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Revolutionizing Epilepsy Care: Insights into Surgical Advancements

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ABSTRACT

Technological improvements in epilepsy surgery have substantially altered preoperative examinations, surgical methods, and prognostications. High-resolution structural imaging has revolutionized anomaly identification, enabling the discovery of minute defects. Machine learning and computer science have enhanced preoperative and outcome data analysis, leading to more accurate prediction models for tailored treatment programs. Robotically aided depth electrode insertion has made seizure networks of drug-resistant epilepsy easier to understand, allowing for secure sampling of epileptogenic nodes. While greater exploration is needed to determine the sustained efficacy of less invasive surgical procedures, they provide intriguing alternatives to ablation or disruption of epileptogenic regions. Despite these advancements, epilepsy surgery remains underutilized globally. Patients who cannot control their convulsions should be assessed as prospective surgical candidates. Collaborative efforts among academic epilepsy institutions are essential to solve longstanding challenges in epilepsy surgery, particularly in conceptualizing spatio-temporal dynamics within epileptogenic networks and their impact on surgical results. Advancements include Stereotactic Electroencephalography (SEEG), VNS, RNS, DBS, and less invasive treatments such as SEEG-guided RF-TC and LITT provide different possibilities. However, clarifying the benefits, indicatiors, and limitations of these evolving tools and concepts is vital throughout this transitional moment in epilepsy surgery's foreseeable future. Collaboration, research, and a fuller knowledge of seizure networks will be crucial in refining treatment regimens and enhancing surgical outcomes.

Keywords: epilepsy surgery; seizure; VNS; RNS; DBS.

INTRODUCTION

The persistent propensity of the brain to generate seizures is known as epilepsy; it is a disorder with social, psychological, cognitive, and neurobiological ramifications [1]. According to WHO 65 million people worldwide suffer from epilepsy, which has a significant negative impact on mortality, comorbidities, costs, stigma, and disability related to seizures. The disease's causes are still mostly unknown, providing patients and doctors conflicting information about the disease's ethology and the most effective course of treatment [2]. Over the past ten years, significant growth has been achieved in elucidating the pathophysiological mechanisms causing the illness and the variables influencing its prognosis. These developments have resulted in updated diagnostic and classification criteria, nomenclature, and operational and conceptual descriptions of epilepsy. Approximately one-third of patients are still resistant to medical treatment, despite a significant rise in the number of antiepileptic medications available during the previous 20 years. The International League against Epilepsy (ILAE) categorizes individuals who fail to respond to a carefully selected combination of two anti-seizure medications (ASMs) as "drug-resistant." This classification stems from the recognition that more than thirty percent of patients do not achieve seizure control with conventional ASMs. [3,4]

Even with the increased success of surgical procedures—over 50% of patients who undergo surgery go on to experience long-term seizure-free lives—a minuscule percentage of patients who are drug-resistant still undergo epilepsy surgery. There are still several areas in which epilepsy sufferer's lives are negatively impacted, including advocacy, education, diagnosis, and treatment, research, and advocacy gaps. Urgent action is required to surmount these concerns. Therefore, considerable emphasis is placed on the advancement of both pharmaceutical and non-pharmacological interventions through targeted research and development efforts. The primary objective is to enhance the quality of life (QoL) and alleviate symptoms for both caregivers and patients.

Recent advancements in epilepsy remedies via surgeries:

Seizures have an effect on multiple cerebral functions, including memory. Because uncontrolled seizures have the potential to progress and affect additional brain regions, their management is critical. There is currently nothing available in the market that can compete with the complete cessation of convulsions that epilepsy surgery can accomplish in certain patients. In currents years, substantial improvement has been made in the evaluation and therapy of epilepsy, enabling individuals to lead lives devoid of seizures and mitigating the negative impacts of prejudice, discrimination, and misinformation. The utilization of high-resolution structural imaging has presented an unprecedented opportunity to detect minute irregularities. Machine learning and computer science are influencing the methods for analysing preoperative and surgical outcome data, which is resulting in the creation of more accurate prediction models that can be utilized to personalize treatment plans. By enhancing safety and the ability to sample epileptogenic nodes within deep structures, robotically assisted depth electrode implantation has contributed to a greater understanding of the seizure networks involved in drug-resistant epilepsy. Although further investigation is required to find out the long-term safety of these minimally invasive surgical techniques, they do present viable surgical alternatives for the purpose of ablate or disruptepileptogenic regions. [5]

