

RESEARCH ARTICLE

Pediatric epilepsy surgery: Global survey of referral and presurgical evaluation practices

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Abstract

Objective: Pediatric epilepsy surgery is well established, but contemporary global data on referral and presurgical evaluation practices are lacking. This International League Against Epilepsy (ILAE) Pediatric Epilepsy Surgery Task Force study provides an updated overview of current trends and regional differences.

Methods: Group-level data were collected from 61 epilepsy surgery programs (49 pediatric-only) across 29 countries and six continents, identified through ILAE networks, and included all children and adolescents treated in 2023 who underwent presurgical evaluation/epilepsy surgery.

Results: Group-level data were available for 2427 patients. Mean age at surgery was 9.1 ± 4.9 years; mean epilepsy duration was 5.3. At surgery, 3.2% were <1 year

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Members of the ILAE Pediatric Epilepsy Surgery Task Force and Study Group are provided in [Appendix A](#).

For affiliations refer to page 11.

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old (highest in Oceania: 5.1%), and 6.1% were nonpharmacoresistant (highest in Europe: 15.0%). Prior neurosurgery was reported in 14.2% (highest in North America: 28.8%), including 8.0% resections (6.1% for epilepsy, 1.5% for tumors; highest in Oceania: 16.5%), 2.3% disconnections (1.3% corpus callosotomy; highest in South America: 4.7%), and 4.2% neuromodulation (3.7% vagal nerve stimulation, .2% responsive neurostimulation, one deep brain stimulation; highest in North America: 12.2%). Developmental and epileptic encephalopathies (DEEs) at surgery included Lennox–Gastaut syndrome (7.4%), infantile epileptic spasms syndrome (5.1%), and DEE with spike–wave activation in sleep (1.5%). Presurgical investigations included fluorodeoxyglucose positron emission tomography (52.6%; highest in Oceania: 79.7%), genetic testing (46.8%; highest in Asia: 54.3%), magnetic resonance imaging (MRI) postprocessing (32.4%; highest in South America: 53.0%), functional MRI (fMRI; 15.2%; highest in North America: 40.3%), magnetoencephalography (11.9%; highest in North America: 39.3%), single photon emission computed tomography (9.6%; highest in North America: 22.2%), high-density electroencephalography (EEG; 1.9%; highest in Europe: 4.7%), source localization (1.6%; highest in Oceania: 7.6%), Wada test (1.2%; highest in North America: 3.5%), and EEG–fMRI (.5%; highest in Europe: 1.1%).

Significance: Despite some early surgeries, including in infancy and before pharmacoresistance, mean epilepsy duration before surgery remains >5 years. Reoperations are common, with resection more frequent than neuromodulation. Genetic testing in nearly half of patients reflects its growing relevance, and the high rate of DEEs underscores the complexity of surgical candidates.

KEYWORDS

developmental and epileptic encephalopathies (DEEs), genetic testing, neuromodulation, pediatric epilepsy surgery, presurgical evaluation, reoperations

1 | INTRODUCTION

Pediatric epilepsy surgery is an evidence-based intervention,^{1,2} and is increasingly utilized worldwide.^{3–9} In 2004, the International League Against Epilepsy (ILAE) conducted the first global survey of pediatric epilepsy surgery practices, published in 2008.¹⁰ That landmark study reported on 543 patients aged ≤18 years across 20 programs in the United States, Europe, and Australia, and provided detailed data on age at surgery, epilepsy duration prior to surgery, reoperation rates, eligible epilepsy syndromes, and use of presurgical investigations.¹⁰

In the 2 decades since that initial survey, the field has changed substantially. Access to epilepsy surgery has expanded in high-income countries¹¹ and has become increasingly available in low- and middle-income settings.⁶ Referral volumes have grown, and the surgical population has diversified, including more infants,^{12–14} children with developmental and epileptic encephalopathies (DEEs),¹⁵ and

patients with genetic epilepsies.^{16,17} Advances in neuroimaging¹⁸ and genetic diagnostics¹⁹ have improved candidate selection, and minimally invasive approaches such as laser interstitial thermal therapy and novel neuromodulation techniques⁴ such as responsive neurostimulation (RNS) and deep brain stimulation (DBS) have broadened the therapeutic spectrum.

Updated 2022 ILAE recommendations²⁰ emphasize early presurgical evaluation—ideally as soon as pharmacoresistance is established—and highlight the importance of timely referral, including for infants and selected nonpharmacoresistant patients with identifiable lesions in noneloquent cortex. As clinical pathways become more individualized, reassessment of referral and presurgical evaluation practices is warranted. Although recent studies have reported national, regional, single-center, or multicenter trends,^{3,7,11,21} none has provided a comprehensive global perspective.

To address this gap, the ILAE Pediatric Epilepsy Surgery Task Force within the Surgical Therapies Commission

2021–2025 launched an international initiative to update and expand the 2004 survey.¹⁰ This study systematically captured center-level referral patterns and presurgical evaluation strategies, invasive explorations, surgical procedures, and etiologies across a broad, globally representative sample of epilepsy surgery programs. Here, we report referral patterns and presurgical evaluation strategies; other domains are presented separately. By documenting changes over the past 2 decades and highlighting regional variation, we aimed to provide updated benchmarks and inform clinical guidance and research priorities in pediatric epilepsy surgery.

2 | MATERIALS AND METHODS

2.1 | Study design

This international, cross-sectional survey collected group-level data on referral patterns and presurgical evaluation practices in pediatric epilepsy surgery. Eligible patients were aged ≤ 18 years and underwent epilepsy surgery in 2023. Included procedures were resective, disconnective, ablative, or neuromodulatory, as well as invasive electroencephalographic (EEG) evaluations, including cases where no subsequent intervention was performed. Patients who underwent noninvasive presurgical evaluation but did not proceed to invasive EEG evaluation or surgery were excluded. Postsurgical seizure, developmental, or behavioral outcomes were not assessed.

2.2 | Survey development and scope

A web-based data entry form was developed in REDCap and hosted on secure servers at the University Children's Hospital Zurich. The form was designed to collect standardized, deidentified group-level clinical data on pediatric epilepsy surgery cases treated in 2023.

