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Current state of the art of traditional and minimal invasive epilepsy surgery approaches

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ABSTRACT

Introduction: Open resective surgery remains the main treatment modality for refractory epilepsy, but is often considered a last resort option due to its invasiveness.
Research question: This manuscript aims to provide an overview on traditional as well as minimally invasive surgical approaches in modern state of the art epilepsy surgery.
Materials and methods: This narrative review addresses both historical and contemporary as well as minimal invasive surgical approaches in epilepsy surgery. Peer-reviewed published articles were retrieved from PubMed and Scopus. Only articles written in English were considered for this work. A range of traditional and minimally invasive surgical approaches in epilepsy surgery were examined, and their respective advantages and disadvantages have been summarized.
Results: The following approaches and techniques are discussed: minimally invasive diagnostics in epilepsy surgery, anterior temporal lobectomy, functional temporal lobectomy, selective amygdalohippocampectomy through a transsylvian, transcortical, or subtemporal approach, insulo-opercular corticectomies compared to laser interstitial thermal therapy, radiofrequency thermocoagulation, stereotactic radiosurgery, neuromodulation, high intensity focused ultrasound, and disconnection surgery including callosotomy, hemispherotomy, and subpial transections.
Discussion and conclusion: Understanding the benefits and disadvantages of different surgical approaches and strategies in traditional and minimal invasive epilepsy surgery might improve the surgical decision tree, as not all procedures are appropriate for all patients.

1. Introduction

Surgical techniques and approaches in epilepsy surgery have been extensively discussed over the last several decades. However, procedures to achieve favorable outcomes can vary, depending on pathology, location, and even surgeons' preferences (Dorfer et al., 2020). Resective surgery remains the primary traditional treatment modality for refractory epilepsy (Herta and Dorfer, 2019). In recent decades, a trend has emerged to shift from large open surgeries to minimally invasive surgical techniques. This change is driven by progress in diagnostic and curative therapeutic modalities, as well as technological innovations that target epileptogenic zones. Epileptogenic zones are defined as

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regions capable of generating seizures and the removal or disconnection of which leads to seizure freedom (Dorfer et al., 2020; Herta and Dorfer, 2019). Seizure freedom is one of the major predictive factors for the quality of life of these patients. Previously published trials report 60–80 % seizure freedom after 1–2 years and approximately 50 % after ten years following anterior temporal lobectomy for epilepsy caused by mesial temporal sclerosis (Chang et al., 2015; Englot et al., 2013; Wiebe et al., 2001; Jeha et al., 2006; Vadera et al., 2012).

However, considerable variations in clinical practice patterns to achieve favorable outcomes exist, even though surgery remains an underutilized treatment option. This manuscript aims to provide a state of the art overview of traditional and minimally invasive surgical approaches in epilepsy surgery.

2. Method

This narrative review synthesizes both historical and contemporary surgical approaches in epilepsy surgery. Peer-reviewed published articles were retrieved from PubMed and Scopus. Only articles written in English were considered. A range of minimally invasive surgical approaches in epilepsy surgery were examined, and their respective advantages and disadvantages have been summarized.

3. Results

In this overview, the following approaches and techniques are discussed: minimally invasive diagnostics in epilepsy surgery, anterior temporal lobectomy, functional temporal lobectomy, selective amygdalohippocampectomy through transsylvian, transcortical, or subtemporal approaches, insulo-opercular cortectomies, laser interstitial thermal therapy, radiofrequency thermocoagulation, stereotactic radiosurgery, neuromodulation, high-intensity focused ultrasound, and disconnection surgery, which encompasses callosotomy, hemispherotomy, and subpial transections. Table 1 summarizes landmark papers for various approaches (Table 1). Table 2 classifies and summarizes epilepsy surgery techniques (Table 2). Diagram 1 illustrates the number of publications retrieved for each technique (Diagram 1).

Table 1
Landmark papers in epilepsy surgery.