Neuromodulation for the Management of Epilepsy:

The usage of neuromodulation to treat drug-resistant epilepsy shows considerable potential. Since the early 19th century, electrical stimulation has been used to treat neurologic diseases. To treat drug-resistant epilepsy patients, neuromodulatory techniques utilizing direct or induced electrical currents have been developed with the purpose of reducing both the frequency and duration of seizures. The methods that is currently accessible, such as transcranial stimulation, DBS, RNS and VNS, and their applications, clinical recommendations, results, and hypothesized mechanisms. Despite promising outcomes observed in adults and children with drug-resistant epilepsy, several obstacles persist within the field of neuromodulatory treatments. These include the heterogeneity among epilepsy types and etiologies, challenges related to adjusting stimulation parameters, and a dearth of direct comparisons between different neuromodulatory approaches.

Implications: One of the most significant clinical domains where neuromodulation has treatment implications is epilepsy. It is a rapid developing topic in clinical neuroscience. It has the potential to be less invasive than conventional surgical methods and to provide efficacious therapy for drug-resistant convulsions

Vagusnerve stimulation:

Compared to the general population, both youth and adults experiencing uncontrolled seizures bear a significant burden characterized by elevated rates of mortality, accidents, and injuries. Furthermore, they often contend with heightened cognitive and psychological impairments, diminished self-esteem, increased levels of anxiety and despair, as well as social stigmatization or isolation [6, 7]. VNS therapy is one of the therapies (such as device therapy) that are necessary to improve overall success, as AEDs, nutritional therapy, and epilepsy surgery have not been able to meet these requirements countries, vagus nerve stimulation technique has been permitted for seizure therapy no matter ages or epilepsy type. In more than 70 nations, it is also licensed for the therapy of treatment-resistant depression. The Vagus Nerve Stimulation (VNS) therapy system comprises several components, including the pulse generator, bipolar VNS lead, programming wand with associated software designed for a handheld computer, tunnelling instrument, and portable magnets. [8,9], via the lead, the generator delivers electrical signals to the vagus nerve(Figure. 1).

The programming wand can be put over the generator to read and modify the stimulation parameters due to the software. Although there are several parameter choices, recommendations are given so that physicians can commence provides the most popular and effective settings for each generator model. Two seconds of ramp-up and two seconds of ramp-down time precede and follow each stimulation phase. Vagus Nerve Stimulation (VNS) therapy can be initiated and programmed in either an open-loop configuration, where stimulation occurs at planned intervals, or in a closed-loop mode, which may operate in conjunction with the open-loop setting. Closed-loop stimulation, found exclusively in later models, enables the device to automatically adjust stimulation levels in response to a detected heart rate increase of 20% or more.

Additionally, individuals have the option to trigger stimulation on demand using a portable magnet device.Adverse effects associated with Vagus Nerve Stimulation (VNS) therapy may encompass cough (45%), dyspnoea (16%), hoarseness (66%), and pain (17%). [10-13] There are now five distinct VNS treatment generator models available. Demi pulse versions 103 and 104 (single and dual pin) are manufactured by LivaNova USA, Inc., Houston, TX. The dual-pin generator, Model 104, is only suited for replacement procedures in patients who formerly had dual-pin lead versions.

The more modern Aspire Model 105, AspireSR Model 106, and SenTiva Model 1000 (LivaNova USA, Inc., Houston, TX) are all single pin only devices; available models varies by country. The Perennia Model 303 and Perennial Model 304 (LivaNova USA, Inc., Houston, TX) are the two leads that are presently available. The lead that is utilized virtually exclusively is the Perennialflex.

To accommodate various vagus nerve widths, all current lead versions are single pin and available in two sizes (2.0 or 3.0 mm), which correspond to the inner diameters of the helical coil. In 1986, the first preclinical evidence of VNS effectiveness was presented, demonstrating that VNS decreased the frequency of convulsions in a chimpanzee model of epilepsy. [14]

Data from animal models later corroborated these findings, demonstrating that vagal stimulation might lower seizure frequency and decrease continuing seizure activity—but not stop it. [15, 16]. Because VNS was first used in humans in 1988[17]. When compared to other neuromodulatory methods, there is a comparatively substantial amount of clinical data available. The first successful implantation was followed by numerous case reports, but the first clinical trials weren't carried out until the early 1990s [18, 19]. In which documented decreased seizure frequency following VNS in individuals with partial epilepsy unresponsive to medication.

