Role of Electrocorticography at Surgery for Lesion-related Frontal Lobe Epilepsy

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ABSTRACT: *Background:* The prognostic significance of epileptiform activity (EA) recorded intra-operatively at electrocorticography (ECOG) in patients with lesion-related frontal lobe epilepsy (FLE) is unknown. *Methods:* The results of ECOG performed in 22 patients with intractable FLE and a circumscribed frontal lobe structural lesion were compared with postoperative seizure control. Three patients underwent re-operation for a total of 25 cases, 23/25 with post-resection ECOG. Lesions were neoplasms (12), hamartomas (6) and arteriovenous malformations (4). *Results:* Outcomes were 15/25 Class I, 5/25 Class III and 5/25 Class IV (Engel classification). Class I outcome was associated with pre-excision EA recorded from ≤ 2 gyri ($p < 0.05$) and absence of EA, or EA limited to the resection border, at post-excision ECOG ($p < 0.01$). Complete lesion excision was highly correlated with Class I outcome ($p < 0.001$). The most significant correlations were seen when ECOG and lesionectomy variables were considered together: all 12 cases with complete lesionectomy and absent post-excision EA distant to the resection border had Class I outcome ($p < 0.00015$) and all 13 cases with complete lesionectomy and pre-excision EA recorded from ≤ 2 gyri had Class I outcome ($p < 0.00005$). *Conclusions:* Postoperative seizure control in lesion-related FLE is assured in the setting of complete lesion resection with pre-excision EA recorded from ≤ 2 gyri and no post-excision EA distant to the resection border; complete lesion excision is of paramount importance.

RÉSUMÉ: Le rôle de l'électrocorticographie peropératoire dans l'épilepsie du lobe frontal associée à une lésion. *Introduction:* La signification pronostique de l'activité épileptiforme (AÉ) enregistrée par électrocorticographie (ÉCOG) peropératoire chez les patients atteints d'épilepsie frontale (ÉF) associée à une lésion est inconnue. *Méthodes:* Nous avons étudié les résultats de l'ÉCOG effectuée chez 22 patients ayant une ÉF réfractaire au traitement et une lésion circonscrite du lobe frontal en relation avec le contrôle des crises en postopératoire. Trois patients ont subi une deuxième intervention pour un total de 25 cas, dont 23/25 ÉCOG post-résection. Les lésions étaient des néoplasmes (12), des hamartomes (6) et des malformations artérioveineuses (4). *Résultats:* Selon la classification d'Engel, 15/25 ont été classés I, 5/25 ont été classés III et 5/25 IV. Les résultats de classe I étaient associés à une AÉ préexcision enregistrée de ≤ 2 gyri (p < 0,05) et absence d'AÉ, ou AÉ confinée à la limite de la résection à l'ÉCOG post-excision (p < 0,01). Une excision complète de la lésion était hautement corrélée à un résultat de classe I (p < 0,001). Les corrélations les plus significatives ont été observées quand les variables ÉCOG et excision de la lésion étaient considérées ensemble: les 12 cas chez qui l'excision de la lésion était totale et en l'absence d'AÉ post-excision à distance de la limite de résection avaient des résultats de classe I (p < 0,00015) et les 13 cas chez qui l'excision de la lésion était totale et qui avaient une AÉ préexcision enregistrée à ≤ 2 gyri avaient des résultats de classe I (p < 0,00005). *Conclusions:* Le contrôle des crise en postopératoire dans l'ÉF reliée à une lésion est assuré dans le contexte de la résection complète de la lésion avec une AÉ pré-excision de ≤ 2 gyri et pas d'AÉ post-excision à distance de la limite de résection; l'excision complète de la lésion est donc très importante.