Year	Authors	Procedure
1886	Horsley	Cortical resection in posttraumatic epilepsy
1928	Dandy	Hemispherotomy in glioma surgery
1935	Foerster and Altenburger	First use of electrodes for invasive monitoring
1938	McKenzie	Hemispherotomy in epilepsy surgery
1940	Van Wagenen and Herren	Callosotomy
1942	Lynn et al.	High intensity focused ultrasound
1958	Niemeyer et al.	transventricular amygdala-hippocampectomy
1962	Talairach and Bancaud	Functional stereotaxic exploration of epilepsy
1974	Rasmussen	Functional hemispherotomy
1977	Wilson et al.	Anterior two-thirds callosotomy
1978	Heppner	Laser interstitial thermal therapy
1980	Cooper et al.	Deep brain stimulation targeting the anterior nuclei
1981	Lesser et al.	Subdural electrodes for cortical mapping of speech
1982	Levy et al.	Cortical electrode array for seizure investigation
1989	Morrell et al.	Subpial transections disconnecting neocortical eloquent epileptogenic zones
1999	Hori et al.	Subtemporal approach
2000	Olivier et al.	Transcortical approach through a middle cranial fossa craniotomy
2004	Guenot et al.	SEEG-guided RF-TC
2006	Shimizu et al.	Multiple hippocampal transection
2008	Duckworth et al.	Approach through the inferior temporal lobe
2010	Yasargil et al.	Transsylvian approach avoiding the lateral temporal lobe
2012	Türe et al.	Paramedian supracerebellar-transtentorial

Table 2
Overview of included approaches.

Approach	Year	Procedure
Temporal	1958	transventricular amygdala-hippocampectomy
	1999	Subtemporal approach
	2000	Transcortical approach through a middle cranial fossa craniotomy
	2012	Paramedian supracerebellar-transtentorial
Extratemporal	1886	Cortical resection in posttraumatic epilepsy
	1989	Subpial transections disconnecting neocortical eloquent epileptogenic zones
Hemispheric	1928	Hemispherotomy in glioma surgery
	1938	Hemispherotomy in epilepsy surgery
	1940	Callosotomy
	1974	Functional hemispherotomy
	1977	Anterior two-thirds callosotomy
	1981	Subdural electrodes for cortical mapping of speech
	1982	Cortical electrode array for seizure investigation
Non-resective	1942	High intensity focused ultrasound
	1978	Laser interstitial thermal therapy
	1980	Deep brain stimulation targeting the anterior nuclei
	2004	SEEG-guided RF-TC
Diagnostic	1935	First use of electrodes for invasive monitoring
	1962	Functional stereotaxic exploration of epilepsy
	1981	Subdural electrodes for cortical mapping of speech
	1982	Cortical electrode array for seizure investigation

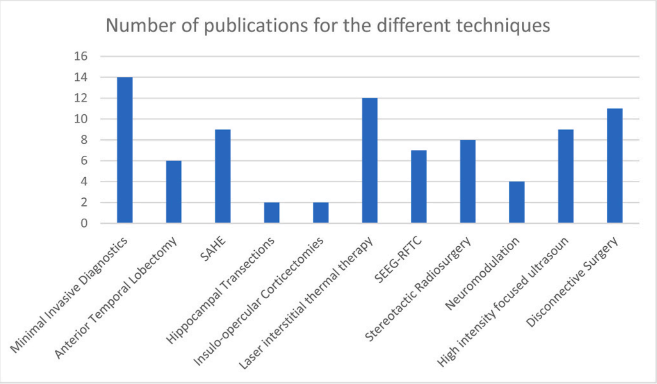

Diagram 1. Number of publications for the different techniques included in this report. SAHE (Selective Amygdalohippocampectomy); SEEG-RFTC (Stereoelectroencephalography guided radiofrequency thermocoagulation).

4. Discussion

Quality standards in epilepsy surgery are exceptionally high, as these procedures are elective. Optimal postoperative outcomes can only be achieved through precise diagnostics that enable accurate delineation of the epileptogenic zone (Rosenow et al., 2016; Shan et al., 2021). However, a tailored, patient-specific approach depends on both the location and nature of the pathology. Consequently, minimally invasive techniques have been developed to target specific epileptogenic zones avoiding complications from eloquent brain areas, especially from the approach but also from adjacent areas. While most epileptogenic zones are associated with pathologies visible on magnetic resonance imaging (MRI), others are MRI negative without a clear focus and thus necessitate further diagnostic measures including non-invasive and invasive modalities (Kunieda et al., 2012; Swaminathan, 2021).