Responsive Neurostimulation (RNS):

The fundamental concept behind RNS is that electrical currents can be applied precisely to the brain, just like in deep brain stimulation, and can only be focused if continuous epileptiform activity is detected. The electrocorticogram recording electrodes and activation electrodes are combined in this basic arrangementalong with a circuit design that allows stimulation to be initiated in response to convulsive activity detection, which is based on predetermined thresholding parameters. Instead of being administered continuously, this electrographic-stimulation loop is activated by endogenous activity patterns, requiring no human intervention beyond the initial setup. In essence, this closed-loop system can be likened to an automated defibrillator, which, upon activation, records electrocardiographic data and administers a shock only when the patient is in an appropriate phase of the cardiac cycle. In fact, fundamental concept behind closed-loop neurostimulation is that seizures can be precisely stopped during a seizure by applying high currents that are strong enough to interfere with continuing network activity. It is generally not simple to compare stimulation parameters because each patient's clinician defines the thresholds and parameters based on the patient's electrocorticogram data. As of right now, the FDA has only approved one device—the RNS System from Neuro Pace in Mountain View, California—for use in treating epilepsy. The device is designed so that, even though up tofour electrodes are implanted, only two of them are activated for stimulating at any one moment. Electrodes, including depth electrodes for recording and stimulation, are surgically inserted. Subsequent to implantation, a recording period ensues during which seizure detection parameters and thresholds, typically predicated on band-pass power thresholds, are established empirically. Generally, the stimulation is well tolerated, with rare instances reporting discomfort when implantation is conducted in eloquent cortex regions, resulting in symptoms such as dysesthesia, paraesthesia, photopsia, and muscle trembling. While Responsive Neurostimulation (RNS) is FDA-approved exclusively for adults, anecdotal evidence from case reports suggests its potential safety for children less than 18 years through off-label use. [20-24]

RNS is a very promising therapeutic approach; However, there are still a number of unanswered problems and areas that may be improved. To start, there is no agreement on the best method to enhance automated seizure detection. It appears that recent attempts to enhance automated seizure detection are promising [25, 26] they are crucial because, in principle, more precise and quice recognition of seizures may result to more precise application of stimulation. The fact that ideal stimulation parameters are still unknown is possibly even more significant.

Deep Brain Stimulation:

The stimulating electrode in deep brain stimulation (DBS) is placed deep within brain tissue, frequently inside a suspected node of the epileptic network as shown in (fig. 2), setting it apart from other types of neuromodulations [27]. The aim is to produce a lesion of a seizure node that is functional and reversible so that it can influence the dynamics of the network and stop seizures from starting or spreading. Similar to the previously discussed systems, a subcutaneously implanted pulse generator is coupled to an implanted stimulation electrode inside the target area In Deep Brain Stimulation (DBS) for epilepsy, two electrodes are surgically inserted into the thalamic anterior nucleus with the aid of stereotactic guidance. These electrodes are then affixed to the cranium to ensure stability and proper positioning.A cable is routed through a subcutaneously implanted generator, facilitating the delivery of high-frequency open-loop stimulation programmed to occur intermittently as planned. Bilateral stimulation is imperative for achieving anticonvulsant effectiveness. In a sham-controlled trial, the observed reduction in seizures attributed to Deep Brain Stimulation (DBS) was determined to stem from neurostimulation rather than an insertional effect. DBS was shown to decrease seizure frequency in individuals with intractable epilepsy who had not responded to prior interventions such as Vagus Nerve Stimulation (VNS) or epilepsy surgery. Potential problems include implant site the infection (12.7% or 30.9%), mispositioning of leads (8.2%), and sensations of paranesthesia (23.6%).

A notable difference between Deep Brain Stimulation (DBS) and Responsive Neurostimulation (RNS) lies in their stimulation methodologies explained in (Table1) DBS employs predetermined stimulation parameters (open-loop), although closed-loop systems are theoretically feasible. Stimulation parameters in DBS may vary and are adjustable by the physician to optimize therapeutic efficacy. Small thalamic lesions was also proposed to raise the seizure threshold by preclinical findings in animal models. Later, it was demonstrated that ANT lesions decreased seizures in a cat model of epilepsy [29]. Similarly, in guinea pigs, injuries of the mammillothalamic tract (which sits between ANT and mammillary bodies) halted convulsions [30].

