ORIGINAL ARTICLE

The Changing Nature of Epilepsy Surgery: A Retrospective Review of Practice Profiles

Satyakam Baruah, André Olivier, Jeffery A. Hall

ABSTRACT: ***Objectives:*** Recent literature documents a trend of gradual decline in temporal lobe (resective) epilepsy surgery over the past decade. Amongst these, a large scale, comprehensive survey done in selected European, Australian and American centres documents trends of resective temporal epilepsy surgery across two decades. Montreal Neurological Institute has been the leading epilepsy surgery centre for more than 50 years now. It has been at the forefront of investigating and managing epilepsy in Canada. We have looked into the trends of epilepsy surgery in our institute in the past 44 years. ***Methods:*** The records of all adult epilepsy surgery procedures (excluding reoperations) performed by the senior authors were analysed from 1971 to 2015. Data retrieved for analysis included type of surgery (intracranial recording, resective, and neuromodulatory) and the specific surgical target for resection. Procedures were grouped into temporal resective, extratemporal (ET) resective and placement of intracranial electrodes (stereotactic electroencephalogram (SEEG)). ***Results:*** A total of 2,078 new procedures were performed from 1971 to 2015 at the Montreal Neurological Institute. Temporal procedures constituted the bulk of the proportion of all procedures each year and the entire study period. SEEG group shows linear increase in the number of cases over the years catching up with the total number of temporal procedures. ***Conclusions:*** Our study involving a homogenous dataset spanning nearly 50 years shows a decline in temporal lobe surgeries and an increase in intracranial investigations despite the class I evidence of its effectiveness. This corroborates the trends in epilepsy surgery practice profiles in tertiary centres of developed countries.

RÉSUMÉ : Le caractère évolutif de la chirurgie de l'épilepsie : une analyse rétrospective des types d'intervention. ***Objectif :*** La littérature scientifique la plus récente a mis en relief une tendance au déclin progressif au cours de la dernière décennie de la chirurgie de l'épilepsie ciblant le lobe temporal (chirurgie résective). Parmi tous ces travaux, une enquête exhaustive menée à grande échelle dans certains établissements de santé européens, australiens et américains a documenté les tendances de la chirurgie résective de l'épilepsie du lobe temporal sur deux décennies. À ce sujet, il est bon de rappeler que l'Institut et hôpital neurologiques de Montréal (IHNM) demeure le principal centre de chirurgie de l'épilepsie depuis maintenant plus de 50 ans. Qui plus est, ce centre continue au Canada à être à l'avant-garde de la recherche et de la prise en charge des patients souffrant d'épilepsie. En cela, nous avons voulu nous intéresser aux tendances de la chirurgie de l'épilepsie au sein de notre établissement depuis les 44 dernières années. ***Méthodes :*** À l'exclusion des ré-opérations, les dossiers portant sur tous les types d'intervention chirurgicale liés à l'épilepsie et destinés à des patients adultes et mis en pratique par les auteurs principaux (*senior authors*) ont été analysés pour la période allant de 1971 à 2015. Les données obtenues en vue d'une analyse ont inclus le type d'intervention (enregistrement intracrânien, résective et de neuro-modulation) ainsi que la cible chirurgicale spécifique en vue d'une résection. L'ensemble de ces interventions ont été regroupées dans diverses catégories : chirurgie résective du lobe temporal, chirurgie résective du lobe extra-temporal et pose d'électrodes intracrâniennes. ***Résultats :*** Au total, 2078 nouvelles interventions ont été effectuées à l'IHNM entre 1971 et 2015. À chaque année et pour toute la période à l'étude, les interventions concernant le lobe temporal ont constitué l'essentiel des interventions. Celles se rapportant à la catégorie « pose d'électrodes intracrâniennes » ont montré une augmentation linéaire de leur fréquence au fil des années et ont fini par rattraper le nombre total d'interventions visant le lobe temporal. ***Conclusions :*** Notre étude a donc porté sur un ensemble de données homogènes couvrant près de 50 ans. Elle a montré un déclin des chirurgies résectives du lobe temporal et un accroissement des examens intracrâniens en dépit d'un niveau 1 de preuve quant à leur efficacité (*class I evidence effectiveness*). Cela corrobore les tendances de la chirurgie de l'épilepsie qui existent dans les établissements de santé tertiaires des autres pays développés.