4.1. Diagnostical surgical techniques

Over the past years, diagnostic methods have been refined to better identify epileptogenic zones (Herta and Dorfer, 2019; Milovanović et al., 2020). Subdural electrode (SDE) placement and intracerebral depth electrode placement, as well as stereoelectroencephalography (sEEG) recordings, have coexisted for decades, with preferences for each method largely dependent on traditional local practice or geographic location. Reports from Canada, France, and Italy have shown a preference for stereoelectroencephalography diagnostics, while centers in Germany, Austria, the United Kingdom, and the United States of America have favored subdural electrodes (Dorfer et al., 2020; Bauman et al., 2005; Lüders et al., 1992; Van Gompel et al., 2008; Cardinale et al., 2013).

Recently, an increasing number of centers worldwide have begun to prefer invasive stereoelectroencephalography using depth electrodes, with centers that primarily used subdural electrodes also adopting this latter technique for most patients (De Barros et al., 2020). This shift can be attributed not only to the relatively higher morbidity and complication rates associated with subdural grid placement compared to minimal invasive depth electrodes placement, as well as to the emergence of innovations, including a wide range of navigational applications (Dorfer et al., 2014, 2020; Vakharia et al., 2017).

Robotics in neurosurgery strive to enhance the accuracy and surgical workflow for implanting depth electrodes (Wang et al., 2022). Over recent years, numerous robotic devices have been described. The latest automated machine introduced is a cold ablation robotic-guided laser osteotome utilizing Er:YAG laser technology. However, to date, this device has not yet been tested in human trials (Roessler et al., 2021). A recent meta-analysis encompassing frameless, frame-based, and robotic systems determined that robotic systems were at least non-inferior to traditional frame-based systems and superior to frameless systems (Dorfer et al., 2020; von Langsdorff et al., 2015). Accordingly, invasive monitoring followed by alternative ablation techniques that substitute for classic brain resections is on the rise (Jehi et al., 2015).

4.2. Anterior temporal lobectomy

Traditionally, temporal lobe epilepsy is the most prevalent form of drug-resistant epilepsy and, as such, is the primary focus of most resective epilepsy surgery approaches (Gross et al., 2015). The extent of anterior temporal lobe resection differs between the dominant and non-dominant hemispheres. To prevent injury to the language area of the dominant hemisphere, the resection should not extend more than 4, 5 cm posteriorly. In the non-dominant hemisphere, the posterior extent of resection can reach up to 5.5 cm. However, anatomical variations of the vein of Labbé may limit the extent of resection more strictly (Chang et al., 2015; Vadera et al., 2012; Spencer and Spencer, 1985). Complications reported after maximizing the posterior resection margin include homonymous hemianopia, resulting from injury to the optic radiation, and a decline in verbal memory at the dominant side (Chang et al., 2015; Vadera et al., 2012). Additionally, branches of the middle cerebral artery are at risk, becoming visible through the pia when the inferior insular circular sulcus appears.

Recently, neuronavigation can be employed to localize the temporal horn of the lateral ventricle. The roof of the temporal horn of the lateral ventricle serves as a reliable landmark for the superior border of mesial structures. Upon achieving this, the hippocampus, parahippocampal gyrus, and amygdala become visible. The amygdala can be removed once the posterior amygdala-hippocampal sulcus is exposed. Subsequently, the hippocampus and parahippocampal gyrus can be excised subpially. The tail of the hippocampus neighboures the brainstem, necessitating cautious subpial dissection.

Recently, Yong et al. proposed a functional anterior temporal lobectomy in a pilot study involving 25 patients (Liu et al., 2023). This approach reduced the craniotomy size to a 3 cm diameter. The tip of the temporal horn of the lateral ventricle is accessed by dissecting the superior temporal gyrus. Following this, the amygdala, parahippocampal gyrus, and hippocampus are resected en bloc. However, a controlled trial remains necessary to compare these results with the standard anterior temporal lobectomy (Liu et al., 2023). Recently, the significance of removing the piriform cortex for notably improved seizure outcomes has been emphasized (Galovic et al., 2019a).