Transcranial Stimulation (TMS and TCS):

Usage of direct or induced electrical current is used in transcranial Neuromodulatory procedures (TMS and TCS) to modify network dynamics and lessen seizure burden. While TACS, is a procedure that employs an alternating current, it is also becoming more and more popular (described in the "Future Strategies" section). Traditionally, TCS employs direct current stimulation. The most apparent advantage of these methods is that they are non-invasive, meaning there are no associated dangers (such bleeding or infection) because they do not involve surgical procedures.

Furthermore, because they have a much lower barrier to use than other methodologies, they may have a wider applicability. In order to produce A changing magnetic field that eventually leads to an electrical current to be induced across the brain, Transcranial Magnetic Stimulation (TMS) functions by delivering a brief but intense electrical current through a coil positioned close to the scalp [31].

Although there are many various coils that alter the magnetic field's focus and intensity, the fundamental idea is always the same. Here, we delve into the therapeutic applications of Transcranial Magnetic Stimulation (TMS), wherein repeated pulses are employed to modulate ongoing neural network activity within the magnetic field. While TMS has traditionally been utilized for diagnostic purposes, its therapeutic potential is increasingly recognized and explored.

Top of Form

Transcranial applied current has been shown in preclinical research has demonstrated promising outcomes in reducing seizures in animal models of cortical epilepsy [32]. Clinical data supporting the usage of Transcranial Magnetic Stimulation (TMS) for the treatment of epilepsy is relatively limited. A Cochrane review [33]. It has been found that, when compared to sham stimulation, three out of the seven included trials reported a positive beneficial effect of Transcranial Magnetic Stimulation (TMS) on seizure rate, while four trials did not observe such effects.

Transcranial focal electrical stimulation utilizing concentric ring:

Techniques for electrical stimulation, such as the well-known extracranial neurostimulation of vagus nerve stimulation [34]. DBS, which have demonstrated beneficial results in people [35]. Nevertheless, these treatments have been linked to negative side effects [36, 37]. A thorough literature review found that VNS caused local inflammation, unbearable persistent cough, hoarseness variable degrees of vagus nerve injury and throat discomfort have been reported as potential adverse effects of Vagus Nerve Stimulation (VNS), whereas Deep Brain Stimulation (DBS) targeting the anterior nucleus of the thalamus has been associated with complications such as infection, intracranial hemorrhage, depression, and memory impairment. Treatments involving non-invasive stimulation have been devised to influence a number of brain conditions, including epilepsy.

Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (tDCS) are two techniques that have shown promise in the management of epilepsy to have positive long-term impacts on epilepsy patients' ability to manage their seizures [38, 39] as well as in temporal lobe epilepsy experimental animal models [40, 41].

One non-invasive experimental paradigm for treating Pharmacoresistant epilepsy is the use of TCRE for transcranial focal electrical stimulation (TFS). Compared to traditional disc electrodes, the TCRE, which are used in this electrical stimulation treatment, offer a more consistent current density [42] and concentrate the electrical stimulation so that it is directly beneath the electrode, causing even subcortical regions to induce electric fields [43] without damaging the rat's skin surface or mental faculties [44,45]. TFS has proven effective in reducing seizure frequency in rodents with mild epilepsy models, including those treated with penicillin and Tetrazole. Applying TFS following SE resulted in an increase in the rodents' survival rate as well as electrographic alterations. Furthermore, a decrease in the well-coordinated brain activity in the beta and gamma bands was seen, indicating a protracted impact of TFS on brain activity.

While equipment and costs for electrical stimulation approaches are available, a comprehensive analysis of the consequences of time-targeted electrical disturbance of epileptic episodes in animal trials is necessary. Crucially, the preponderance of research has not gone beyond the treatment's immediate effects. Comprehending the enduring impact of a stimulation paradigm is crucial, since most patients have a chronic epileptic process.[46]

SEEG-guided radiofrequency thermocoagulation among patients experiencing focal epilepsy-

Stereotactic lesioning has become increasingly significant as a surgical treatment option for focal epilepsy, particularly serving as an alternative to conventional surgery in cases such as mesial temporal lobe epilepsy or when focal lesions are not suitable for surgical resection, such as periventricular nodular heterotopias. Various stereotactic techniques have been developed over the years, including laser interstitial thermotherapy (LiTT), radiosurgery, high-intensity focal ultrasound (HIFU), and stereo-electroencephalography-guided radiofrequency-thermocoagulation (SEEG-guided RF-TC).