Outcome with respect to seizure control after surgery for frontal lobe epilepsy (FLE) is poorer than for temporal lobe epilepsy, especially in the absence of a visible structural lesion.[1-8] The less favorable outcome results, and the small but real risks of surgery, have led to the suggestion that early consideration for surgical management of intractable extratemporal epilepsy be limited to patients having identifiable structural lesions,[9] with both foreign tissue lesions and posttraumatic focal encephalomalacia identified as good prognostic indicators.[10-11]

Recent reports indicate that the extent of interictal epileptiform activity (EA) recorded at electrocorticography (ECOG) is also of prognostic significance in surgery for FLE. Specifically, poorer outcomes are associated with large epileptogenic zones and persistent post-resection EA while, in contrast, favorable

outcomes are associated with restricted zones of pre-resection EA and absence of post-resection EA.[12-13]

The findings at ECOG in cases of lesional FLE have been described in the literature for only a very small number of patients, typically as part of larger series with lesions including the central region and more posterior structures above and below the Sylvian fissure.[14-15] With respect to epilepsy surgery, the central region, comprising the pre- and post-central gyri, is considered as a distinct entity,[3] and thus true lesional FLE is restricted to patients with lesions in the frontal lobe anterior to the pre-central gyrus.

To examine the role of ECOG in surgery for FLE related to foreign tissue lesions, post-surgical seizure control was compared with the distribution of pre- and post-excision EA, and with the extent of lesion resection, in a series of patients with lesional FLE.

MATERIALS AND METHODS

The study group comprised 22 patients with intractable partial epilepsy related to a circumscribed foreign tissue lesion in one frontal lobe. The patients were part of a larger review of consecutive frontal lobe surgical cases performed with pre- and post-excision ECOG (and re-operations) at the Montreal Neurological Hospital between 1970-1994 plus the single case of lesion-related FLE operated at The Toronto Hospital since 1995. Ten of the patients with non-tumoral lesions were included in another report.[13] Three patients underwent re-operation with ECOG for a total of 25 records. Lesions included neoplasms (3 oligodendrogliomas, 3 low grade astrocytomas, 2 ganglio-gliomas, 1 mixed astrocytoma/oligodendroglioma, 1 protoplasmic astrocytoma, 1 anaplastic astrocytoma, 1 meningioma), hamartomas (4/6 with diagnosis of tuberous sclerosis) and arteriovenous malformations (AVMs; 4). All patients underwent extensive neuropsychological and neuroimaging investigations prior to surgery as well as prolonged EEG monitoring with extracranial +/- intracranial electrodes. Cases involving primarily the central region (pre- and post-central gyrus) were not included. Clinical outcomes were obtained from review of patients' hospital and office records and classified according to Engel.[16] Mean follow-up was 5.8 years (range = 1-17 years). A summary of patient data is given in Table 1.

ECOG was performed under either neuroleptanalgesia with fentanyl and droperidol or light general anesthesia with nitrous oxide supplemented with fentanyl. Nitrous oxide, as used during ECOG at the Montreal Neurological Hospital, has not been noted to affect the quantity of EA recorded at ECOG, an observation recently confirmed in a controlled trial.[17] Thus, cases performed with and without nitrous oxide were considered together. Depth of anesthesia was similar for both pre- and post-excision recordings.

Pre-excision recordings utilized sixteen carbon ball electrodes placed in four parallel rows of four electrodes each to record from the first, second and third frontal gyri, including the central region, as well as (usually) the superior temporal gyrus. Referential montages were referred to a bone margin electrode. Post-excision recordings typically utilized the same four row electrode array, extending posteriorly from the resection border to include the central region as well as the superior temporal gyrus. Post-excision EA was that present after the final cortical

resection had been performed. Pre-excision chemical activation with methohexital (30-50 mg) was carried out in 12 patients (cases 7-13, 15, 17r, 18r-20) and with thiopentone in 1 patient (case 22). Only in one case did methohexital induce the appearance of EA (Table 1). Post-excision methohexital activation was undertaken in 11 cases (40 mg in patients 8-13, 20, 21; 10-20 mg in patients 7, 14, 18); classification of post-excision EA abundance (see below) was not changed after methohexital administration in any case. Duration of pre- and post-excision recordings averaged 10 minutes.