4.3. Selective amygdalohippocampectomy

Consecutively, selective amygdalohippocampectomy represents a less invasive approach for resecting medial temporal structures, enabling the preservation of the lateral temporal neocortex potentially through a smaller craniotomy. This concept was initially introduced by Niemeyer et al. in the 1950s (Boling, 2010). Various approaches exist for selective amygdalohippocampectomy. The transsylvian approach, which involves a pterional craniotomy that avoids resection of the lateral temporal lobe, was described by Yasargil et al. (Chang et al., 2015; Yaşargil et al., 2010) The amygdala can be resected in its entirety through an incision between the opercular temporal arteries, exposing the ventricular horn. However, accessing the body and tail of the hippocampus necessitates at least partial interruption of the temporal stem (Chang et al., 2015; Boling, 2010). Olivier initially described a transcortical approach through a middle cranial fossa craniotomy for selective amygdalohippocampectomies (Olivier, 2000). In this approach, neuronavigation serves as a valuable tool. The first visible landmark encountered is the temporal horn of the lateral ventricle, accessed through the middle or inferior temporal gyrus (Chang et al., 2015; Olivier, 2000; Tanriverdi and Olivier, 2007). The transcortical approach, previously known as the transventricular approach, avoids larger arteries and veins, thereby aiming to minimize vascular complications. However, achieving a sufficient route through the middle or inferior temporal lobe may result in disconnection of the basal lateral temporal lobe.

Another favorable approach for selective amygdalohippocampectomy involves a subtemporal method through a small keyhole craniotomy, initially described by Hori et al. and subsequently adapted by Park et al. (Chang et al., 2015; Hori et al., 1999, 2007; Little et al., 2009) For this route, stereotactic guidance and ultrasonic aspiration are essential to facilitate access to the amygdala and hippocampus. Although patient positioning can prove challenging, particularly in obese individuals, the advantage of this approach lies in minimizing damage to surrounding structures (Boling, 2010). Drawbacks include elevated retraction pressures and an increased risk of injuries to basal temporal draining veins.

A paramedian supracerebellar-transtentorial approach has first been described in an anatomical cadaver study by Türe et al. (2012) This approach exposes the entire length of the mediobasal temporal region enabling a selective removal of the anterior two-thirds of the parahippocampal gyrus and hippocampus, as well as the amygdala.

In 2008, Duckworth reported an approach through the inferior temporal lobe, representing a compromise as it circumvents the pitfalls of the subtemporal approach and also prevents verbal memory loss, which is being associated with the superior and middle temporal gyri (Chang et al., 2015). Neuropsychological outcomes were not evaluated in their series. Nevertheless, recent studies on selective amygdalohippocampectomies and anterior temporal lobe resection have not demonstrated neuropsychological benefits or reduced postoperative comorbidities by sparing the lateral temporal lobe (Chang et al., 2015; Türe et al., 2012).

5. Corticoamygdalohippocampectomy (CAHE) and selective amygdalohippocampectomy (SAHE)

In nearly half of the patients with temporal lobe epilepsy, the temporal pole is involved in the origin of seizures, before or concurrently with the hippocampus, which strongly argues for CAHE instead of SAHE as a successful operative strategy (Chabardes et al., 2005). But according to other studies, both CAHE and SAHE can lead to similar favorable seizure outcome in patients with mesial temporal lobe epilepsy (Tanriverdi et al., 2008). Apart from the similar seizure outcome, SAHE seems to have a better neuropsychological outcome (Schramm, 2008), but this is controversially discussed in the literature. Both, CAHE and SAHE can lead to several neuropsychological impairments, depending on the side of the surgery (Tanriverdi et al., 2010). After all, CAHE confers an improved chance of achieving seizure freedom in temporal lobe epilepsy (Josephson et al., 2013).

Recently a new player for a better seizure outcome of temporal lobe resection has been described: The piriform cortex anatomically upper-frontal-mesial to the amygdala has been identified as a main modulator in temporal lobe seizures, with significant better seizure outcome after resection for temporal lobe epilepsy (Galovic et al., 2019b).