SEEG-guided RF-TC involves coupling stereotactic lesioning with intracranial EEG monitoring through common electrodes, allowing for the selective lesioning of specific volumes targeting the seizure-onset zone. Additionally, this approach may reduce the risk of surgical complications by minimizing the frequency of invasive stereotactic procedures. However, despite promising results, seizure outcomes with SEEG-guided RF-TC remain uncertain, with seizure-freedom rates ranging from 4% to 71% across studies.

Top of Form

These two elements of stereotaxy gave rise to the idea of SEEG-guided RF-TC:

•documenting;

•lesioning.

This novel technique of guiding RF-TC was first presented in 2004 utilizing stereo electroencephalographic (SEEG) measurements of ictal activity. There are numerous benefits to this method [47].

• The electrodes utilized to perform thermocoagulation are those implanted for Stereo-Electroencephalography (SEEG), thereby mitigating the surgical risk associated specifically with electrode implantation. Therefore, conducting thermo-SEEG does not inherently increase the surgical risk related to electrode implantation.

• During thermo-SEEG, it's possible to create multiple lesions between the contacts of the SEEG electrodes

• Thermocoagulation can be directed towards the area where seizures start, as identified by SEEG recordings.

• The procedure doesn't need anesthesia.

• Performing thermo-SEEG before functional mapping with cortical stimulation can prevent the development of a neurological deficit after the procedure. To do a SEEG-guided RF-TC, an inpatient SEEG that is not eligible for the corresponding surgery can be performed. The foundation of bipolar RF-TC is the propagation of an RF current among a dipole's two poles. As a result, the electric field (E-field) between these two poles oscillates at each point, forcing the charged ions in the electrolyte adjacent to move at the same rate and generating an ionic oscillation current known as j. The frictional heating of the tissue brought on by the J-field induces RFTC. The J-field is directly related to both power deposition and temperature elevation [48, 49]. The literature contains both in vitro and in vivo findings on humans and the animals [50, 51, 52], give proof that employing a SEEG electrode to conduct bipolar RF-TC is a safe operation.

Experiments on animals both in vivo and in vitro demonstrated that even over extended periods of time, larger lesions are produced by varying the intensity and voltage of the supplied current until these parameters quickly collapse (equivalent to a rapid alteration of impedances). A abrupt change in the impedance's value, if it can be monitored directly, signifies the occurrence of coagulation. It is noteworthy that the coagulation may be perceptible to the patient or the neurosurgeon prior to attaining its maximal dimension, underscoring the need of concentrating on the impedance. In fact, the patient should be informed in advance of this prospective symptom of hearing the coagulation phase noise. This method has been contrasted with the first empirical procedure's parameters (50 V; 120 mA, yielding a power of 6 W) [53]. It performs better in terms of size optimization and reproducibility. This is a significant finding establishing the efficacy of the SEEG-guided RF-TC treatments since it indicates that lesions of this size cannot be inadvertently created. Bipolar lesions generated in vitro under these ideal conditions are linked to temperatures of 78–82 ◦C.

Subdural grid and depth electrode surveillance in juvenile patients –

A fundamental component of epilepsy surgery is now intrusive electroencephalographic surveillance with implantable subdural and intraparenchymal depth electrodes are used for brain monitoring and stimulation. For many individuals, the additional operation and monitoring time are justified due to enhanced localization of epileptic foci. When combined with imaging and functional investigations, informed use of intrusive monitoring results in a smaller, safer, and more successful procedure for epilepsy surgery.

Surgical Planning and Indications before proceeding with a stage two invasive monitoring procedure, it's important to ensure several criteria are met: documented medical intractability, significant impact of seizures on quality of life, potential for seizure reduction with resection, and patient's readiness for multiple intracranial surgeries. Due to the possibility of lead displacement, violent or aggressive patients were traditionally not suitable candidates for extra operative monitoring. With proper lead security during surgery and the administration of intravenous dexmedetomidine, many children previously deemed ineligible for evaluation can now be assessed. Practitioners should be told that the expense of the extra operative monitoring alone can vary from $77,000 to $130,000, even though it is not right now emphasized in the making decision process.

