Recent developments in the surgical management of paediatric epilepsy

Vijay M Ravindra,1 Matthew T Sweney,2 Robert J Bollo1

ABSTRACT

Among the 1% of children affected by epilepsy, failure of pharmacological therapy and early age of seizure onset can lead to worse long-term cognitive outcomes, mental health disorders and impaired functional status. Surgical management often improves functional and cognitive outcomes in children with medically refractory epilepsy, especially when seizure remission is achieved. However, surgery remains underused in children with drug-resistant epilepsy, creating a large treatment gap. Several recent innovations have led to considerable improvement in surgical technique, including the recent development of minimally invasive diagnostic and therapeutic techniques such as stereotactic EEG, transcranial magnetic stimulation, MRI-guided laser ablation, as well as novel paradigms of neurostimulation. This article discusses the current landscape of surgical innovation in the management of paediatric epilepsy, leading to a paradigm shift towards minimally invasive therapy and closing the treatment gap in children suffering from drug-resistant seizures.

INTRODUCTION

In children, epilepsy occurs in approximately 1% of the population, and medical therapy is the first line of treatment. For most patients, medications are effective in controlling seizures, although trials of several different antiepileptic drugs and dosages may be necessary. However, although epileptic seizures may be well controlled through medical therapy, nearly one-third of these patients are pharmacoresistant.1,2 Drug-resistant epilepsy (DRE) is defined by the International League Against Epilepsy as the ‘failure of adequate trials of two tolerated, appropriately chosen and used antiepileptic schedules to achieve sustained seizure freedom’.1 DRE can present significant treatment challenges and is associated with progressive cognitive impairment, depression, anxiety, developmental delay and impairment of executing activities of daily living.3,4 Children with DRE are potentially surgical candidates to cure their epilepsy or significantly reduce the seizure burden. Especially in younger children, earlier surgery may provide a longer window of developmental plasticity and facilitate improved cognitive outcomes.

EPIEMIOLOGY OF PAEDIATRIC DRE

Surgery was historically the last resort for the treatment of DRE; however, surgical treatment for appropriately selected patients can result in long-term seizure control rates of up to 70%.5 Surgery for the treatment of DRE remains underused despite compelling level I evidence for significant improvement in overall health and quality of life. An estimated 100 000–500 000 patients with DRE are surgical candidates in the USA annually, but <1% receive an operation for treatment of DRE.6,7 In an effort to improve patient care and access/referral to epilepsy surgery and close the treatment gap, the American Academy of Neurology published a recommendation for surgery as the treatment of choice for certain patients with DRE.8 This recommendation is a mandate for early patient referral and evaluation to minimise the adverse developmental and social effects of uncontrolled seizures.8 Despite this, there have been no improvements in the time from diagnosis to surgical consultation for children with DRE.9,10 An online tool to evaluate the appropriateness for a surgical evaluation in the setting of DRE for paediatric patients >12 years old incorporates data about seizure type, frequency, epilepsy duration, seizure severity, previous medication use, side effects to medication regimen and previous electrical (EEG) and structural (MRI) evaluation.11

The hesitation to refer patients for surgical evaluation in the context of DRE is multifactorial. The most commonly cited reasons are fear of surgical comorbidity, cost, hope that new pharmaceutical therapies will stop seizures in patients in whom multiple other medications have not and limited knowledge of minimally invasive surgical options.6,7

Recently, several novel surgical tools for both invasive diagnosis and treatment of seizures have greatly expanded the armamentarium of the paediatric epilepsy surgeon. Perhaps more importantly, these tools have introduced new treatment options for children with DRE who were not previously considered good surgical candidates. In this review, we highlight the development and practical application of several new surgical techniques, including robotic-assisted stereotactic EEG (SEEG) for intracranial EEG recording, transcranial magnetic stimulation (TMS) for extracranial mapping, MRI-guided laser interstitial therapy (MRgLITT) for minimally invasive ablation of the epileptogenic zone and responsive neurostimulation (RNS) as potential emerging technologies for use in children (figure 1).