5.1. *Multiple hippocampal transections*

Multiple hippocampal transection (MHT) was first introduced in 2006 by Shimizu et al. as a means to minimize hippocampal damage through a less invasive procedure than anterior temporal lobectomy (Marathe et al., 2021; Abramov et al., 2022). This technique involves multiple transections of the longitudinal fibers parallel to the anterior-posterior length of the hippocampus, while sparing the circular fibers. Circular fibers are associated with neuronal circuitry crucial for memory function, thus reducing the risk of memory deficits after surgery (Abramov et al., 2022). The procedure can be performed via the transcortical approach through the middle temporal gyrus, the transsylvian approach, or a transsulcal approach. A transcortical superior temporal gyrus approach is typically avoided due to the risk of postoperative language impairments (Marathe et al., 2021). Nevertheless, larger series with rigorous patient outcome data are still needed to fully support this technique for broader application.

5.2. *Insulo-opercular corticectomies*

Open surgeries for insular epilepsy pose challenges due to the close anatomical relationship between the insular arteries and the highly functional cortex of the opercula (Eichberg et al., 2018). The risks for postoperative deficits, such as hemiparesis and dysphasia, particularly on the dominant side, are high. The largest surgical series of 44 insulo-opercular cortectomies for insular epilepsy reported a high rate of seizure-free outcomes. However, postoperative deficits were observed in 7 % of patients (Eichberg et al., 2018; Ryvlin and Nguyen, 2021). Consequently, minimally invasive approaches, including laser interstitial thermal therapy and radiofrequency thermocoagulation, will be possibly more favored for this location in the future.

5.3. *Laser interstitial thermal therapy (LITT)*

LITT, also referred to as stereotactic laser ablation (SLA), is a minimally invasive surgical technique first described in 1978 (Heppner, 1978; Hoppe et al., 2017). While it is highly appealing to patients due to short hospitalization and typically minimal postoperative pain, it has the drawback of being dependent on intraoperative magnetic resonance imaging and also necessitates an experienced technician to monitor heat ablation safely.

In patients with epilepsy, LITT has been reported in the treatment of mesial temporal sclerosis, hypothalamic hamartoma, periventricular nodular heterotopia, focal cortical dysplasia, tuberous sclerosis, and cavernous malformations (Vadera et al., 2012; Curry et al., 2018; Wu et al., 2019; Palma et al., 2018; Perry et al., 2017; McCracken et al., 2016; Zemmar et al., 2020). Another valuable application for LITT is the treatment of multiple tubers in children with tuberous sclerosis complex. In fact, one of the first applications of epilepsy surgery involved such a case (North et al., 2017). When targeting mesial temporal structures, the temporal horn of the lateral ventricle and the basal cisterns absorb a significant amount of heat, extending the preferred targets and preventing thermal injury to surrounding tissue (Shan et al., 2021; Hoppe et al., 2017). Postoperative complications following LITT procedures are generally low, with the most common issue being visual field defects, which depend on the location of ablation (Vadera et al., 2012; Waseem et al., 2015; Willie et al., 2014).

5.4. *Stereoelectroencephalography guided radiofrequency thermocoagulation SEEG-RFTC*

The traditional minimal invasive brain lesioning method, the SEEG-RFTC is performed by connecting a radiofrequency generator to the electrode contact points and relies on a current flow between two contiguous electrode contact points (bipolar) (Shamim et al., 2022; Wellmer et al., 2016; Catenoix et al., 2018). Multiple coagulations have to be applied in a single operative session for a target larger than 7–10 mm, as the maximal diameter for a single coagulation ranges only from 3 to 7 mm (Willie et al., 2014). The safety of the procedure is ensured by pre-coagulation stimulation of the involved brain area in order to detect relevant neurological deterioration of function. One of the advantages of SEEG-RFTC is that general anesthesia is not required, and the patient serves as his/her own – clinical – control (Wellmer et al., 2016). In cases where the target area does not exhibit neurological function and is situated more than 2 mm from vessels, single or multiple coagulations can be performed (Catenoix et al., 2018). When RFTC does not result in seizure freedom, it can serve as a predictor for successful outcomes following surgery or currently followed by LITT, based on the so-called “responder effect” (i.e. > 50 % seizure reduction).