2.3 | Participating centers and inclusion criteria

To achieve broader global coverage than the 2004 ILAE survey,¹⁰ which included 20 programs in Europe, the United States, and Australia, epilepsy surgery centers from all six ILAE regions (Africa, Asia-Oceania, Eastern Mediterranean, Europe, Latin America, and North America) were invited to participate. The initial call was disseminated through members of the ILAE Pediatric Epilepsy Surgery Task Force, the ILAE Surgical Therapies

Key points

- Group-level data from 61 epilepsy surgery programs in 29 countries ($n = 2427$) across six continents provide a global overview of pediatric epilepsy surgery practices in 2023.
- Despite some early interventions, including in infancy and before pharmacoresistance, mean epilepsy duration prior to surgery remains > 5 years.
- Prior neurosurgery was reported in 14.2% of cases, including 8.0% resections (6.1% for epilepsy, 1.5% for tumors) and 2.3% disconnections.
- Prior neuromodulation was reported in 4.2% of cases, most commonly vagal nerve stimulation.
- Genetic testing was performed in 46.8% of cases, reflecting its growing diagnostic role.
- A substantial proportion of patients had severe developmental and epileptic encephalopathies, including Lennox–Gastaut (7.4%) and infantile epileptic spasms syndrome (5.1%).

Commission, and regional ILAE leadership. In addition, centers that had participated in the 2004 ILAE survey were contacted directly. A formal record of invited but nonparticipating centers was not maintained. Eligible centers included both pediatric-only and mixed-age programs with dedicated pediatric services. Participation required the ability to provide group-level data on all pediatric patients (≤ 18 years) who underwent surgery or invasive EEG in 2023. Centers were excluded if their pediatric surgical activity was largely limited to vagal nerve stimulator (VNS) implantation, as these programs were not considered to reflect the scope of pediatric epilepsy surgery practice addressed in this survey.²²

2.4 | Data collection

Each center appointed one or more local leads responsible for data extraction and entry into REDCap. The survey did not capture the specific professional role of local leads. Data collection covered referral characteristics (e.g., age at seizure onset, age at surgery, epilepsy syndrome, pharmacoresistance, prior neurosurgery) and the use of presurgical investigations including video-EEG, structural magnetic resonance imaging (MRI), neuropsychological testing, fluorodeoxyglucose positron emission tomography (FDG-PET), single photon emission computed tomography (SPECT), high-density

EEG, magnetoencephalography (MEG), EEG source localization, EEG–functional MRI (EEG–fMRI), MRI postprocessing, functional MRI, Wada test, and genetic testing. The survey documented their use and frequency but not their impact on surgical decision-making.

2.5 | Statistics

Descriptive statistics were calculated for all study variables. Categorical variables are reported as frequencies and percentages, and continuous variables as means and SDs.

Comparisons across continents were assessed using generalized estimating equations (GEE). For continuous outcomes, a Gaussian family with identity link was used; for proportional outcomes, a binomial family with a logit link was applied. Models were fitted using the *geeglm()* function from the *geepack* package in R. To account for clustering within countries, an exchangeable correlation structure was used. To mitigate center-size imbalance without allowing a small number of hubs to dominate the analysis, GEE models incorporated weights proportional to each center's patient count. Europe served as the reference category for all continent-level comparisons, because it included a large proportion of participating centers and patients and provided a stable comparator for analysis. Africa was excluded from inferential analyses due to small sample size ($n = 17$).

For outcomes with few events, estimates were imprecise (wide confidence intervals) and should be interpreted cautiously. When zero or sparse counts yielded unstable GEE estimates, results were considered not estimable; these are provided in the Supporting Tables but are not discussed in the main text.

A separate GEE model assessed the association between the proportion of patients with prior surgery and mean epilepsy duration across centers.

Statistical significance was defined as a two-sided p -value $\leq .05$. All analyses were performed using R (v. 4.3.1).²³

3 | RESULTS

3.1 | Participating centers and patient cohort

We collected data on 2427 children and adolescents who underwent epilepsy surgery in 2023 from 61 epilepsy surgery programs in 29 countries across six continents (Figure 1, Table S1). Of these, 49 centers were pediatric-only and 12 were mixed-age centers with dedicated pediatric services. Based on World Bank income classification,²⁴

42 of 61 participating centers (68.9%) were located in high-income countries and 19 (31.1%) in low- or middle-income countries. Patient distribution by continent was as follows: Asia ($n = 960$), Europe ($n = 795$), North America ($n = 427$), South America ($n = 149$), Oceania ($n = 79$), and Africa ($n = 17$). Annual surgical volume varied; 27 centers treated fewer than 20 patients (small volume), 22 treated 20–49 patients (medium), eight treated 50–99 patients (large), and four treated 100 or more (very large). The median number of patients per center was 24 (interquartile range = 12–45). The cohort comprised 55.3% males and 44.7% females. The proportion of females varied across regions, ranging from 40.3% in Asia to 57.0% in South America, and was below 50% in Asia and Europe.

3.2 | Referral patterns

The mean epilepsy duration prior to surgery was 5.3 years, ranging from 4.6 years in Asia to 6.6 years in North America. Compared to Europe, epilepsy duration was significantly longer in North America (GEE, $p = .027$; Figure 2, Table S2). The mean age at seizure onset was 3.8 ± 3.8 years, lowest in Asia (3.4 years) and highest in South America (5.1 years), although no regional differences were statistically significant compared to Europe. The mean age at surgery was 9.1 ± 4.9 years, ranging from 8.0 years in Asia to 10.7 years in North America. Compared to Europe, patients in North America underwent surgery at a significantly older age ($p = .031$), whereas patients in Asia underwent surgery at a significantly younger age ($p = .039$).

Surgery in the first year of life was reported in 3.2% of all patients, with the highest rates in Oceania (5.1%) and lowest in North America (2%). However, no region differed significantly from Europe. Surgery before meeting pharmacoresistance criteria was reported in 6.1% of all patients, most commonly in Europe (15.0%) and not at all in Asia. Compared to Europe, North America had significantly lower odds of surgery before meeting pharmacoresistance criteria ($p < .001$; Figure 3, Table S2).