EVOLUTION OF EPILEPSY SURGERY

Improvements in microsurgical technique and diagnostic technology have vastly improved the implementation and delivery of the surgical management of epilepsy over the past 30 years.12 Magnetoencephalography, functional MRI (fMRI) and simultaneous EEG–fMRI recordings with capability to capture localised changes in blood flow associated with interictal spikes and ictal EEG

[Note: The rest of the text is not visible in the provided excerpt.]
discharges,12 all of which were considered ‘experimental’ in the 20th century, are now commonplace in the work-up of paediatric epilepsy. The advent of technology to further localise epileptogenic foci has resulted in improvements in targeted surgical therapy with hopes of minimising trauma to unaffected brain tissue. Traditional surgical procedures to treat epilepsy, including temporal lobectomy and cortical and neocortical lesionectomy, have been improved as a result of improvement in MRI resolution in the 1990s, which allowed for definitive radiographic support for hippocampal sclerosis13 and, more recently, cortical dysplasia.14 This has allowed a proportion of patients who previously would have been thought to be poor surgical candidates to undergo surgery and afford improved functional outcomes.12 Thus, improvements in diagnostic techniques have been accompanied with improved surgical outcome and feasibility.

A revolution in the surgical treatment of epilepsy came during the first Palm Desert Conference on Surgical Treatment of the Epilepsies in 1986, which initially compared outcomes and subsequent publications on the topic of surgical treatment for epilepsy.15

STEREOTACTIC EEG

Diagnostic intracranial EEG monitoring is indicated in children when the seizure-onset zone cannot be localised by scalp EEG, which has limited spatial resolution. Often, this is achieved via large multistage craniotomy, which has been associated with high morbidity in some paediatric series. An alternative, minimally invasive technique used for intracranial recording is the stereotactic placement of depth electrodes for intracranial EEG recording. Originally described by Talairach et al17 and Bancard and Dell18 in the 1970s at Saint Anne Hospital in Paris, France, the technique has been modified and enhanced with improvements in stereotaxis, imaging techniques and monitoring technologies over the past 15 years. A specific advantage of SEEG is the ability to demonstrate three-dimensional spatiotemporal information about seizure onset and progression. Perhaps just as important, the introduction of robotic technology for electrode placement has facilitated a higher level of accuracy (1–3 mm), facilitated safer electrode trajectories, and reduced surgical times.19 20 The indications for SEEG are listed in box 1.

Surgical technique

This decision to pursue invasive intracranial monitoring with SEEG is best made in a multidisciplinary manner. SEEG targets are determined based on non-invasive evaluation of the hypothetical seizure-onset zone, including abnormalities on structural MRI, scalp EEG, magnetoencephalography and metabolic studies including interictal PET and peri-ictal SPECT. Preoperative stereotactic, three-dimensional MRI with contrast is critical to safe electrode targeting.21 SEEG can be advantageous in children with multifocal epilepsy including patients with tuberous sclerosis complex or suspected deep targets including insular cortex, the cingulate gyrus and the mesial temporal structures. The overwhelming advantage to SEEG is the ability to avoid craniotomy to perform intracranial recordings and the three-dimensional investigation of complex epileptic networks.22

Evidence supporting SEEG use in children

SEEG provides very accurate targeting of epileptogenic foci with low rates of morbidity, especially when combined with robotic guidance and electrode placement. Multiple reports from various centres have confirmed its efficacy and safety in children. In one study, SEEG provided useful information regarding extratemporal or multilobar resections in 90% of cases, with extremely low morbidity.23 Subsequently, Cosset et al24 described 15 patients that underwent SEEG; 13 proceeded to surgical resection of the epileptogenic zone, and 6 of these demonstrated seizure freedom (Engel class Ia) (tables 1 and 2) at 12-month follow-up.19

Figure 1  Diagnostic and therapeutic treatment approach to children with drug-resistant epilepsy (DRE). The inclusion of stereotactic EEG (SEEG), MRI-guided laser interstitial therapy (MRgLITT) and responsive neurostimulation (RNS) (red) as they pertain to the diagnostic and therapeutic management of children with DRE. ECoG, electrocorticography; FDG-PET, fluorodeoxyglucose positron emission tomography; SDG, subdural grid; SPECT, single-photon emission CT. Modified with permission from Vendrame and Loddenkemper.64
Box 1  Current indications for stereotactic EEG

- Drug-resistant epilepsy (DRE) without a structural lesion on MRI and non-lateralising scalp EEG
- Suspected multifocal epilepsy (eg, tuberous sclerosis complex)
- Anatomic proximity of ictal onset to functionally eloquent cortex
- DRE with discordant non-invasive surgical evaluation
- Previous surgery with subdural scarring
- Suspected widespread epileptogenic networks