EA (sharp waves, spikes and multiple spikes) was identified at ECOG using the same criteria outlined for scalp EEG by Gloor.[18] Pre-excision EA was classified according to gyral distribution as present over 1, 2 or ≥ 3 gyri (i.e., first frontal, second frontal, third frontal, central and/or temporal). Pre-excision EA restricted to one gyrus was considered "focal", that recorded from 2 gyri "regional" and that recorded from ≥ 3 gyri "lobar" or "multilobar".

When present, post-excision EA was classified as either (a) restricted to the resection border, if recorded only from ≥ 1 electrode situated adjacent to the excision margin, or (b) distant to the resection border, if recorded from ≥ 1 electrode not situated adjacent to the excision margin. Electrodes adjacent to the resection border were typically situated within 5-10 millimetres of the excision margin. Abundance of post-excision EA was classified using a previously described "spike-per-page" schema,[19] based on visual analysis of representative 60 second epochs, into four groups of increasing spike discharge frequency: A = ≤ 6 spikes/minute; B = > 6-12 spikes/minute; C = > 12-24 spikes/minute; D = > 24 spikes/minute.

The type of surgical excision in the majority of cases (16/25) was "lesionectomy and corticectomy" (Table 1). The size of lesionectomy was dependent on lesion size: the extent of peri-lesional corticectomy was decided by the surgeon, influenced by the findings at ECOG. The remaining cases underwent larger frontal resections, as described by Olivier:[7] frontal lobectomies extended back to the pre-central sulcus; anterior (subtotal) lobectomies included most of the frontal lobe, sparing a 1.5-2 centimetre strip of cortex in front of the pre-central gyrus; and mediodorsal resection included the first frontal gyrus. Subpial cortical transections were performed in the lower central region in addition to lesionectomy and corticectomy in one patient (case 20). Completeness of lesion excision was estimated by the surgeon and verified by comparison of post-operative CT or MRI with pre-operative neuroimaging.

Statistical analyses utilized the Fisher exact test for discrete variables and the Mann-Whitney U-test for continuous variables. All p values given are for two-tailed tests.

RESULTS

Outcomes were 15/25 (60%) Class I, 5/25 (20%) Class III and 5/25 (20%) Class IV. Side of resection (11/25 left hemisphere) was not correlated with outcome.

The gyral distribution of pre-excision EA is outlined for each patient in Table 1. No pre-excision EA was recorded in 8 patients. In 4 patients pre-excision EA was restricted to one gyrus in proximity to the lesion (and, in case 18r, to the previous lesionectomy margin). Ten of these 12 patients with absent or focal pre-excision EA had a Class I outcome. Seven patients had

Table 1: Summary of patient data.