3.3 | Surgical history prior to current procedure

Prior neurosurgery, including prior epilepsy surgery and neurosurgery for other indications, was reported in 14.2% of all patients, ranging from 4.0% in Asia to 28.8% in North America. Compared to Europe, prior surgery was significantly more frequent in North America (GEE, $p = .029$; Figure 4, Table S3) and less frequent in Asia ($p = .003$).

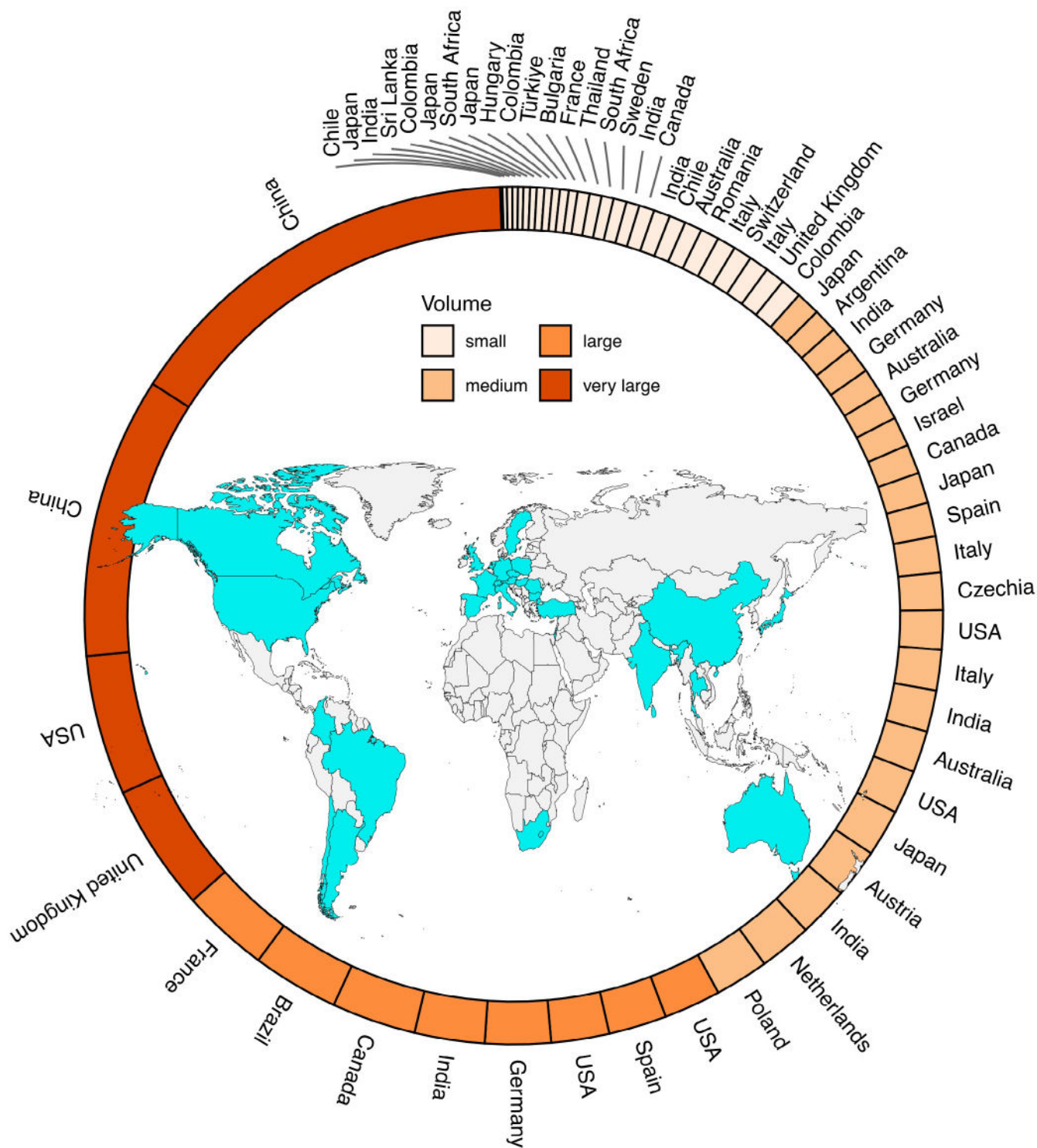


FIGURE 1 Global distribution of contributing epilepsy surgery programs. Data were contributed by 29 countries across six continents (highlighted in cyan), representing a total of 2427 pediatric patients who underwent epilepsy surgery in 2023. The central map illustrates the geographic spread of participating countries. The surrounding ring is subdivided into segments corresponding to individual centers. Segment width is proportional to each center's patient count, and segment color indicates surgical volume: small (<20 patients, beige), medium (20–49, light orange), large (50–99, orange), and very large (≥ 100 , dark orange).

Prior resective procedures had been performed in 8.0% of all patients (6.1% for epilepsy and 1.5% for tumor), ranging from 3.0% in Asia to 16.5% in Oceania. Prior disconnections

were not significantly different when compared to Europe. Disconnective procedures were reported in 2.3% of all patients, including 1.3% with prior corpus callosotomy and

