, particularly in resource-limited settings.

2. Risk-Benefit Considerations: While Minkin reported manageable intraoperative seizures in 29% of awake cases, this complication rate highlights the inherent risks of stimulation-based mapping. Similarly, the invasive nature of subdural electrode placement carries risks of infection, hemorrhage, and brain swelling.

3. Mapping Beyond Motor and Sensory Functions: While mapping primary motor and sensory functions is relatively straightforward, mapping higher cognitive functions such as language remains challenging. Individual variability in functional organization further complicates the standardization process.

4. Limited Sample Sizes: As noted in de la Vaissière's work, many studies in this field have relatively small sample sizes, which limits the generalizability of findings. The retrospective nature of many studies also introduces potential selection biases.

Future Directions

The reviewed literature points to several promising directions for advancing cortical mapping in epilepsy surgery:

1. Integration of Multiple Modalities: Further research should focus on optimizing the integration of different mapping techniques to maximize information while minimizing patient risk and operative time.

2. Standardization of Protocols: Developing standardized protocols for different mapping techniques could help expand their adoption beyond specialized epilepsy centers.

3. Advanced Network Analysis: Moving beyond simple localization of function toward understanding the complex networks involved in both normal function and epileptogenesis could transform surgical planning.

4. Accessibility Improvements: Innovations that reduce the cost and complexity of cortical mapping techniques would make these valuable approaches more widely available, particularly in resource-limited settings.

5. Availability of expertly trained personnel:

The integration of cortical mapping into the surgical management of epilepsy represents a significant advancement in precision medicine. By allowing surgeons to tailor interventions based on individual functional anatomy, these techniques exemplify the move toward personalized neurosurgical approaches. As mapping technologies continue to evolve, their role in improving outcomes for patients with drug-resistant epilepsy will likely expand, potentially transforming what are currently challenging cases into surgically manageable ones.

CONCLUSION

Intraoperative multimodality neurophysiological cortical mapping plays a pivotal role in the real-time localization of epileptogenic zones and in minimizing postoperative neurological deficits. Its ability to delineate seizure foci, identify the origins of epileptic spasms, and detect Bereitschaftspotentials underscores its necessity in epilepsy surgery. As techniques evolve, cortical mapping holds promise not only for functional preservation but also for precise localization of eloquent cortex and potentially malignant tissue, particularly in cases of drug-resistant epilepsy. We strongly advocate for its integration into awake craniotomy protocols to enhance surgical precision, optimize patient outcomes, and support intraoperative decision-making. Nonetheless, further research is essential to standardize protocols, improve accessibility, and establish cortical mapping as a universally adopted gold standard in epilepsy surgery.

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