Available Implants-

Subdural/surface- The use of subdural grid (SG) electrodes significantly enhances the amount of data that can be collected via scalp electrodes. This enhancement is achieved through improved signal sensitivity, reduced noise, and better spatial resolution.

Grid conductors

SG electrodes come in a range of designs, but they generally have a single multicontact lead with platinum contacts placed in a thin silastic rectangle. Ever since iatrogenic prion cases were documented in the 1970s, discard leads have been the norm [54]. Grid arrangements can span extensive sections of cortex, and they are particularly well-suited to convexity locations, which makes them perfect for desired motor or language mapping. In order to correctly suit the grids, subdural grid electrodes typically enablesthe meticulous cutting of individual lead paddles from the array's edge. Notifying the neurophysiologists of these modifications and testing the new array's impedance values are crucial.

Strip circuits

The unique subset of SG electrodes known as subdural strip electrodes (SSEs) are identified by the presence of just one or two electrode connections in their width. These flexible narrow arrays can be positioned at the margins of a skull reconstruction or independently by a minuscule trepanation since they can be securely traversed in the subdural area without direct visibility. Mesial temporal, orbitofrontal, and interhemispheric cortices are particularly receptive to covering. Patients with inconsistent or bilateral nonsurgical localization, but with a presumed hypothesis and focal seizure semiology, are frequently candidates for SSE installation. In this case, trepanations are positioned bilaterally over the appropriate lobes, and if a frontal origin is postulated, they are also sometimes put in the frontal parasagittal region.

Depth sensors

Intracerebral Depth electrodes-

Single-lead, thin (0.8–1.3 mm) cylindrical multicontact probes with stereotactic guidance that may be implanted towards subcortical regions. The epileptogenic zone can be represented in three dimensions (3D) with DEs, and subcortical areas that are not accessible by surgery can be studied. They can also be employed in perilesional recordings, and they are frequently used to target deep areas such the orbito frontal cortex, the cingulum, and mesial temporal structures.

Foramen ovale

Transcutaneous FO electrodes can be built to order and come in configuration of an acupressure needle or a typical short (four-contact) electrode [55-57]

FO electrodes don't need a craniotomy—in fact, using one is not recommended. When scalp data are equivocal in situation of putative mesial temporal epilepsy, larger amplitude mesial electrocorticography may reveal the presence of an early epileptogenic focus or lateralization. In these instances, FO electrodes can be employed. As gathering data will be utilized to either proceed forward with surgery or rule it out, cases are well chosen for FO placement. Furthermore, this method might also be useful for organizing SG or DE processes. There is some debate about this approach, and a number of studies contend that there is little to no advantage to using it instead of cranial electrode recordings.

Implantation Technique-

Subdural/surface

Subdural grid conductors

A few guiding principles can be used to guide the positioning of SG electrodes, which may be done in many different methods:

1. Organizing a large enough craniotomy to fit grids over the intended area of assumed epileptogenesis and allow for the collection of exploratory electrocorticography (ECoG) data.

Important Points

• It is safe and efficient to utilize grid and depth electrodes sparingly.

• Patient selection for SDE monitoring and careful surgical procedures can reduce risk.

• Utilizing extra-operative monitoring and functional mapping enhances the effectiveness and efficiency of reconstructive surgery by accurately pinpointing seizure foci.

2 Securing the grid lead in the event of potentially uncontrolled seizures in order to protect patients and guarantee precise long-term localization.
3 Taking into consideration a method to account for Oedema, fluid buildup, and the mass effect from grids. Because of this, some surgeons support the use of duraplasty, hinged craniotomy, or craniectomy, and subgaleal drainage.

Depth sensors

DEs can be implanted using either an orthogonal or parasagittal technique. Although parasagittal implantation, also known as the occipital technique, usually necessitates a lengthier electrode insertion distance into the brain, it can circumvent the need to slice the Sylvian fissure for insular recording and is advantageous for monitoring along the hippocampus's axis. In most cases, orthogonal electrode insertion minimizes the distance required to reach the target, permits multilobar coverage, and functions well in tandem with systems that also aim to provide grid coverage. In some circumstances, oblique placement is an option that could be a reasonable trade-off between approach and geographical coverage.