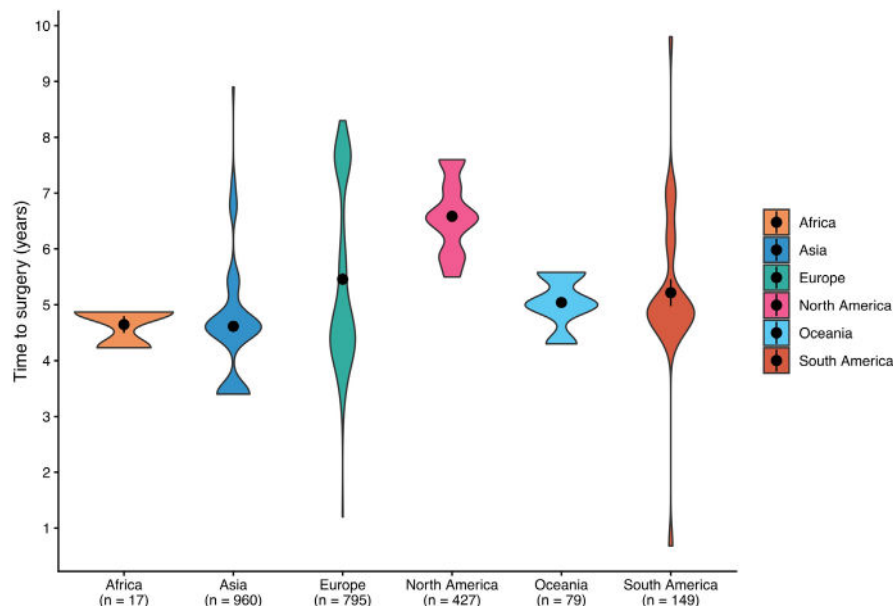


FIGURE 2 Time from epilepsy onset to surgery by continent. Violin plots show the distribution of time from epilepsy onset to surgery by continent. Each violin represents the distribution density for one continent; the black dot indicates the mean. Across the cohort, the mean duration from epilepsy onset to surgery was 5.3 years. Asia had the shortest interval (4.6 years) and North America the longest (6.6 years). Compared with Europe, patients in North America had a significantly longer duration from epilepsy onset to surgery ($p = .027$).

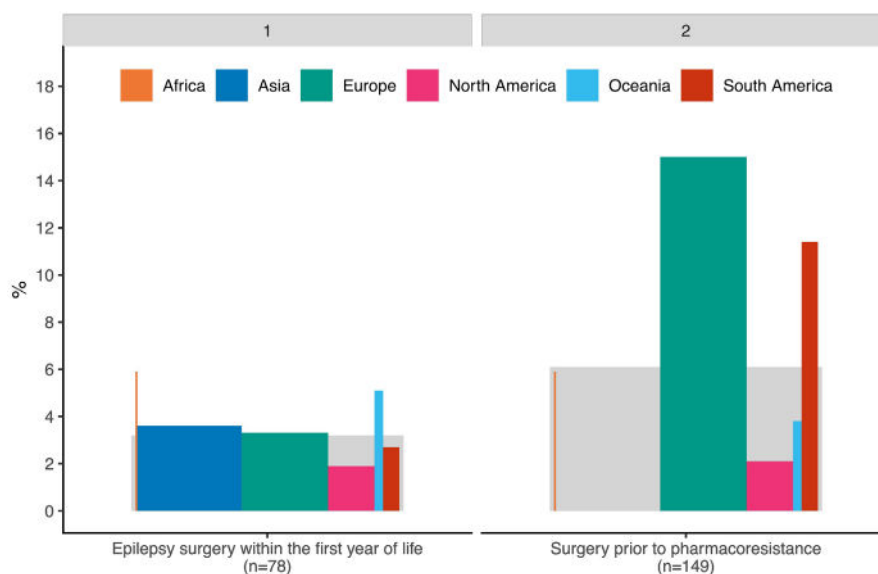


FIGURE 3 Surgery in infancy and surgery before pharmacoresistance by continent. Bar plots show the proportion of patients who underwent epilepsy surgery (1) in the first year of life and (2) before meeting pharmacoresistance criteria. Globally, surgery in infancy was reported in 3.2% of patients and surgery before pharmacoresistance in 6.1%. Surgery in infancy was more frequent in Oceania (5.1%), and surgery before pharmacoresistance was more common in Europe (15.0%). Bar width reflects regional sample size; gray background bars indicate global percentages.

one case of multiple subpial transections. These were most common in Oceania (5.1%) and least common in Asia (.7%), but differences were not significant compared to Europe; estimates for Asia could not be calculated due to sparse events.

Neuromodulation prior to the index epilepsy surgery (resective, disconnective, or ablative) was reported in 4.2% of all patients: 3.7% VNS, .2% RNS, and one case of DBS. Rates of prior neuromodulation were highest in North

America (12.2%), with no cases reported in Oceania. Compared to Europe, prior neuromodulation was significantly less common in Asia ($p = .007$).

A higher proportion of patients with prior neurosurgery was significantly associated with longer epilepsy duration ($p < .001$; Table S4). Specifically, a 10% increase in the proportion of patients with prior neurosurgery was associated with an estimated 6-month-longer epilepsy duration at the time of index surgery.