Furthermore, it does not preclude surgery or make it technically more complex (Xu et al., 2022). SEEG-RFTC has been utilized for various indications, such as focal cortical dysplasia, hypothalamic hamartoma, and periventricular heterotopias. This final patient category appears to yield the most promising results. A recent meta-analysis comparing radiofrequency ablation outcomes to LITT outcomes suggested inferior outcomes in the radiofrequency ablation group (Shamim et al., 2022; Kohlhase et al., 2021). Depending on the site of coagulation, the most commonly reported temporary complications include hyponatremia, short-term memory loss, Horner syndrome, and hemorrhage (Shamim et al., 2022).

5.5. *Stereotactic radiosurgery*

As this treatment option does not necessitate invasive surgical intervention, it will not be further discussed in this review article. Nevertheless, it is worth mentioning, particularly as it remains a viable option for patients who do not consent to invasive surgery or those who suffer from various comorbidities (Barbaro et al., 2018). This approach can target the amygdala, the head of the hippocampus, or the parahippocampal gyrus targeting lesions including but not limited to hypothalamic hamartomas without damaging surrounding brain tissue (Shan et al., 2021; Shamim et al., 2022; Régis et al., 2000a, 2000b; Chang et al., 2010). Although postoperative side effects are rare, they may include severe headaches from post-radiation edema, visual deficits, and papilledema (Barbaro et al., 2009). Barbaro et al. conducted the ROSE trial, a randomized controlled trial comparing radiosurgery versus open surgery for mesial temporal lobe epilepsy (Barbaro et al., 2018). They found that postoperative seizure control after radiosurgery was less effective compared to surgical resection and may only occur in a delayed way 12–24 months after radiation (Shan et al., 2021; Chang et al., 2010; Barbaro et al., 2009; Quigg et al., 2011; Ben-Menachem et al., 1994).

5.6. *Neuromodulation*

Neuromodulation involves the delivery of electrical energy to neural targets. In the treatment of epilepsy, neuromodulation was approved for extracranial vagus nerve stimulation in 1997 after a controlled study of vagus nerve stimulation for the treatment of partial seizures was published in 1994 (Ben-Menachem et al., 1994). Intracranial approaches where approved by the U.S. Food and Drug Administration for responsive neuromodulation in 2013 and deep brain stimulation in 2018.

Deep brain stimulation can target the anterior nucleus or the centromedian nucleus of the thalamus, or the hippocampus. Advantages of these techniques include their reversible nature. Complications, although rare, may encompass hardware issues, infections and hemorrhage. Drawbacks entail the potential need for repeat surgery at the end-of-life of the implantable pulse generator. The first positive results in studies targeting the anterior nuclei which projects both to superior frontal and temporal lobe structures commonly involved in seizures, were published by Cooper et al., in 1980 (Cooper et al., 1980). In 2010 the SANTE study group reported a multicenter, double-blinded, randomized trial of bilateral stimulation of the anterior nuclei of the thalamus for localization-related epilepsy with 110 participants (Fisher et al., 2010). By two years, a reduction in seizure frequency of at least 50 % was achieved in 54 % of patients, while reporting modest complications including acute, transient stimulation-associated seizures, memory problems and an increased depression rate (Fisher et al., 2010). Their results also suggest an effect of stimulation independent of an earlier implantation surgery in addition to an improvement in the stimulated group versus the control group during the blinded phase, which may rule out a contribution from a microlesion effect after deep brain stimulation which was first described bei Hodaie et al., in 2002 (Hodaie et al., 2002).

5.7. High intensity focused ultrasound (HIFU)

This technique has not been frequently reported, although it was first described by Lynn et al., in 1942, and its potential still requires further exploration in epilepsy surgery. To date, limited knowledge exists regarding the acoustic energy absorption in different tissues. High-intensity focused ultrasound generates frictional heat exceeding 56 °C, leading to cell death (Quadri et al., 2018; Lynn et al., 1942; Kennedy et al., 2003). Potential targets include the anterior nucleus of the thalamus, the amygdala, the hippocampus, the piriform cortex, and lesional pathologies such as focal cortical dysplasia, periventricular heterotopia, and hypothalamic hamartoma, among others (Vadera et al., 2012; Monteith et al., 2013, 2016; McDannold et al., 2010). Particularly when combined with and guided by magnetic resonance imaging, this technique may emerge as a viable treatment option. Currently, only a handful of case reports are available (Tierney et al., 2022; Lee et al., 2022). In future directives HIFU may be considered in the treatment of various medically refractory seizure disorders. The ability to target larger lesions to capture the entirety of the epileptogenic zones with HIFU is still unknown. In addition, little is yet known for the effect and absorption of ultrasound in sclerotic or calcified tissue.