| Patient | Age | Side | Pathology | Pre-excision ECOG EA | | | | | Surgery | Lesion excision | Post-excision ECOG EA | | Outcome | F/U (years) |
				F1	F2	F3	C	T			Border	Distant		
1	15	L	Oligodendroglioma	+	+	+	+	+	L&C	Complete*		C	IV	2
1r	17	L	Gliosis	nr	+	+	+	nr	ASL	Complete		B	III	5
2	28	R	Oligodendroglioma	+	–	–	–	–	ASL	Complete	–	–	I	7
3	25	R	Meningioma + gliosis	–	–	–	–	nr	L&C	Complete	–	–	I	17
4	17	R	Hamartoma	+	+	+	+	+	Lob	Incomplete**		D	IV	10
5	21	L	AVM	+	+	–	–	nr	L&C	Complete	–	–	I	12
6	26	L	Astrocytoma (low grade)	+	–	–	–	–	L&C	Complete	–	–	I	10
7	10	R	AVM	–	+	+	–	nr	L&C	Complete*	A		I	6
8	20	R	Astrocytoma (low grade)	+a	+a	+	–	+	Lob	Incomplete	–	–	III	5
9	27	L	Astrocytoma (low grade)	+	–	+	–	–	L&C	Incomplete*		C	III	3
10	19	L	Hamartoma	–	+	–	–	–	MD	Complete**	–	–	I	7
11	37	L	Oligodendroglioma	–	–	–	–	–	L&C	Complete	–	–	I	7
12	35	L	Mixed astrocytoma/oligodendroglioma	+	+	–	–	–	L&C	Complete**	–	–	I	8
13	57	L	Anaplastic astrocytoma	–	–	–	–	–	L&C	Incomplete	–	–	I	4
14	5	R	Tuberous sclerosis	+	+	+	+	+	ASL	Incomplete*		D	IV	7
15	30	L	Ganglioglioma	–	–	–	–	nr	L&C	Incomplete	–	–	III	2
16	8	R	Protoplasmic astrocytoma	+	+	+	+	nr	ASL	Complete		B	I	10
17	10	R	Tuberous sclerosis	–	+	+	–	–	L&C	Incomplete	–	–	IV	2
17r	12	R	Tuberous sclerosis	–	–	–	–	–	ASL	?Incomplete	No post	recording	IV	8
18	13	R	Tuberous sclerosis	–	+	+	–	–	L&C	Incomplete		B	III	3
18r	16	R	Tuberous sclerosis	–	+	nr	–	–	ASL	?Complete*	A		I	5
19	38	R	AVM	–	–	–	–	–	L&C	Complete	–	–	I	2
20	20	R	AVM	–	–	+	+	–	L&C + ct	Complete	–	–	I	1
21	30	R	Tuberous sclerosis	–	–	–	–	nr	L&C	Complete	–	–	I	1
22	25	L	Ganglioglioma	–	–	–	–	nr	L&C	Complete	No post	recording	I	1

aEA only after methohexital administration.
*Resection extended once because of post-excision ECOG.
**Resection extended twice because of post-excision ECOG.
A = spike frequency ≤ 6 spikes/minute; B = spike frequency > 6-12 spikes/minute; C = spike frequency > 12-24 spikes/minute; D = spike frequency >24 spikes/minute; F1, F2, F3, C, T = first frontal, second frontal, third frontal, central, temporal gyri, respectively; Lob = frontal lobectomy; ASL = anterior (subtotal) lobectomy; MD = mediodorsal resection; L&C = lesionectomy and corticectomy; ct = subpial cortical transection (central region); F/U = follow-up; r = re-operation; nr = no recording.

a regional (2 gyri) distribution of pre-excision EA (Figure): 4 of these 7 patients had a Class I outcome.

Table 2A shows the significant correlation between the distribution of pre-excision EA and outcome, with poorer (Class III or IV) outcomes most likely in the presence of lobar or multilobar pre-excision EA. The correlation is stronger if patients with regional pre-excision EA are left out of the comparison: i.e., 10/12 patients with absent or focal EA in Class I versus 5/6 patients with lobar or multilobar EA in Class III or IV ($p < 0.03$).

Presence or absence, and relative abundance, of post-excision EA is given for each patient in Table 1. Fourteen patients had no post-resection EA. Two other patients showed infrequent EA

restricted to the resection border (Figure). Thirteen of these 16 patients had a Class I outcome. The remaining 7 patients had EA recorded distant to the resection border: 6 of these 7 patients had a Class III or IV outcome. Table 2B shows the significant correlation between persistent post-excision EA recorded distant to the resection border and poorer outcome. A trend was noted towards poorer outcomes with increasing abundance of distant post-resection EA (e.g., both Group D patients had a Class IV outcome while, among Group B patients, 1/3 had a Class I outcome and 2/3 had a Class III outcome) but numbers were insufficient for further analysis.