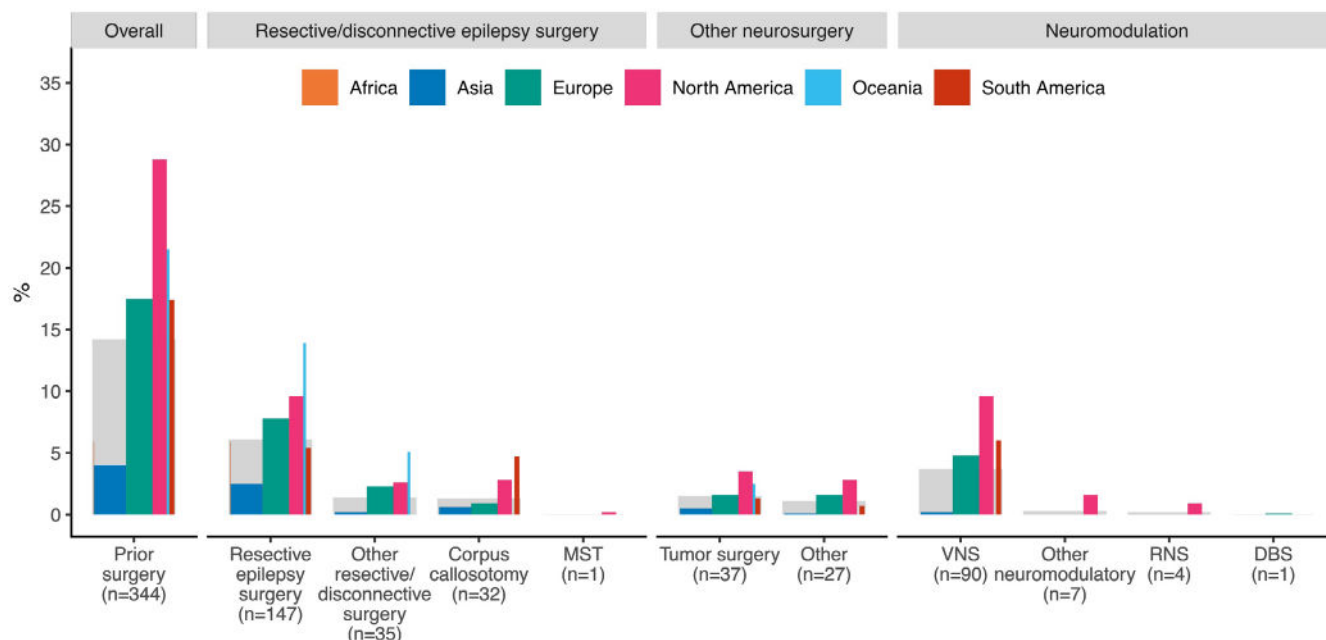


FIGURE 4 Prior neurosurgery by continent. Bar plots show the proportion of patients with prior neurosurgical procedures, grouped as resective/disconnective epilepsy surgery, other neurosurgery, and neuromodulation. Globally, 14.2% of patients had prior neurosurgery, ranging from 4.0% in Asia to 28.8% in North America. Prior resective/disconnective surgery included prior epilepsy surgery in 6.1% of patients and corpus callosotomy in 1.3%. Other neurosurgery included tumor resections in 1.5% of patients. Neuromodulation preceded surgery in 4.2% overall, most commonly vagal nerve stimulation (VNS; 3.7%), followed by responsive neurostimulation (RNS; .2%) and deep brain stimulation in one case (DBS; .04%). Prior neuromodulation was more common in North America (12.2%) and absent in Oceania. Bar width reflects regional sample size; gray background bars indicate global percentages. MST, multiple subpial transections.

3.4 | Epilepsy syndromes

A prior history of an electroclinical syndrome was reported in 24.8% of all patients, ranging from 15.3% in Asia to 37.6% in South America. The most common were infantile epileptic spasms syndrome (IESS; 12.3%), Lennox–Gastaut syndrome (LGS; 6.2%), and developmental epileptic encephalopathy with spike-and-wave activation in sleep (DEE-SWAS; 1.6%). Compared to Europe, a history of LGS was significantly more common in South America (GEE, $p < .001$), whereas DEE-SWAS was significantly less common in North America ($p = .001$) and South America ($p = .007$), and no DEE-SWAS cases were reported in Oceania (Figure S1, Table S5).

At the time of presurgical evaluation, a current electroclinical syndrome was identified in 18.5% of all patients, ranging from 12.5% in Asia to 30.9% in South America. LGS remained the most frequent (7.4%), followed by IESS (5.1%), and DEE-SWAS (1.5%). Compared with Europe, no significant regional differences were found for IESS, LGS, or DEE-SWAS (Figure 5, Table S6). At the time of evaluation, IESS was most common in Asia (6.4%), whereas LGS (19.5%) was most common in South America and DEE-SWAS (2.4%) was most frequent in Europe.

3.5 | Diagnostic modalities

Core presurgical investigations—structural MRI, long-term video-EEG, and neuropsychological evaluation—were performed in 98.8%, 92.7%, and 81.0% of all patients, respectively. The mean number of diagnostic tests per patient was 4.5, with the highest mean reported in North America (4.9), Asia (4.8), and Oceania (4.8), followed by Europe (4.1) and South America (3.8). The number of diagnostic modalities used in Asia was significantly higher compared to Europe ($p = .042$, GEE; Figure 6, Table S7).

For epileptogenic zone localization, FDG-PET was the most commonly used advanced imaging modality beyond MRI, applied in 52.6% of all patients. Utilization ranged from 13.4% in South America to 79.7% in Oceania. Compared to Europe, FDG-PET use was significantly more frequent in Asia ($p < .001$), Oceania ($p = .001$), and North America ($p = .003$), and significantly less frequent in South America ($p = .031$; Figure 6, Table S8). MRI postprocessing was performed in 32.4% of cases, ranging from 11.7% in North America to 53.0% in South America. No significant differences were observed compared to Europe. SPECT was applied in 9.6% of cases, most commonly in North America (22.2%) and not at all in South America. Compared to Europe, SPECT use was significantly more common in North America ($p = .005$).

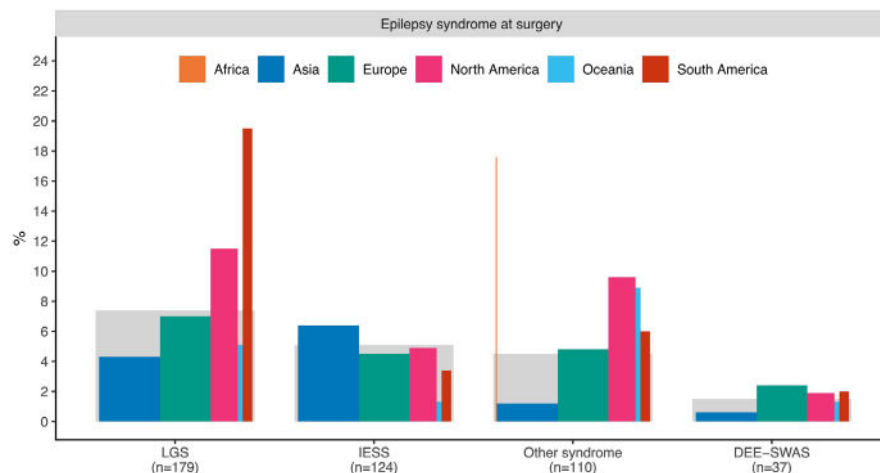


FIGURE 5 Epilepsy syndromes at presurgical evaluation by continent. Bar plots show the proportion of patients diagnosed with infantile epileptic spasms syndrome (IESS), Lennox–Gastaut syndrome (LGS), developmental epileptic encephalopathy with spike-and-wave activation in sleep (DEE-SWAS), or other defined epilepsy syndromes at presurgical evaluation. Globally, 18.5% of patients presented with an epilepsy syndrome, most commonly LGS (7.4%), IESS (5.1%), and DEE-SWAS (1.5%). LGS (19.5%) was most frequent in South America, IESS in Asia (6.4%), and DEE-SWAS in Europe (2.4%). Bar width reflects regional sample size; gray background bars indicate global percentages.