Keywords: Epilepsy surgery, Drug-resistant epilepsy, Temporal lobe epilepsy, Stereotactic EEG, Extratemporal epilepsy, Montreal Neurological Institute

doi:10.1017/cjn.2021.115 Can J Neurol Sci. 2022; 49: 387–392

From the Consultant Neurosurgery, Institute of Neurosciences, Medanta The Medicity, Gurugram, India (SB); Emeritus Professor of Neurology & Neurosurgery (Retired), Montreal Neurological Institute, Montreal, Canada (AO); and Epilepsy - Neuro-Oncology - Supportive Care Associate Professor of Neurosurgery, Department of Neurosurgery, McGill University Montreal Neurological Institute and Hospital Montreal, QC, Montreal, Canada (JAH)

Received August 12, 2020. Final Revisions Submitted May 6, 2021. Date of Acceptance May 10, 2021.

Correspondence to: Jeffery A. Hall, Epilepsy - Neuro-Oncology - Supportive Care Associate Professor of Neurosurgery Department of Neurosurgery, McGill University Montreal Neurological Institute and Hospital 109D - 3801, University Street, Montreal, QC, H3A 2B4 Canada. Email: jeff.hall@mcgill.ca

Rationale

Epilepsy is a chronic and disabling condition, and the International League against Epilepsy (ILAE) as well as the International Bureau for Epilepsy have agreed to consider it to be a disease.[1]

According to the WHO, epilepsy afflicts more than 50 million people worldwide. The prevalence of epilepsy in the developed countries ranges from 5 to 10 cases per 1,000.[2] The developing and tropical countries have reported a higher prevalence rates of epilepsy, ranging from 14 to 57 cases per 1,000 persons.[3,4] Among all these afflicted patients, approximately 30% are refractory to medications5 of which mesial temporal lobe epilepsy is the most common type.[6]

Current literature documents a trend towards a gradual decline in resective temporal lobe epilepsy surgery in certain high-volume epilepsy surgery centres.[7–10] This is somewhat unexpected given that there is class I evidence for the efficacy of temporal resection in medically refractory temporal lobe epilepsy.[6]

The Montreal Neurological Institute has been performing epilepsy surgery since 1934. This retrospective review was undertaken to establish if similar trends to those mentioned above can be confirmed at our centre.

Methods

The records of all adult epilepsy surgery procedures (excluding reoperations) performed by the authors AO and JH were analysed from 1971 to 2015. Data retrieved for analysis included the type of surgery (intracranial recording, resective and neuromodulatory) and the specific surgical target for resection. Procedures were then grouped into temporal resective, extratemporal (ET) resective, and placement of intracranial electrodes.

Temporal resective procedures (temporal) included all surgeries limited to the temporal lobe irrespective of hemispheric lateralisation. It included procedures such as cortico-amygdalohippocampectomy, selective amygdalohippocampectomy, resection of temporal pole, neocortical resections, gliotic tissue, dysplastic tissue, benign tumours, and vascular lesions. Malignant neoplasms were excluded.

Procedures grouped under ET resections included all procedures irrespective of the hemispherical lateralisation, outside the anatomical temporal lobes. These mostly consisted of resection of epileptic foci, for example, dysplastic tissue, benign tumours, vascular lesions and palliative procedures such as corpus callosotomy and hemispherectomy. Other palliative procedures such as vagal nerve stimulation and deep brain stimulation were excluded from the analysis.

The procedures grouped under intracranial electrodes consisted predominantly of stereotactic depth electrode placements which could be frame-based, frameless and robot-assisted irrespective of the hemispheric or intra-hemispheric lateralisation. This group was hence named stereotactic electroencephalogram (SEEG) group as all cases were depth electrode implantations.