Lesion excision was judged to be complete in 16/25 patients (Table 1). The initial resection was extended in 8 patients based on
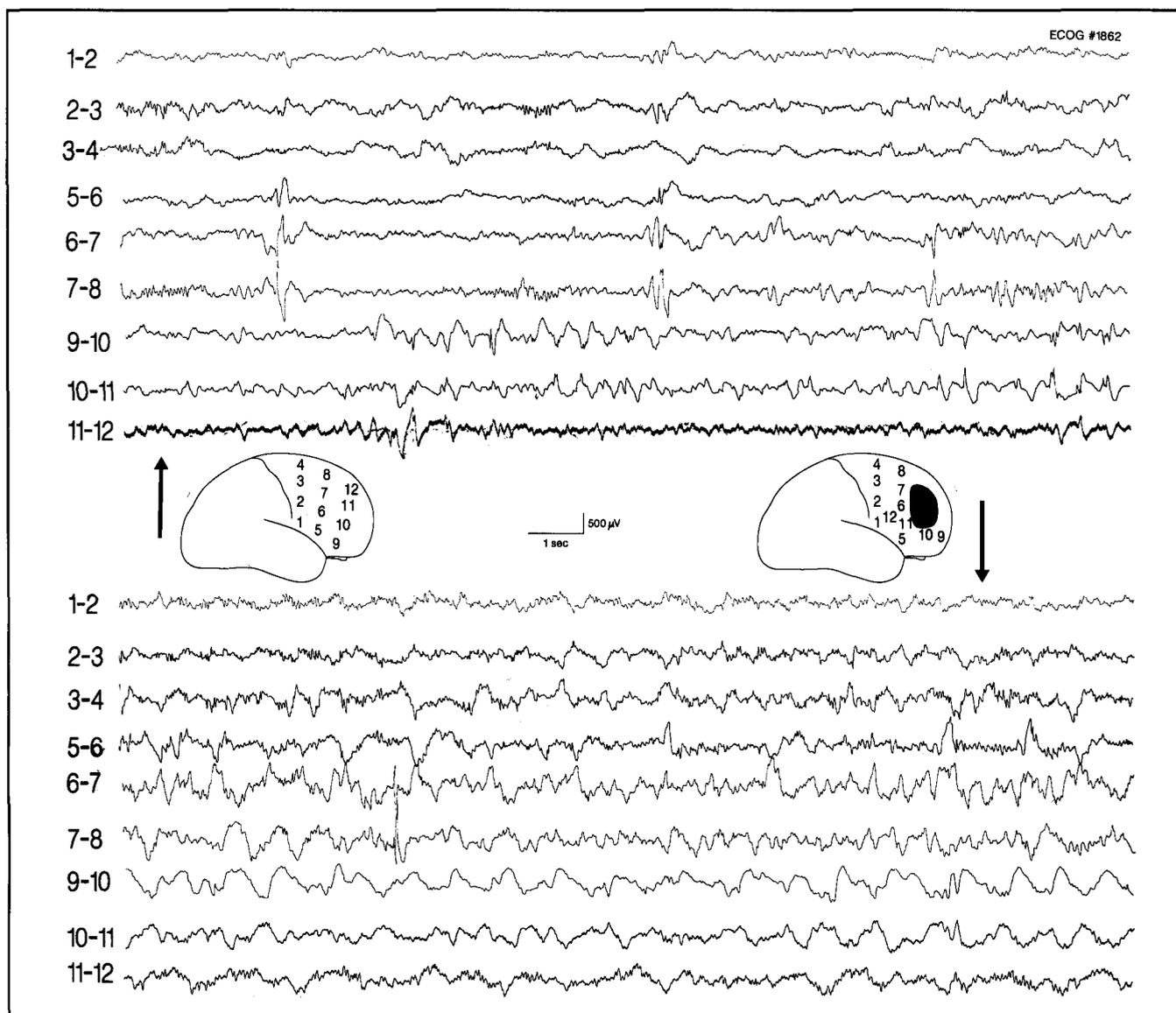
Figure: Patient 7 (Top) Regional pre-excision EA (F2, F3) around AVM. (Bottom) Single post-excision spike at resection border (Class I outcome).

the findings at post-excision ECOG (Table 1). Incomplete lesion resections were due either to encroachment of pre-central and/or cingulate cortex (patients 8, 9, 13, 15, 17) or inability to determine the boundaries of hamartomatous lesions (patients 4, 14, 18). Table 2C shows the highly significant correlation between complete lesion resection and Class I outcome.