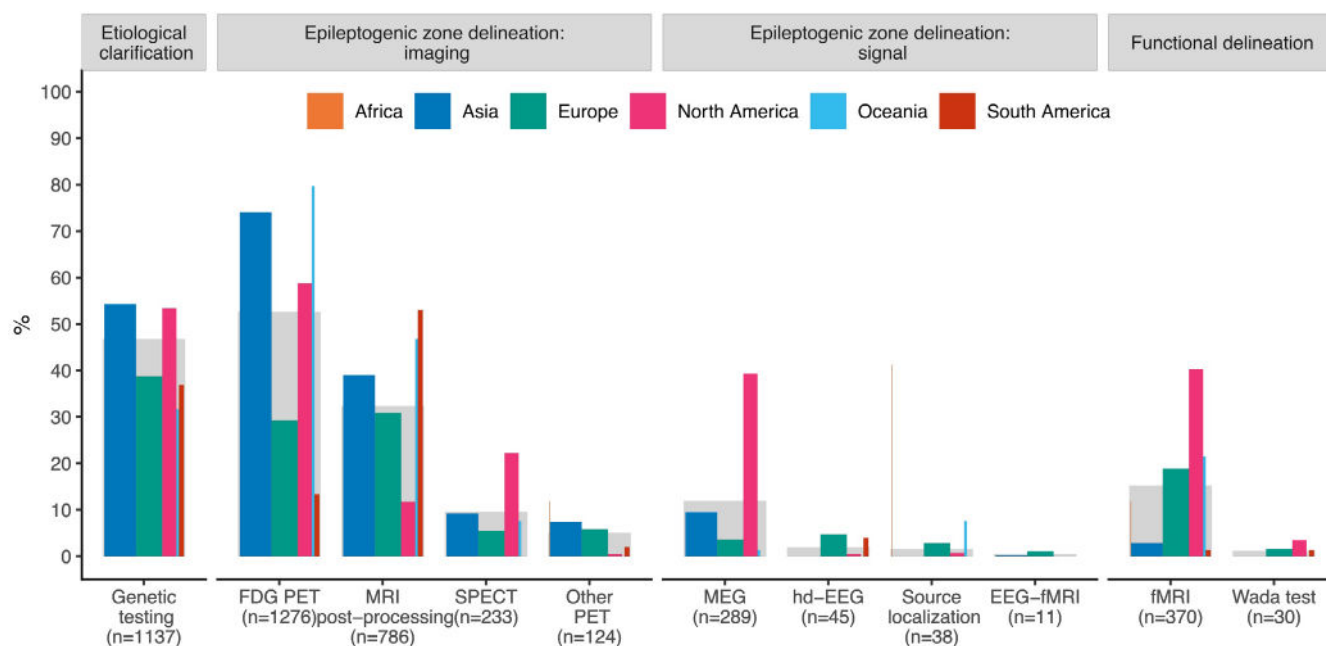


FIGURE 6 Auxiliary presurgical investigations by continent. Bar plots show auxiliary presurgical investigations, grouped by purpose: (1) etiological clarification, (2) epileptogenic zone delineation by imaging or electrophysiology, and (3) functional mapping. The most frequently used modalities globally were fluorodeoxyglucose positron emission tomography (FDG PET; 52.6%), genetic testing (46.8%), magnetic resonance imaging (MRI) postprocessing (32.4%), functional MRI (fMRI; 15.2%), magnetoencephalography (MEG; 11.9%), and single photon emission computed tomography (SPECT; 9.6%). Other techniques—including the Wada test, high-density electroencephalography (hd-EEG), source localization, EEG-fMRI, and non-FDG PET—were each used in <2.0% of the cohort, with absent or minimal use in several regions. Bar width is proportional to the number of patients per region. Gray background bars indicate global usage rates.

For functional mapping, fMRI was applied in 15.2% of all patients, ranging from 1.3% in South America to 40.3% in North America. Compared to Europe, fMRI use

was significantly higher in North America ($p=.002$) and significantly lower in Asia ($p<.001$) and South America ($p=.016$). The Wada test was used in 1.2% of all patients,

most frequently in North America (3.5%) and not at all in Asia or Oceania.

Among signal analysis techniques, MEG was used in 11.9% of all patients overall, with the highest use in North America (39.3%) and no use in South America. Compared to Europe, MEG use was significantly higher in North America ($p < .001$). High-density EEG was used in 1.9% of all patients, most commonly in Europe (4.7%), with no reported use in Asia or Oceania. Source localization was applied in 1.6% of all patients, most frequently in Oceania (7.6%), with no reported use in Asia or South America. EEG-fMRI was performed in .5% of cases, with the highest rate in Europe (1.1%) and no use in Oceania, North America, or South America.

Genetic testing was the second most commonly used auxiliary investigation, performed in 46.8% of all patients. Utilization ranged from 31.6% in Oceania to 54.3% in Asia, with no significant regional differences compared to Europe.

4 | DISCUSSION

This international survey provides the most comprehensive global overview to date of pediatric epilepsy surgery practices, capturing referral characteristics and presurgical evaluations from 61 programs across 29 countries. It builds on the landmark 2004 ILAE survey,¹⁰ which included 543 patients from 20 centers across North America, Europe, and Oceania. In contrast, the present dataset comprises group-level data on 2427 patients—almost five times as many—and includes all six ILAE regions, incorporating previously underrepresented areas such as Asia, South America, and Africa. This broader geographic scope likely reflects both expansion of pediatric epilepsy surgery capacity over the past 2 decades, including in high- and middle-income countries, and more systematic international outreach through current ILAE networks. Notably, Africa was represented by only two centers within a single city in one country and contributed the fewest patients overall, leading to exclusion from several statistical analyses. This underrepresentation underscores the need to expand epilepsy surgery capacity and research participation across Africa to improve access and strengthen global evidence.