Statistical Analysis

The total number of each procedure for each year was retrieved from our database and the frequency distribution of each procedure for each year was plotted. The proportion of each procedure of the total procedures performed, in each year, was calculated. The frequency distribution of each of these groups was then measured for the entire time period. Each group was then compared with the other and plotted. We applied a locally weighted scatterplot smoothing smoother to our data points to model secular trends in procedural volumes and proportions.

The resultant graphs as shown in Figures 1 and 2 indicated a definite trend. We proceeded to analyse whether these trends were statistically significant. We divided the time period into four groups, each consisting of a decade. Since the total number of procedures in the first few years (year 1971–1976) was very small (total number of procedures <= 25), the data from these years were excluded. Qualitative data were represented in the form of frequency and percentage. Quantitative data were represented using mean and standard deviation. Analysis of quantitative data was done using ANOVA with Tukey's multiple comparison. A

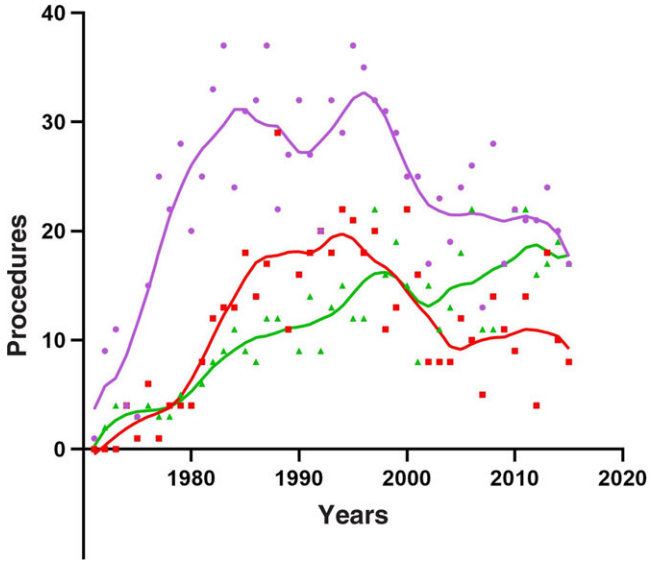

Figure 1: *Secular trends of total epilepsy surgeries at MNI. Temporal; ET; SEEG*

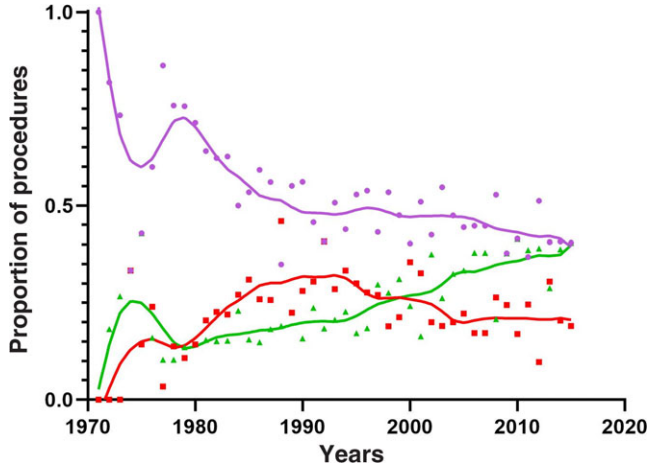

Figure 2: *Secular trends of proportion of epilepsy surgeries during the study period at MNI. TEMP%; ET%; SEEG%*

https://doi.org/10.1017/cjn.2021.115 Published online by Cambridge University Press

Table 1: The percentage of each procedure performed in each decade group against the total number of that procedure performed in the entire study period. Thus, for example, of all the temporal procedures performed during the entire study period, 25.4% were performed in the first decade group. 16.3% and 12.4%, respectively, of ET and SEEG procedures were performed in the first decade group

Time period	Temporal		Extratemporal		Stereotactic electroencephalogram	
	n	%	n	%	n	%
1976–1985	260	25.4	83	16.3	62	12.4
1986–1995	295	28.8	186	36.6	115	23
1996–2005	260	25.4	136	26.8	149	29.8
2006–2015	209	20.4	103	20.3	174	34.8
Total	1024	100	508	100	500	100

p-value of <0.05 was considered to be statistically significant. Analysis was done with IBM SPSS Version 22 for Windows.