Table 1  Engel classification for seizure freedom

<table>
<thead>
<tr>
<th>Engel classification</th>
<th>Definition</th>
<th>Clinical outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Completely seizure-free since surgery</td>
<td>Non-disabling simple partial seizures</td>
</tr>
<tr>
<td></td>
<td>Completely free of disabling seizures for at least two years</td>
<td>Convulsions only when medications are withdrawn</td>
</tr>
<tr>
<td>II</td>
<td>Initially may have been seizure free, but is continuing to have disabling seizures since surgery</td>
<td>Rare disabling seizures since surgery</td>
</tr>
<tr>
<td></td>
<td>More than rare disabling seizures after surgery but now rare seizures for at least two years</td>
<td>Nocturnal seizures only</td>
</tr>
<tr>
<td>III</td>
<td>Worthwhile seizure reduction</td>
<td>Prolonged seizure-free intervals amounting to more than half the follow-up period, but not &lt;2 years</td>
</tr>
<tr>
<td>IV</td>
<td>No significant seizure reduction</td>
<td>No appreciable change</td>
</tr>
<tr>
<td></td>
<td>Seizures getting worse</td>
<td></td>
</tr>
</tbody>
</table>

Table 2  Large series of stereotactic EEG (SEEG) use in paediatric epilepsy

<table>
<thead>
<tr>
<th>Authors</th>
<th>Type of epilepsy</th>
<th>Mean age of patients (months)</th>
<th>Number of children who underwent SEEG</th>
<th>Number of patients with seizure freedom (Engel class I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dygjergi et al</td>
<td>DRE—focal insular epilepsy</td>
<td>76.8</td>
<td>10</td>
<td>7 (70%)</td>
</tr>
<tr>
<td>Liava et al</td>
<td>DRE—posterior cortex epilepsy</td>
<td>94.8</td>
<td>24</td>
<td>18 (75%)</td>
</tr>
<tr>
<td>Cossum et al</td>
<td>DRE—suspected focal origin</td>
<td>34.1</td>
<td>15</td>
<td>6 (40%)</td>
</tr>
<tr>
<td>Tausvig et al</td>
<td>DRE</td>
<td>29.8</td>
<td>65</td>
<td>44 (67%)</td>
</tr>
<tr>
<td>Cossum et al</td>
<td>DRE</td>
<td>322.8*</td>
<td>211</td>
<td>119 (56.4%)</td>
</tr>
</tbody>
</table>

*This study included both adults and children (mean age 26.9 years, range 2–56 years).

DRE, drug-resistant epilepsy.

A large, retrospective review of 211 patients with 2666 electrodes demonstrated the utility of SEEG when non-invasive diagnostic measures did not localise the epileptogenic zone. In this series, 174 patients proceeded to surgical resection, including 47 temporal resections (27%), 55 frontal (31.6%), 14 parietal (8%), 1 occipital (0.6%), 1 Rolandic (0.6%) and 56 multilobar resections (32.2%). Seizure outcomes in the 165 patients with ≥12-month follow-up were Engel class I for 56.4% of patients, class II in 15.1%, class III for 10.9% and class IV for 17.6%. SEEG was critical for identification of the seizure-onset zone. Complications from electrode placement occurred in 12 procedures (5.6%).

Liava et al described 62 children with DRE and focal seizures from the posterior cerebral cortex, including 24 patients in whom SEEG facilitated localisation of the epileptogenic zone. Among patients who underwent SEEG, 73% achieved seizure freedom. The most common epileptogenic substrates were focal cortical dysplasia (50%), tumour (24%) and gliotic lesions (14.5%). Dygjergi et al described 10 children with drug-resistant insular epilepsy in whom SEEG was used to localise the epileptogenic zone and guide resective surgery. In seven patients, an Engel class I outcome was achieved, along with neuropsychological and behavioural improvement. Tausvig et al used SEEG in 65 paediatric patients, 78% of whom underwent surgical resection. The mean clinical follow-up was 24 months, with 67% of children achieving an Engel class I outcome. Table 2 demonstrates large series of paediatric patients who underwent intracranial monitoring with SEEG and their respective seizure outcomes. Overall seizure freedom rate was high, indicating that SEEG is efficacious in accurately identifying and characterising the epileptogenic zone in children.