4.1 | Persistent delays in surgical referral

Despite growth in surgical programs and patient volume, delays persist. The mean epilepsy duration prior to surgery was 5.3 years, similar to the 6.3 years reported in

the 2004 ILAE survey.¹⁰ This finding indicates ongoing prolonged exposure to uncontrolled seizures before referral,²⁵ despite accumulating evidence supporting earlier intervention.²⁵ The ILAE Pediatric Epilepsy Surgery Task Force highlighted the importance of timely referral nearly 2 decades ago,²⁶ and multiple studies have since reinforced that earlier evaluation and surgery improve both seizure and cognitive outcomes.^{27,28} Yet, surgery remains underutilized; US data suggest that fewer than one third of eligible children ultimately receive surgery, with slower growth and longer delays among socially disadvantaged groups, underscoring persistent inequities.²⁹ Geographic and systems variability, limited specialist access, and insurance complexity further impede timely referral and evaluation, even in high-income settings with established programs.^{30,31} Practical steps include earlier referral protocols, rapid-access or telemedicine-based presurgical consultations to reduce distance and waiting time, and standardized shared decision-making with proactive outreach to primary neurologists and families to normalize earlier evaluation.^{32,33}

Surgery in the first year of life was reported in 3.2% of all patients, modestly higher than the 1.5% reported in the 2004 ILAE survey, but still low given the high incidence of seizure onset in infancy¹⁰ and growing evidence that infants with focal lesions benefit from early surgery.^{12–14,28,34} Many such cases are DEEs, where early seizure control may mitigate the neurodevelopmental impact of pharmacoresistant epilepsy. As epilepsy surgery is safe and effective across the lifespan,^{12–14} early access should be prioritized. Epilepsy duration remains the only modifiable predictor of surgical outcome,^{35–38} and early intervention, especially in infancy, may leverage critical windows of neuroplasticity, such as those supporting language development, and enable optimal long-term cognitive and behavioral outcomes.

Although pharmacoresistance remains the main threshold for presurgical evaluation, surgery before meeting formal criteria³⁹ was reported in 6.1% of all patients, suggesting that early referral is increasingly considered in selected cases. This finding adds important new information, as previous large surveys—including the 2004 ILAE survey and several regional series—either did not assess this variable^{3,5,9,10} or only included pharmacoresistant cases by design.^{4,40} Although still debated, early surgery in nonpharmacoresistant patients with clear structural lesions^{28,41} has been associated with favorable outcomes, including seizure freedom and antiseizure medication (ASM) withdrawal.^{42,43}

Current ILAE recommendations support early referral once pharmacoresistance is established and endorse surgical consideration in selected nonpharmacoresistant patients with lesions in noneloquent cortex.²⁰ Several lines of

evidence support earlier surgical intervention. In children with early onset epilepsy, particularly those with focal cortical dysplasia,⁴⁴ the likelihood of sustained response to ASM is low, and failure of even one ASM significantly increases the risk of pharmacoresistance.³⁹ Longer epilepsy duration is consistently associated with poorer postsurgical seizure outcomes, regardless of age, localization, or etiology.^{45–47} Early surgery may also facilitate developmental gains, especially if ASM can be reduced or withdrawn.^{48–52} Conversely, delayed surgery risks cognitive decline due to ongoing seizures, interictal discharges, or ASM side effects,^{48,50} and may miss critical windows for neuroplasticity, limiting the potential for functional recovery.

4.2 | Prior neurosurgical interventions and treatment sequencing

Prior neurosurgical interventions were reported in 14.2% of cases, less frequent than in the 2004 ILAE survey (22.0%).¹⁰ Most reported prior procedures were resective, with smaller proportions involving tumors (1.5%) or disconnections (2.3%). The lower reoperation rate may reflect changes in case mix (more infants, DEEs, and MRI-negative cases)¹⁵; greater use of staged treatment strategies, often starting with less invasive interventions; more definitive primary resections enabled by improved planning⁵³; and inclusion of regions not represented in the earlier survey where constraints may limit multiple interventions. Still, reoperations remained more common in some settings, particularly North America, where nearly one third of patients had prior neurosurgery. These patterns may reflect regional differences in referral pathways and sequencing of less invasive interventions ahead of more extensive procedures aimed at seizure freedom.⁵⁴

In contrast to the earlier survey, where tumors accounted for 40% of reoperations,¹⁰ tumor-related prior resections represented 1.5% of all patients in this cohort. Although denominators differ, precluding direct comparison, this may reflect more targeted initial treatment of low-grade epilepsy-associated tumors (LEATs).⁵³ Optimal management of LEATs requires multidisciplinary input from epileptology, neuro-oncology, and neurosurgery, and surgical planning should address both the tumor and the surrounding epileptogenic cortex to optimize seizure control, neurological function, and oncologic outcome.⁵⁵

Prior neuromodulation was reported in 4.2% of all patients, predominantly VNS, similar to the 5.0% reported in the 2004 ILAE survey, which was conducted before wider use of other devices such as RNS or DBS. Pediatric labeling varies by region and device, and these modalities are used off-label in select centers. Regional variation was notable; in North America, 12.2% received neuromodulation

before surgery, suggesting that some programs prioritize seizure reduction-oriented neuromodulation ahead of resection, which may postpone seizure freedom-oriented surgery in candidates with realistic chances of seizure freedom. This pattern mirrors the 2004 survey, where VNS use was more common in US centers, indicating that the practice has persisted. Children with pharmacoresistant epilepsy should be evaluated at expert comprehensive epilepsy centers, and when they are reasonable candidates for seizure freedom-oriented surgery, this should be prioritized over neuromodulation, which more often offers seizure reduction than seizure freedom.