Results

A total of 2078 new procedures, meeting these specific criteria, for epilepsy surgery were performed from 1971 to 2015 at the Montreal Neurological Institute (MNI). Temporal procedures constituted the bulk of the proportion of all procedures each year and thus also over the entire study period. However, its share shows a decrease from 2000 onwards. The procedures grouped under ET show a similar gradual rise followed by a decline and then a plateau. The most striking change is seen in the SEEG group which shows an almost linear increase in the number of cases over the years catching up with the total number of temporal procedures towards the end of the study period (Figure 1).

Upon plotting the proportion of procedures for each group in a given year, we find a decrease in percentage of temporal procedures over the years. This decrease in percentage of temporal procedures per year is seen with a concomitant increase in the proportion of ET and SEEG procedures per year. Among the SEEG and ET procedures, the SEEG group shows a steady increase overtaking the temporal group towards the end of the study period (Figure 2).

Analysis looking into the statistical significance of these trends revealed that over the time period studied, the temporal and ET procedures have declined gradually while SEEG increased significantly (Table 1 and Figure 3). During the fourth decade, the percentage of procedures under SEEG shows an increase to 34.8% as compared to 20.4% and 20.3% of temporal and ET procedures (Table 1).

Temporal and ET procedures increased during the second decade but declined during the third and fourth decades (Figure 4). This declining trend was statistically significant ($p < 0.01$ & $p < 0.000$) (Table 2). The data under SEEG procedures show a gradual uptrend which is statistically highly significant ($p < 0.000$).

On multiple comparisons among the four decades, the difference in trends across all decades were significant for SEEG ($p < 0.05$) (Figure 5). However, those trends were significant only from the second to the fourth decade for temporal and ET procedures (Figure 5). Thus, the declining trends of temporal and ET from the second decade onwards and the upward trend of SEEG across all the decades were statistically significant. (Table 2 and Figure 5).

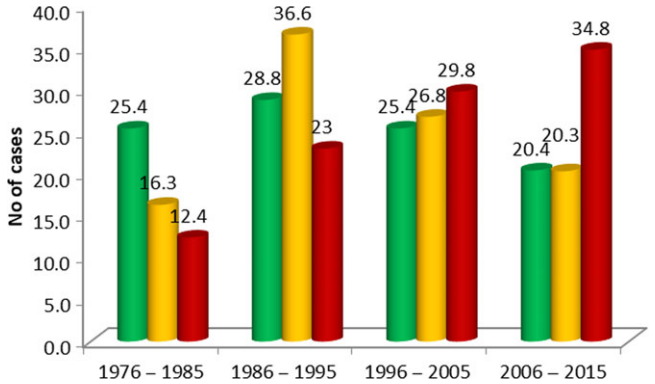

Figure 3: *Graphical representation of Table 1. X-axis showing the time period divided into four decade groups. Y-axis showing the percentage of the total number of procedures for each procedure during the study period. Thus, for example, of all the temporal procedures performed during the entire study period, 25.4% were performed in the first decade group. 16.3% and 12.4% of ET and SEEG procedures, respectively, were performed in the first decade group. ■ Temporal; ■ extratemporal; ■ stereotactic electroencephalogram (EEG)*

Discussion

The strength of our study lies in its homogeneity. The dataset spanning 44 years for epilepsy surgery is derived from a single, tertiary care institution and predominantly by a single surgeon (senior surgeon AO). The second surgeon was trained by AO and in the same institution. Thus, the protocols followed have been consistent. The pool of patients was referred by our epilepsy monitoring unit and also via direct consults to the surgeons. This homogenous dataset shows a consistent decline in the proportion of temporal lobe surgeries and an increase in the share of ET surgeries and intracranial investigations during the study period.

In the period between 2001 and 2005, the data show a drop in the total number of cases. This time coincided with leadership and administrative changes in the non-surgical arm of the epilepsy team.