5.8. Disconnective surgery

Disconnection aims to isolate epileptogenic zones in order to achieve seizure reduction or seizure freedom (Rosenow et al., 2016). Various disconnection strategies have been discussed, including callosotomy, hemispherotomy, and subpial transections. Callosotomies are primarily performed in children to prevent interhemispheric seizure spread and drop attacks. This approach was first described by Van Wagenen and Herren in 1940, involving dissection of the ipsilateral fornix, the anterior commissure, and massa intermedia (Van Wagenen and Herren, 1940). Over the decades, the approach underwent modifications until Wilson et al. limited it to the anterior two-thirds, as well as the anterior and ventral hippocampal commissures in 1977 (Rosenow et al., 2016; Wilson et al., 1977; Uda et al., 2021). Nonetheless, this approach is frequently associated with postoperative disconnection symptoms, such as language decline and unilateral deterioration of motor function (Rosenow et al., 2016; Ueda et al., 2021).

Subpial transections were first described by Morrell et al., in 1989 to disconnect neocortical eloquent epileptogenic zones (Rosenow et al., 2016; Morrell et al., 1989; Patil et al., 2004). This technique involves numerous perpendicular cuts usually 5 mm apart through the gyrus to segregate intracortical horizontal fibers while sparing subcortical white matter and U-fibers. These interval cuts may prevent the spread of epileptic discharges and therefore prevent seizures.

Hemispherotomy has limited indications, primarily for unilateral encephalopathies, including Rasmussen encephalitis, Sturge-Weber syndrome, and perinatal stroke (Rosenow et al., 2016; Bahuleyan et al., 2013). This technique was first described in glioma surgery by Dandy in 1928 and in epilepsy surgery by McKenzie in 1938 (Bahuleyan et al., 2013). Although it can achieve favorable seizure freedom rates of up to 80 %, the risk of hemorrhage, late hydrocephalus, and hemosiderosis remains high. Consequently, Rasmussen introduced the functional hemispherotomy in 1974 to minimize the extent of brain removal while maximizing white matter disconnection (Rosenow et al., 2016; Bahuleyan et al., 2013; Rasmussen, 1973). Currently, there are two concepts and approaches for functional hemispherotomy: the peri-insular hemispherotomy and the vertical parasagittal hemispherotomy (Bahuleyan et al., 2013). Although very favorable seizure outcomes can be achieved, complications may include impairments in reading and speech, as well as hydrocephalus (Rosenow et al., 2016; Griessenauer et al., 2015).

In 2020 Weil et al. published a multicenter, international, retrospective cohort study proposing a hemispheric surgery outcome prediction scale (HOPS) to predict seizure freedom in children at three months after undergoing cerebral hemispheric surgery after analyzing 1267 surgeries (Weil et al., 2021). In their study seizure onset age and semiology, as well as presence of contralateral interictal FDG-PET hypometabolism, and previous resective surgery were the most robust predictors of 1-year seizure freedom in the pediatric patient cohort (Weil et al., 2021). However, these findings also concluded that 30 % of patients receiving curative hemispheric surgeries develop seizure recurrence. Although postoperative morbidity is rare as the trend continuous toward less tissue resection, expected neurologic deficits include but are not limited to paresis, homonymous hemianopsia, auditory processing disorders, language disturbances, and spasticity.

6. Conclusion

In summary, this comprehensive review delves into the significance and challenges associated with the increasing trend towards minimally invasive techniques in epilepsy surgery. By comprehending the strengths and weaknesses of various surgical approaches and strategies, the decision-making process in epilepsy surgery can be enhanced, taking into account that not all procedures are universally suitable for every patient. Ultimately, epilepsy surgery demands individualized, patient-centric approaches to maximize the likelihood of achieving seizure freedom and optimizing treatment outcomes.

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