4.3 | Surgical candidacy for DEEs

In our cohort, 7.4% of patients were diagnosed with LGS and 5.1% with IESS, similar to the 2004 ILAE survey (8.6% and 4.0%, respectively).¹⁰ This underscores the ongoing inclusion of complex electroclinical phenotypes in pediatric epilepsy surgery and growing recognition that selected patients can benefit from surgery even with bilateral or multifocal discharges, when a focal or lateralized epileptogenic zone or lesion is identified.^{12,28,34} Selected patients with IESS can achieve excellent seizure and developmental outcomes with early surgery, particularly when a clear lesion is present.^{12,34,56} However, many are referred only after initial response to hormonal therapy and later relapse.⁵⁷ The higher rate of LGS may reflect the broader range of surgical strategies now available—resective, disconnective, and neuromodulatory—tailored to etiology.¹⁵ These findings underline the need for referral to specialized pediatric centers with expertise in early onset epilepsies and DEEs, where individualized treatment decisions are made through multidisciplinary evaluation.^{22,26}

Genetic testing was performed in 46.8% of patients, reflecting its growing role in presurgical evaluation. In younger children, particularly those with early seizure onset, developmental delay, MRI-negative findings, or suggestive family history, genetic results increasingly inform candidacy, including in DEEs.¹⁵ Current recommendations endorse early, individualized etiologic workup in these subgroups to guide management.^{58,59} Notably, genetic testing was absent from the 2006 ILAE presurgical evaluation guidelines²⁶ and from both the 2004 global survey¹⁰ and the 2014 diagnostic test survey.⁶⁰ Since then, genetic testing has become routine in many programs,⁶¹ driven by advances in epilepsy genomics⁶² and the shift toward precision medicine. Findings may support surgery (e.g., mTOR pathway and *SLC35A2* gene variants^{62,63}) or argue against resection when specific pathogenic variants predict poor outcomes (e.g., *SCN8A*, *GABRA1*, *PCDH19*). A confirmed

diagnosis may determine whether to proceed with invasive valuation, modify the surgical plan, or defer surgery. In some cases, post hoc tissue testing after invasive evaluation or resection^{62,64,65} clarifies etiology, explains suboptimal outcomes, and guides future counseling.

4.4 | Evolution in diagnostic modalities

Although core presurgical investigations—video-EEG, structural MRI, and neuropsychological testing⁶⁶—remained nearly universal ($\geq 81.0\%$), patients underwent a mean of 4.5 diagnostic tests, reflecting increasingly complex and individualized evaluations, particularly in high-resource settings such as North America.

Compared with the 2004 ILAE survey,¹⁰ Wada testing declined sharply (from 9.0% to 1.2%) and fMRI use increased modestly (12.0% to 15.2%), consistent with a broader shift toward noninvasive functional mapping. FDG-PET use more than doubled (24.0% to 52.6%), possibly reflecting improved spatial resolution, wider availability, and ease of interictal acquisition.⁶⁷ By contrast, SPECT use dropped from 25.0% to 9.6%, possibly related to logistical complexity and less consistent reliability. MEG use quadrupled (3.0% to 11.9%), and techniques absent from both the 2004 ILAE survey¹⁰ and the 2014 diagnostic test review⁶⁰ such as source localization,^{68,69} high-density EEG,⁷⁰ and EEG-fMRI⁷¹ are now used selectively. Together, these changes reflect technological progress and a shift toward higher resolution, noninvasive strategies.

Nevertheless, considerable regional variation persists. North America reported the highest mean number of tests per patient and more frequent use of MEG, SPECT, and fMRI. MRI postprocessing was more common in South America and less used in North America. PET was widely used in Asia, Oceania, and North America, whereas SPECT and fMRI were rarely used in South America. These differences likely reflect disparities in infrastructure, expertise, and resource availability rather than shared regional or patient-specific practice frameworks.

Overall, the number and diversity of presurgical investigations have expanded since 2004.¹⁰ Several modalities, including MRI postprocessing and source localization, have transitioned from research tools into selective clinical use, particularly in high-resource regions. Whether this broader diagnostic toolkit improves surgical planning or outcomes remains unknown and warrants further study.

4.5 | Future directions

This study has limitations. Data were collected at the group level, precluding patient-level analyses and adjustment for

individual confounders, and postsurgical outcomes were not assessed. In addition, the absence of a formal record of invited but nonparticipating centers limits assessment of response rates and representativeness. Future studies should use prospective patient-level data and more systematic center recruitment to evaluate outcomes and the impact of specific presurgical strategies on surgical decision-making.

5 | CONCLUSIONS

This global survey provides a contemporary overview of pediatric epilepsy surgery across all ILAE regions. Compared with 2 decades ago, surgical programs are more widely available geographically and diagnostic approaches have diversified, with increased use of advanced imaging and genetic testing. Yet the mean epilepsy duration prior to surgery remains >5 years, and early surgery, especially in infancy or before pharmacoresistance, remains uncommon. DEEs, such as LGS and IEES, continue to comprise a substantial share of surgical candidates. Marked regional differences in diagnostic strategies, reoperation rates, and treatment sequencing indicate limited harmonization of practice. High-resource centers often use more presurgical tests, but the added clinical value of broader diagnostic workup is uncertain. Clarifying which modalities meaningfully inform surgical planning and outcomes is needed. By capturing center-level practices across a large global cohort, this study provides updated benchmarks and highlights areas where greater harmonization within regions and patient subgroups may be achievable. Future studies using individual patient data are needed to determine how specific evaluation strategies affect outcomes and resource use.

AUTHOR CONTRIBUTIONS

Georgia Ramantani, J. Helen Cross, Dorottya Cserpan, Dario Englot, Martha Feucht, Sarah Ferrand Sorbets, Manjari Tripathi, Howard Weiner, Mary Lou Smith, and Elaine Wirrell contributed to the conception and design of the study. All authors contributed data for the article. Georgia Ramantani and Dorottya Cserpan analyzed the data, drafted the manuscript, and prepared the figures, with significant contributions from J. Helen Cross, Mary Lou Smith, and Elaine Wirrell. All authors reviewed, edited, and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The collection and analysis of patient data were approved by and performed according to the guidelines and regulations of the local ethics committee (KEK-ZH Req-2024-00058).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

APPENDIX A

A.1 | ILAE Pediatric Epilepsy Surgery Task Force and Study Group

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