The proportion of temporal procedures when compared with ET procedures has remained larger throughout (Figure 2). The intracranial investigations show a rising trend among all three procedures, not only as a percentage of the total procedures performed in a year but also as total number of procedures over the years *and this rising trend is seen to be statistically*

https://doi.org/10.1017/cjn.2021.115 Published online by Cambridge University Press

Table 2: ANOVA with Tukey's multiple comparison results upon comparison of the procedures across different decade groups. Here 1, 2, 3 and 4 represent decade groups 1976–1985, 1986–1995, 1996–2005 and 2006–2015, respectively

Procedures	Groups (time in decades)	Mean	Std. deviation	p-Value	Significance
Temporal	1	26.0	6.5	$p < 0.01$	Significant
	2	29.5	5.7		
	3	26.0	5.7		
	4	20.9	4.5		
Extratemporal	1	8.3	5.4	$p < 0.000$	Highly sig
	2	18.6	4.9		
	3	13.6	5.2		
	4	10.3	4.2		
Stereotactic electroencephalogram	1	6.2	2.9	$p < 0.000$	Highly sig
	2	11.5	2.3		
	3	14.9	4.1		
	4	17.4	4.1		

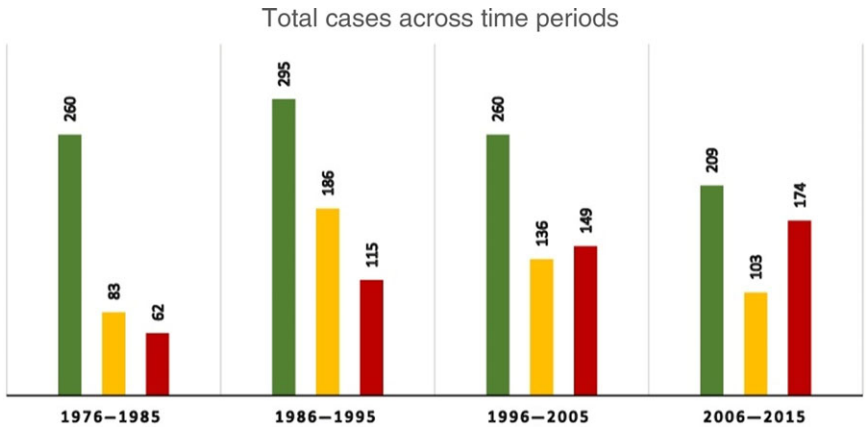

Figure 4: *Graphical representation of Table 1. X-axis showing the time period divided into four decade groups. Y-axis showing the total number of procedures. Temporal; extratemporal; stereotactic electroencephalogram*

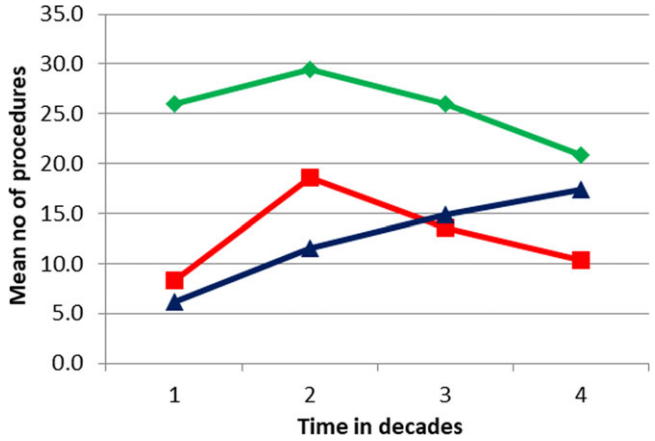

Figure 5: *Graphical representation of Table 2, showing the trends of each procedure as compared to the others across the decade groups. Temporal; extratemporal; stereotactic electroencephalogram*

significant. These trends are similar to the results reported by other groups, suggesting a greater number of ET cases and intracranial investigations over time.[10]

There are a number of possible explanations proposed for this finding.