Combining ECOG and lesionectomy variables further increased the significance of correlations with outcome. All patients (13/13) with complete lesionectomy and pre-excision EA recorded from ≤ 2 gyri and all patients (12/12) with complete lesionectomy and no post-excision EA recorded distant to the resection border had Class I outcome (Table 3).

Though not a focus of this study, associations between outcome and patient age or type of pathology were noted. All patients with AVMs had Class I outcome. A majority (66%) of patients with hamartomatous lesions had a poorer outcome

whereas a similar majority of patients with neoplastic lesions had a Class I outcome, including one patient (patient 13) with a high grade astrocytoma who remained seizure-free until death from tumor recurrence 4 years after surgery. An association between Class I outcome and older mean age at surgery was noted; however this trend was not statistically significant ($0.05 < p < 0.1$).

Discussion

The present study sought to examine the role of ECOG in the surgical management of patients with FLE related to circumscribed foreign tissue lesions, including neoplasms, which are usually considered separately in assessments of outcome after epilepsy surgery.[3,20] The results support previous descriptions of generally favorable outcomes after surgery for epilepsy related to neoplastic lesions[14,15,20] and confirm the significant correlations

Table 2:

A. Pre-excision EA and outcome.

	Class I	Class III and IV	Total
EA ≥ three gyri	1	5	6
EA ≤ two gyri	14	5	19
Total	15	10	25

$(p < 0.05)$

B. Post-excision EA (distant to resection border) and outcome.

	Class I	Class III and IV	Total
Distant EA	1	6	7
Absent	13	3	16
Total	14	9	23

$(p < 0.01)$

C. Completeness of lesion excision and outcome.

	Class I	Class III and IV	Total
Complete	14	2	16
Incomplete	1	8	9
Total	15	10	25

$(p < 0.001)$

Table 3:

A. Complete lesionectomy with no distant post-excision EA and outcome.

	Class I	Class III and IV	Total
Complete resection + absent distant EA	12	0	12
Incomplete resection and/or distant EA	2	9	11
Total	14	9	23

$(p < 0.00015)$

B. Complete lesionectomy with pre-excision EA from ≤ 2 gyri and outcome.

	Class I	Class III and IV	Total
Complete resection + EA ≤ 2 gyri	13	0	13
Incomplete resection and/or EA ≥ 3 gyri	2	10	12
Total	15	10	25

$(p < 0.00005)$

between restricted zones of pre-excision EA, absence of post-excision EA, and favorable outcome in FLE.[13]

The extent of the cortical distribution of pre-excision EA was found to vary substantially between patients, irrespective of the type of underlying lesion (i.e., neoplasm, AVM or hamartoma). The potential relationships between circumscribed structural lesions and cortical epileptogenicity are numerous: tumors have been suggested to induce epileptogenicity through infiltrative, edematous or compressive disruption of normal cortical architecture and metabolism[14,21] or through disconnection and subsequent denervation supersensitivity of peri-tumoral cortex;[22] AVMs may induce epileptogenicity in peri-lesional cortex secondary to either local ischemic "steal" phenomena or hemosiderin-induced cortical damage related to previous hemorrhage;[23,24] cortical dysplastic lesions have been convincingly shown to have an intrinsic epileptogenicity related to their abnormal cytoarchitecture.[25] The potential for an epileptogenic lesion to induce distant EA through secondary epileptogenesis has been demonstrated in patients with neoplastic lesions.[26]

That the cortical distribution of pre-excision EA may extend considerably beyond the boundaries of the visible lesion requires that a decision be made at the time of surgery regarding how much (if any) epileptogenic cortex should be resected in addition to the lesion to ensure the greatest likelihood of post-operative seizure control. The surgical options range from lesionectomy alone (which is inevitably associated with removal of some peri-lesional cortex), through lesionectomy and (ECOG-influenced) peri-lesional corticectomy of epileptogenic cortex, to more extensive resections performed to remove widespread ECOG-defined epileptogenic cortex, often located many gyri removed from the visible (or imaging-documented) lesion.