All the varieties of electrodes are explained in a tabular form table no.2

Intracranial EEG monitoring has evolved from subdural to depth electrodes.

Compared to after SE implantation, patients with DE experience less discomfort and fewer migraines following surgery. After a SEEG, cerebral spinal fluid leakage is hardly ever observed. Last but not least, SEEG's mean operating time is 30 minutes shorter. We have become habituated to three-dimensional thinking in stereo electroencephalography over time and have come to value the prospect of delving into deeper structures like the insula or deeply positioned neuronal heterotopic gray matter. "DE" is a misnomer because DE actually comprise both deep and superficial cortical regions.

Subdural implanters have evolved into a more network-based epileptologist, emphasizing semiology in devising "punctuate" DE for SEEG, which actually takes fewer brain samples. Using these guidelines and increased knowledge of during extra operative cortical stimulation, SE is no longer considered more effective than DE in identifying areas of eloquent cortex. High-resolution extra operative cortex stimulation may be required in specific cases, such as in extremely young patients or individuals who cannot undergo magnetic resonance imaging for presurgical planning, still employ SE and grids and will continue to do so in the future. The arsenal of presurgical invasive diagnostic instruments keeps expanding as new imaging technologies are introduced. To precisely identify the seizure focal, a thoughtful combination of novel and old invasive intracranial monitoring techniques, or both, is still required [58]

Comparison of Subdural Grids v/s Stereo-EEG: Morbidity and Outcomes:

To pinpoint the epileptogenic zone, intracranial electroencephalographic (EEG) recordings are required [59-61] for epilepsy surgery, between 30 and 50 percent of candidates [62, 63]. In North America, the UK, and Germany, the primary procedure for intracranial EEG recordings has been the implantation of subdural electrodes (SDEs) by a craniotomy.[64-71]

Alternatively, the French, [72,73] Brazilian and Italian [74] the Talairach stereo electroencephalographic (SEEG) method is used to evaluate epilepsy [75,76], in which desired objectives are attained by inserting depth electrodes into the brain without the need for a craniotomy [77-79] SEEG is most suited to capture electrical activity from sulci and deep brain regions, as well as when bilateral assessments are required [80] for more than 50 years, both methodologies had coexisted in isolation from one another, operating in parallel until the introduction of SEEG in North America recently [81] a development predominantly fueled by the accessibility of 3-dimensional (3D) navigational platforms for stereotactic robots[82,83]. While there are distinct advantages to both SDE and SEEG procedures, both can be used for most patients who require intracranial EEG, however bilateral SDE implantations are more problematic. Recent years have seen an increase in evidence suggesting that SEEG procedures are safer than SDE surgeries. After SDE implantations, the documented incidence of problems varies from 5% to 17% for each surgery. As to a recent large-scale meta-analysis, the complication rate per the incidence of SEEG surgery is less than 1%. The negative effects of these procedures hinder the main objective of enhancing the quality of life for patients with medically untreatable epilepsy and lead to the limited use of epilepsy surgery, as intracranial monitoring is a diagnostic method used to assess eligibility for surgery and the areas to be operated on. In North America in particular, the gold standard for delineating epileptogenic zones has been the implantation of SDEs; however, SEEG methods are gaining traction[84].Precisemapping of brain surfaces in relation to epileptogenic zones is made possible by the implantation of SDEs. On the other hand, SEEG has an advantage in bilateral explorations and deep lesion sampling because to its enhanced coverage and accurate targeting of deeper structures. Furthermore, improved outcomes for individuals with difficult-to-localize epilepsy may be attributed to the Stereo encephalography method's capacity to plot diffuse epileptic networks engaged in epileptic activity. Patients were more tolerant of the technique than they were for subdural electrode placement, and patients who experienced LITT or resection following Stereo encephalography generally had better results. This study quantifies both of these sensations through an extensive cohort of individuals undergoing intracranial electroencephalography investigation. The accessibility of surgical robotics, including the Neuro Mate and ROSA [85], permits the installation of depth electrodes for SEEG with a combination of efficiency and accuracy. With the latest and continuing developments in robotic surgical support. When compared to SEEG, the implantation of SDEs is also linked to a higher requirement for blood products. Additionally, the SEEG cases required much less medication (P <.001), which lessens the likelihood of downstream side effects like nausea, constipation, sleeplessness, and respiratory depression.