Changing Referral Patterns

As there is class I evidence of the benefits of temporal lobe resective procedures for temporal lobe epilepsy,[6] an established comprehensive epilepsy surgery programme might be expected to emphasise these cases. Newly trained epilepsy surgeons are likely to be more proficient with temporal lobe resective procedures. It may be the case that these newly trained epilepsy surgeons, when practising, would perform more temporal procedures in peripheral hospitals leading to fewer referrals of temporal lobe epilepsies to tertiary centres. Specifically, our

https://doi.org/10.1017/cjn.2021.115 Published online by Cambridge University Press

catchment area, the province of Quebec, has seen the emergence of the highest number of epilepsy surgery centres in Canada.[11]

The efforts of various groups (both medical and social) have certainly resulted in an increase in the awareness in the general population that epilepsy is a treatable condition. At least three randomised control trials have demonstrated the effectiveness of epilepsy surgery in patients.[6,12,13] We might therefore expect more people reporting the condition and seeking medical help. Temporal lobe cases with concordant findings are now being treated in peripheral centres with basic epilepsy services. It is also documented in literature that most new epilepsy care centres first diagnose and treat epilepsies which have best outcomes and which are concordant from the onset such as temporal lobe epilepsy cases. This would help them build confidence among the population they serve.[14] It is therefore very likely that the more complex and ET cases of epilepsy which need detailed and more advanced evaluation are being referred to tertiary centres as indicated by other recent studies.[10]

Better Newer Anti-Epileptic Drugs

The continuous development of newer and potentially better anti-epileptic drugs may play a role in decreasing referral patterns.[15,16]

Subspecialisation in Neurosurgery

Although the trend of subspecialisation started in the 1970s, it has clearly changed the practice of neurosurgery in the past two decades at our centre. More and more neurosurgeons are pursuing subspecialisation in different fields. The most common areas have been spine, paediatric, cerebrovascular, skull base, functional and epilepsy, respectively[17] in large tertiary centres. This has naturally led to a redistribution of patients among the subspecialities. Thus, a patient presenting with seizures will not necessarily be managed by an epilepsy surgeon. For example, a patient with epilepsy diagnosed with an arteriovenous malformation or with a cavernoma in the temporal lobe could be referred to a vascular surgeon. Similarly, many low-grade tumours (dysembryoplastic neuroepithelial tumors gliomas and gangliogliomas) responsible for temporal lobe epilepsy may be referred to an Oncology team. This appears to be true in our centre and may likely have a similar impact on other tertiary/quaternary comprehensive epilepsy centres.

Decreasing Incidence of Mesial Temporal Sclerosis

Epidemiological studies have underlined the strong association of prolonged febrile seizures and febrile status epilepticus with temporal lobe epilepsy. Studies have emphasised the importance of early and better management of childhood febrile seizures which may prevent future temporal lobe epilepsy. These studies have led to aggressive protocols for febrile seizures throughout the developed world. There are studies linking mesial temporal sclerosis (MTS) to perinatal insults. Thus, an overall better perinatal care and better management of febrile seizures in developed nations may have led to decreasing incidence of MTS.[18–20] Studies have demonstrated that lesion-associated epilepsies may be higher in low-/middle-income countries (LMICs), owing to a high prevalence of malaria, other central nervous system infestations and febrile seizures. These may be the factors for developing hippocampal sclerosis.[21] We believe that a similar study of practice profiles of epilepsy surgery in LMIC may reveal a likely different trend of practice profile for epilepsy surgery, given the different epidemiological processes involved.

Conclusion

Our study involving a homogenous dataset spanning nearly 50 years shows a decline in temporal lobe surgeries for epilepsy and a steady increase in intracranial investigations for complex cases despite the class I evidence of its effectiveness. This corroborates the trends in epilepsy surgery practice profiles in tertiary centres of developed countries.

Acknowledgements

Dr. Baruah received financial support from a Mark Rayport & Shirley Ferguson Fellowship in Epilepsy Surgery of the Montreal Neurological Institute and Hospital during the conduct of the study. The authors thank Dr. Oliver A. Lasry, MD, PhD, in the department of Neurosurgery, Montreal Neurological Institute for his advice in the statistical analysis of the data.

Statement of Authorship

JAH was responsible for conception and design of the study. SB was responsible for acquisition and analysis of data. JAH and SB were responsible for drafting a significant portion of the manuscript. AO is the senior surgeon responsible for performing a large proportion of the cases and maintaining the records of his large volume of cases.