Although complications have been reported with SEEG, the vast majority of studies have demonstrated relatively low morbidity and mortality in children. The reported rates of permanent morbidity following SEEG (0–3%) compared with those reported for subdural electrode arrays reflect the relative safety of minimally invasive SEEG, likely due to the avoidance of the morbidity of large craniotomies typically required for subdural electrode placement. However, it is important to note that in many clinical situations the indications for SEEG may be different from the indications for subdural electrodes. For example, large subdural grids may be used to map functionally eloquent cortex.

Interictal characterisation of the epileptogenic zone with SEEG

The implementation of SEEG has also allowed the development of quantitative algorithms to characterise the epileptogenic zone without capturing seizures. An algorithm-derived SEEG pattern was used to correctly identify the ictal-onset zone using interictal fast activity (80–120 Hz) associated with slow transient polarising shifts and voltage depression. A three-dimensional model can be created based on the trajectory and position of the SEEG electrodes. This method was validated in a cohort of 14 patients in whom 100% correlation with the ictal-onset zone (comparing interictal data with captured seizures) was achieved in 13 patients and partial correlation in one case. The use of single-pulse electrical stimulation has also been described in searching for an epileptogenic focus.

Because SEEG electrodes may also be used for cortical stimulation, an array of SEEG electrodes may be seen as a set of three-dimensional bidirectional activator/detectors. Investigators have leveraged this concept to characterise complex three-dimensional networks and map the epileptogenic zone. Additional interictal paradigms used to map the epileptogenic zone with SEEG arrays include using the absolute signal slope,
trending ordinal patterns of EEG activity, multivariate cross-correlation matrices of EEG activity and multivariate model-free information theory. Other interictal features being used to model the epileptogenic zone include the joint sign periodicogram event characterisation transformation algorithm, the ictal ictal–interictal correlation matrices, and high-frequency oscillations. The role of SEEG in the mapping of the epileptogenic zone will continue to grow, especially as further mathematical modelling of interictal features of SEEG recordings generate three-dimensional maps of the epileptogenic zone with improved resolution. These techniques raise the prospect of short periods of intracranial monitoring that do not require actual seizures to characterise complex epileptogenic networks in detail, potentially significantly shortening the duration of intracranial monitoring and further reducing morbidity and improving the safety of intracranial monitoring and accuracy of targeted seizure focus resections in children with DRE.

**TRANSCRANIAL MAGNETIC STIMULATION**

In addition to precise mapping of the seizure onset and epileptogenic zone, subdural intracranial electrode arrays are often implanted in children with DRE and epileptogenic lesions in close proximity to functionally eloquent cortex, including primary sensorimotor cortex and language centres. Seizure-onset zones close to eloquent cortex are often associated with functional reorganisation, especially in children. Both precise functional and seizure mapping are critical to preserving eloquent function and optimising seizure outcome. In addition, non-invasive mapping techniques like fMRI usually require patient participation and are challenging in children, and SEEG does not allow precise functional mapping of the cortical surface. Because of this, children who require functional mapping often still require large, two-stage craniotomies—with the associated morbidity. The advent of outpatient mapping via TMS has opened the door to non-invasive, preoperative cortical stimulation mapping of eloquent function (figure 2).

**Preoperative mapping via TMS**

About a decade ago, early reports demonstrated the clinical feasibility of TMS for preoperative functional mapping in adults and children with DRE and epileptic foci in or near primary motor cortex. Even in children as young as 11 years old, TMS was found to be beneficial to surgical decision-making. Patients undergo a stereotactic MRI loaded into a unit consisting of a navigation system, TMS coil and magnetic stimulator. For motor mapping, electromyographic recordings are made from relevant muscles during magnetic stimulation of putative motor cortex. For language mapping, paradigms are used to produce speech arrest during stimulation of essential language cortex. Accurate identification of primary motor cortex in a 3-year-old boy with a ganglioglioma in Rolandic cortex was also reported. More recently, multiple reports have demonstrated localisation of primary motor cortex in very young children via awake TMS that is at least as accurate as mapping using passive tasks with sedated fMRI. In addition, preoperative language mapping via TMS has high concordance with fMRI and direct cortical stimulation mapping in adolescents and adults, with one centre reporting successful language mapping via TMS in a 6-year-old patient. Together with SEEG, TMS may represent an avenue to avoid large, mutistage craniotomies with subdural electrode arrays in some children with DRE, although further study is necessary.