In general, the SEEG technique is much more tolerated than SDEs and is linked to decreased rates of complications and a decrease in the usage of analgesics for pain management.

The passage emphasizes the shift from Subdural Electrodes (SDE) to Stereoencephalography (SEEG) as a preferred technique [86-88] for localizing epileptogenic zones in epilepsy patients. While SDEs have historically been the criterion standard, SEEG techniques are gaining prominence [89] due to their ability to provide precise functional mapping [90], particularly in deep brain structures[91- 95].The adoption of surgical robots like ROSA and NeuroMate has significantly reduced the time required for SEEG electrode placement compared to SDE, enhancing both accuracy and efficiency [96].Patients undergoing SEEG exhibit greater tolerance, and subsequent surgical outcomes, such as resection or laser interstitial thermal therapy, tend to be more favourable. Additionally, SEEG is associated with lower complication rates, diminished narcotic use, and a decreased risk of haemorrhage compared to SDE placement.[97] The passage suggests that these advantages should make SEEG a more accessible and preferred [98-100] option for surgical candidacy in cases of intractable epilepsy, contesting the historical dominance of SDE as the standard technique.

The safety of Stereo encephalography and Subdural Electrodes approaches has been a subject of extended controversy, [101,102] possibly exacerbated by perceptions of unfamiliarity with either method. Despite numerous observational studies [103-109] reporting on the security aspects of both Stereo encephalography and Subdural Electrodes, direct comparisons are limited, likely due to centre preferences in using one technique predominantly. Most recent meta-analyses independently evaluated the rates of complications associated with SEEG and SDE implantation reveal that both methods exhibit low complication rates, casting light on the comparable safety profiles of these two techniques.

Observational studies comparing seizure freedom rates following respective epilepsy surgery guided by Stereo encephalography or Subdural Electrodes [110-114] show no definitive superiority between the two techniques. Large cohort studies reveal SEEG achieving seizure freedom [115-122] in 56-68% of 411 patients, while SDE ranges from 30-70% in 804 patients. SEEG offers benefits such as decreased perioperative discomfort, shorter recovery time, and safer reoperations compared to SDE. However, further direct comparative studies are needed to determine superiority in specific clinical situations [123-126]. Robotic assistance with SEEG has shown potential in decreasing operative time and enhancing surgical outcomes.

Conclusion

Neuromodulation procedures such as VNS and DBS offer promise in epilepsy treatment by directly influencing aberrant neural pathways. However, further research is necessary to optimize their application and patient selection. Understanding the underlying circuitry of epilepsy is crucial to identify which patients will benefit from specific interventions[127-130]. Presently, these methods are mostly utilized by individuals failing medication or unsuitable for surgery, with variable levels of response. Gathering more clinical data is essential to tailor remedies and refine strategies based on individual patient characteristics. Continuous research is pivotal to enhance these methods and their application pathways. Responsive cortical stimulation displays potential in reducing disabling partial seizures, improving quality of life, and being well-tolerated without altering mood or cognition. It emerges as a potential additional treatment for adults facing medically resistant partial seizures. SEEG -guided RF-TC offers promise in managing intricate epileptic networks when conventional surgery isn't an option [131-134]. Although it may temporarily ameliorate seizures and restore medication responses, repeated procedures using new data can further disrupt the network. Its favourable risk-benefit ratio suggests contemplating it for high-risk surgery cases or as a predictive test before traditional surgery. Progress in neurosurgical techniques, like image-guided and robotic placement of depth electrodes for 3D corticography, allows for enhanced pinpointing of seizure sources. Implantable converters might mitigate risks linked to external wire leads, facilitating extended wireless EEG monitoring at home. Non-invasive alternatives with refined source localization methods seek to precisely pinpoint seizure origins. Ensuring equitable access to technologies like ECoG and epilepsy surgery is crucial for future advancements. The transition to stereotactic ally implanted depth electrodes in drug-resistant epilepsy investigations derived from enhanced techniques, reduced risks, patient comfort, shorter procedures, and identifying previously inaccessible surgical targets. It's imperative to define the advantages, usage criteria, and limitations of these advancing technologies during this transformative phase in epilepsy surgery. Collaboration, research, and deeper comprehension of seizure networks are fundamental to optimizing treatment approaches and surgical outcomes.

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