The practice at the Montreal Neurological Hospital has traditionally been to attempt as complete a resection of the structural lesion as possible, with additional corticectomy performed in adjacent and surgically-amenable areas showing active EA at ECOG.[3,7,21] Persistent spiking at post-resection ECOG has often led to extension(s) of the original resection to diminish the quantity of residual EA, though total eradication of all spikes has not been a necessary goal.

The surgical resections in this series followed the traditional practice of the Montreal Neurological Hospital: it is thus impossible to state with certainty whether the excisions (or, in one case, cortical transections) of peri-lesional epileptogenic cortex or extensions of initial resections influenced by the findings at ECOG contributed to better outcomes. Other reports have suggested that excision of epileptogenic cortex in addition to lesionectomy may increase the likelihood of favorable outcome after surgery for lesion-related epilepsy[3,14,21] though this has not been a consistent finding.[15] There is no correlation between size of resection and outcome in non-tumoral FLE: in fact a trend has been demonstrated towards better outcomes with smaller resections.[13] Likewise, in this study, larger excisions were associated with poorer outcomes in a majority (5/8) of patients (Table 1). This implies that, confronted with a lobar or multilobar distribution of pre-excision EA at ECOG in FLE, one is likely faced with an extensive zone of epileptogenicity that is in part either independent of the visible structural lesion or, especially in the case of hamartomas, indicative of more widespread histopathologic involvement below the level of visual (or MRI) resolution, which may not be surgically treatable.

With respect to the indications for extension of the resection based on the post-excision ECOG findings, the lack of significance of post-excision spiking limited to the resection border has been documented previously[13] and corroborated in the two such patients in this study (patients 7 and 18r). Fifty percent (4/8) of the patients in this study with extension of the initial

resection performed because of persistent post-excision EA had a Class III or IV outcome: three of these four patients with poor outcomes had multilobar EA at pre-excision ECOG, indicative of widespread cortical epileptogenicity unlikely to result in a favorable post-surgical outcome no matter how large the frontal excision (see above).

It has been shown that excision of all EA at ECOG in addition to maximal lesionectomy is most likely to result in a favorable outcome in cases of focal cortical dysplasia.[27] While this would appear to be a definite indication for ECOG-guided corticectomy (as presumably the ECOG gives some indication of the microscopic extent of the dysplastic abnormality), it is frequently not possible to surgically remove the entire extent of such dysplastic, epileptogenic cortex.

The indication for elimination of central area EA through cortical transections[28] performed in addition to an adjacent frontal resection, while theoretically attractive, will remain unknown in the absence of a controlled trial. Certainly such a procedure can be safely performed and may be associated with a very favorable outcome (e.g., patient 20).

Though not a primary goal of this study, relationships between pathology and post-surgical outcome were noted. All patients with AVMs had a Class I outcome, as did a majority of patients with neoplastic lesions, including the sole patient with a high grade infiltrative glioma (see results). In contrast, consistent with previous findings,[25] a majority of cases with hamartomatous lesions had a poorer outcome. One could argue against including patients with tuberous sclerosis in a group of focal lesional cases, as the pathological abnormality in these patients is known to be multifocal. They were included in this study as current practice tends to regard these cases as "focal" if the clinical and electrophysiological evidence indicates one visible tuber to be responsible for a patient's epileptic symptomatology.[9,14] Given the poorer outcomes after surgery for hamartomatous disease in general, this viewpoint may need to be revised in the future.