**MRI-GUIDED LASER INTERSTITIAL THERAPY**

An emerging technology

MRgLITT is a recent innovation that is transforming the surgical management of DRE in children. This technology represents minimally invasive surgical ablation that is being used to treat a rapidly expanding variety of epileptogenic lesions in children with DRE including mesial temporal sclerosis (MCS), hypothalamic hamartoma and deep periventricular tumours (box 2). There are also multiple reports of MRgLITT used in the treatment of periventricular nodular heterotopia, insular epileptic foci, glial neoplasms, brain metastases and teratomas.

**Technical aspects**

MRgLITT delivery involves the use of an optical fibre with a diffusing tip, which is heated by a diode laser insulated in an outer cannula. The outer cannula cools the laser with saline or carbon dioxide. MRgLITT can be applied through a single-twist drill or burr hole under general anaesthesia. The probe is positioned and delivered to the target using frameless stereotaxis, robotic stereotaxis or traditional frame-based stereotactic methods. After the tip is placed at the target, heat is delivered from the probe. Heat delivery is monitored in real time via MR thermography. The cellular damage induced by the heat delivery leads to time-dependent and temperature-dependent cell death. Repeat imaging can ascertain the amount of thermal injury that has been induced, and additional heat may be delivered to achieve the desired effect (figure 3). Multiple foci can also be

**Box 2** **Current and emerging indications for MRI-guided laser interstitial therapy in paediatric epilepsy**

Patients with drug-resistant epilepsy and

- Hypothalamic hamartoma
- Mesial temporal sclerosis
- Cortical dysplasia including insular lesions
- Corpus callosumotomy
- Tuberous sclerosis complex
- Periventricular tumours

Evidence for MRgLITT

MRgLITT provides a critical advantage of monitoring temperature and tissue damage in real time using MR thermography, which distinguishes MRgLITT from other minimally invasive neurosurgical therapies, such as stereotactic radiosurgery and radiofrequency ablation. Several reports in the paediatric (table 3) and adult literature have shown the feasibility and efficacy of MRgLITT. Lewis et al evaluated 19 MRgLITT procedures in 17 children undergoing therapy for DRE with various pathology, including focal cortical dysplasia (n=12), tuberous sclerosis (n=5), hypothalamic hamartoma (n=1), MTs (n=1), Rasmussen encephalitis (n=1) and tumour (n=1). Although a heterogeneous spectrum of ictal substrate, 59% of patients achieved Engel I or II outcome. There were four complications: inaccurate probe placement in two patients, probe system failure in one and steroid-induced postoperative dyspnea in one.

Further study of the use of this technology in children with hypothalamic hamartomas demonstrated Engel I seizure freedom in 86% of patients (mean follow-up 9 months) in a series of 14 patients. Curry et al reported on five paediatric patients (ages 5–13 years) with various pathologies; Engel class I seizure freedom was achieved in three patients (60%); however, the follow-up was limited to 2–13 months.

The most widely studied application of MRgLITT in DRE involves the treatment of MTS. Although traditional craniotomy and anterior temporal lobectomy with amygdalohippocampectomy is supported by class I evidence and is associated with excellent seizure outcomes, significant decline in verbal memory frequently complicates surgery in the dominant hemisphere. This limitation has led to the development of more ‘minimally invasive’ techniques, including MRgLITT and radiofrequency ablation. Kang et al reported that, among 20 children and adults who underwent MRgLITT for MTS, seizure control rates were 53% after 6 months, with four patients requiring formal anterior temporal lobectomy.

The adult literature on this topic provides more robust evidence for the use of MRgLITT in MTS. Most importantly, a prospective study comparing patients undergoing MRgLITT and standard temporal lobectomy for temporal lobe epilepsy in the dominant hemisphere demonstrated similar rates of seizure control in both groups (57.9% vs 61.5%, respectively). However, patients undergoing craniotomy had greater difficulty with facial recognition and naming after treatment than patients treated with MRgLITT (p<0.001).

With increasing ease of use and demonstration of efficacy among adult and paediatric patients, MRgLITT is quickly becoming an attractive method of treatment for various disorders that can lead to paediatric epilepsy.