Disclosures

Dr. Baruah received support from a Mark Rayport & Shirley Ferguson Rayport Fellowship in Epilepsy Surgery of the Montreal Neurological Institute and Hospital during the conduct of the study. Dr. Hall and Dr. Olivier have nothing to disclose.

References

1. Fisher RS, Acevedo C, Arzimanoglou A, et al. A practical clinical definition of epilepsy. Epilepsia. 2014;55:475–82.
2. Bell GS, Sander JW. CPD—Education and self-assessment. The epidemiology of epilepsy: the size of the problem. Seizure. 2001;10:306–16.
3. Burneo JG, Tellez-Zenteno J, Wiebe S. Understanding the burden of epilepsy in Latin America: a systematic review of its prevalence and incidence. Epilepsy Res. 2005;66:63–74.
4. Carpio A, Hauser WA. Epilepsy in the developing world. Curr Neurol Neurosci Rep. 2009;9:319–26.
5. Kwan P, Brodie MJ. Early identification of refractory epilepsy. N Engl J Med. 2000;342:314–19.
6. Wiebe S, Blume WT, Girvin JP, et al. A randomized, controlled trial of surgery for temporal-lobe epilepsy. N Engl J Med. 2001;345:311–8.
7. Carlson C. The changing face of epileptology? Results of the initial Q-PULSE survey. Epilepsy Curr. 2013;13:305–7.
8. Neligan A, Haliasos N, Pettorini B, et al. A survey of adult and pediatric epilepsy surgery in the United Kingdom. Epilepsia. 2013;54:e62–5.
9. Kumlien E, Mattsson P. Attitudes towards epilepsy surgery: a nationwide survey among Swedish neurologists. Seizure. 2010;19:253–5.
10. Jehi L, Friedman D, Carlson C, et al. The evolution of epilepsy surgery between 1991 and 2011 in nine major epilepsy centers

https://doi.org/10.1017/cjn.2021.115 Published online by Cambridge University Press

across the United States, Germany, and Australia. Epilepsia. 2015;56:1526–33.
11. Bui KA, Wahby S, Jetté N, et al. Inequalities in the utilisation of epilepsy surgery for adults and children in Canada. Epilepsy Res. 2018;148:63–8.
12. Engel J, McDermott MP, Wiebe S, et al. Early surgical therapy for drug resistant temporal lobe epilepsy: a randomized trial. JAMA. 2012;307:922–30.
13. Dwivedi R, Ramanujam B, Chandra PS, et al. Surgery for drug-resistant epilepsy in children. N Engl J Med. 2017;377:1639–47.
14. Sylaja PN, Radhakrishnan K. Surgical management of epilepsy. Problems and pitfalls in developing countries. Epilepsia. 2003;44:48–50
15. Benbadis SR, Heriaud L, Tatum WO, Vale FL. Epilepsy surgery, delays and referral patterns—are all your epilepsy patients controlled? Seizure. 2003;12:167–70.
16. Rho JM, White HS. Brief history of anti-seizure drug development. Epilepsia Open. 2018;3:114–19.
17. Jimenez DF. Current subspecialisation trends in neurosurgery. Neurosurgery. 1997;41:728–9.
18. Helmstaedter C, May TW, von Lehe M, et al. Temporal lobe surgery in Germany from 1988 to 2008: diverse trends in etiological subgroups. Eur J Neurol. 2014;21:827–34.
19. Choy M, Dube CM, Ehrengruber M, et al. Inflammatory processes, febrile seizures, and subsequent epileptogenesis. Epilepsy Curr. 2014;14:15–22.
20. Dube CM, Ravizza T, Hamamura M, et al. Epileptogenesis provoked by prolonged experimental febrile seizures: mechanisms and biomarkers. J Neurosci. 2010;30:7484–94.
21. Preux P-M, Druet-Cabanac M. Epidemiology and aetiology of epilepsy in sub-Saharan Africa. Lancet Neurol. 2005; 4:21–31.

https://doi.org/10.1017/cjn.2021.115 Published online by Cambridge University Press