RESPONSIVE NEUROSTIMULATION

Although RNS is currently only approved for the treatment of DRE in adults, its indications are likely to be expanded to include children with DRE in the near future. Indirect brain stimulation through the vagus nerve has been an effective and well-tolerated method of seizure control, especially in children. Direct stimulation of critical brain structures has been essential in the treatment of epilepsy. Deep-brain stimulation targeting of the cerebellum, centromedian thalamic nucleus, anterior nucleus of the thalamus, hippocampus, subthalamic nucleus and caudate have all been reported in the treatment of epilepsy. This early work using neurostimulation for epilepsy provided the framework for RNS.

Therapeutic effect

Treatment of epilepsy by RNS is a novel form of neurostimulation and the first to use a continuous feedback loop that monitors a focal EEG signal via intracranial electrodes placed over the ictal-onset zone. Based on continuous EEG analysis, direct stimulation of the cortex is performed to disrupt seizure propagation. The RNS device can measure epileptic activity by bandpass line 333 Hz, amplitude of 0.5–12 mA and pulse width of 40–1000 μs.

The first commercially available RNS system by NeuroPace (Mountain View, California, USA) was FDA-approved in 2013 for use in patients ≥18 years of age with DRE and partial-onset seizures, ≤2 epileptogenic foci and ≥3 seizures per 3-month average (box 3). NeuroPace can use information from both subdural and depth electrodes that are able to detect seizure activity and respond with electrical stimulation.
Evidence for RNS

The initial trial of the NeuroPace RNS system that led to FDA approval was published by the RNS system in Epilepsy Study Group in 2011. The double-blinded, randomised, placebo-controlled study involved 191 adults (mean age 34.9 years) who underwent intracranial placement of subdural depth electrodes covering one or two predetermined epileptogenic foci. After recovery from surgery for device implantation, patients were randomised to either stimulation or sham stimulation for 3 months, followed by an open-label period where all patients received stimulation. There was an initial reduction in seizure frequency in both groups; however, a sustained reduction of 37.9% was seen in patients randomised to stimulation compared with 17.3% of patients who underwent sham stimulation. Forty-six per cent of patients had a 50% reduction in mean seizure frequency with an improvement in secondary outcomes, which included health-related quality-of-life metrics. Long-term reduction in seizure frequency was seen in nearly two-thirds of patients over a 5.5-year follow-up, again with improved quality-of-life metrics.

There have been no reports of complete seizure freedom with RNS, but 36.7% of patients had at least one seizure-free period of >3 months, 23% had a seizure-free period of >6 months and 12.9% had a seizure-free period of >12 months. There have been 11 deaths reported: 7 as a result of sudden unexpected death in epilepsy (SUDEP), 2 from suicide, 1 from status epilepticus and 1 from lymphoma. The rate of SUDEP associated with RNS does not appear to be elevated compared with the overall incidence among patients with epilepsy.

A critical follow-up and secondary analysis of neuropsychological outcomes demonstrated persistent improvement at 2 years following implantation. In addition, there was a 32% improvement in naming scores reported in patients with focal neocortical epilepsy (76 patients) and 8.5% improvement in verbal memory in patients with mesial temporal onset (86 patients). Although seizure freedom may not be common, RNS can significantly alter the character and intensity of seizures in patients who are not candidates for or fail surgical treatment with curative intent, likely contributing to improved neurocognitive outcomes.

Future use in children

Although RNS technology is not currently approved for use in children with DRE, it very likely will be an option in the near future for children who may not be a candidate for other surgical treatments or in whom those methods have already failed. In addition, its use as a potential diagnostic tool for long-term, real-time electrocorticography in the ambulatory setting has been described (off-label). RNS holds much promise to expand the surgical options for children with DRE, but further study is needed to delineate its specific role.

SUMMARY

A wide variety of emerging tools is transforming the evaluation and surgical management of epilepsy in ways never before seen and ushering in a paradigm shift towards minimally invasive technologies that hold great promise to close the treatment gap for children with DRE. An understanding of these new technologies is critical for practitioners caring for paediatric patients debilitatingly affected by pharmaco-resistant seizures. SEEG, TMS, MRgLITT and RNS represent minimally invasive diagnostic and therapeutic techniques that significantly broaden the armamentarium for the management of children with DRE, especially when they are leveraged together to combine non-invasive functional mapping and minimally invasive intracranial recordings and ablation. It is hoped that they will contribute to decreased surgical morbidity, facilitate the treatment of more children with epilepsy and close the treatment gap for children suffering from seizures.

Competing interests

None declared.

Provenance and peer review

Commissioned; externally peer reviewed.