Overall, the results of this study indicate the paramount importance of complete lesion excision, where possible, in the surgical management of FLE related to circumscribed structural lesions. The additional benefit gained from peri-lesional corticectomy guided by ECOG remains unclear and requires comparison with a similar series of patients with lesional FLE operated without ECOG-influenced corticectomies, such as has recently been done for (non-lesional) temporal lobe epilepsy.[29] The additional prognostic significance to be gained from ECOG is however very striking, with a seizure-free outcome assured in the setting of complete lesion resection with pre-excision EA from ≤ 2 gyri and no post-excision EA distant to the resection border.

Finally, it should be noted that recent advances in magnetoencephalography and magnetic source imaging (MSI) have been accompanied by a renewed interest in interictal spike localization in the planning of epilepsy surgery, especially for extratemporal epilepsy.[30] As EA identified by MSI has been shown to correspond well with EA recorded at ECOG,[30,31] the pre-resection findings of this study and others[5,13] may be of prognostic use in the evaluation of patients with FLE investigated noninvasively with MSI.

REFERENCES

1. Rasmussen T. Surgical therapy of frontal lobe epilepsy. Epilepsia 1963; 4: 181-198.
2. Talairach J, Bancaud J, Szikla G, et al. Approche nouvelle de la neurochirurgie de l'épilepsie. Methodologie stéréotaxique et résultats thérapeutiques. Neurochirurgie 1974; 20 (Suppl. 1): 1-240.
3. Rasmussen T. Tailoring of cortical excisions for frontal lobe epilepsy. Can J Neurol Sci 1991; 18: 606-610.
4. Quesney F, Constain M, Rasmussen T, Olivier A, Palmini A. Presurgical EEG investigation in frontal lobe epilepsy. Epilepsy Res 1992 (Suppl. 5): 55-69.
5. Salanova V, Morris H, Van Ness P, et al. Comparison of scalp electroencephalogram with subdural electrocorticogram recordings and functional mapping in frontal lobe epilepsy. Arch Neurol 1993; 50: 294-299.
6. King D, Smith J, Murro A, et al. Outcome of frontal resection for intractable seizures. Neurology 1993; 43 (Suppl. 2): 417.
7. Olivier A. Surgery of frontal lobe epilepsy. In: Jasper H, Riggio S, Goldman-Rakic P, eds. Epilepsy and the Functional Anatomy of the Frontal Lobe. New York: Raven Press, 1995: 321-348.
8. Quesney F, Cendes F, Olivier A, Dubeau F, Andermann F. Intracranial electroencephalographic investigation in frontal lobe epilepsy. In: Jasper H, Riggio S, Goldman-Rakic P, eds. Epilepsy and the Functional Anatomy of the Frontal Lobe. New York: Raven Press, 1995: 243-258.
9. Cascino G, Sharbrough F, Trenerry M, et al. Extratemporal cortical resections and lesionectomies for partial epilepsy: complications of surgical treatment. Epilepsia 1994; 35: 1085-1090.
10. Cukiert A, Olivier A, Andermann F. Posttraumatic frontal lobe epilepsy with structural changes: excellent results after cortical resection. Can J Neurol Sci 1996; 23: 114-117.
11. Kazemi N, So E, Mosewich R, et al. Resection of frontal encephalomalacias for intractable epilepsy: outcome and prognostic factors. Epilepsia 1997; 38: 670-677.
12. Salanova V, Quesney F, Rasmussen T, Andermann F, Olivier A. Reevaluation of surgical failures and the role of reoperation in 39 patients with frontal lobe epilepsy. Epilepsia 1994; 35: 70-80.
13. Wennberg R, Quesney F, Olivier A, Rasmussen T. Electrocorticography and outcome in frontal lobe epilepsy. Electroencephalogr Clin Neurophysiol 1998; 106: 357-368.
14. Awad I, Rosenfeld J, Ahl F, Hahn J, Lüders H. Intractable epilepsy and structural lesions of the brain: mapping, resection strategies, and seizure outcome. Epilepsia 1991; 32: 179-186.
15. Britton J, Cascino G, Sharbrough F, Kelly P. Low-grade glial neoplasms and intractable partial epilepsy: efficacy of surgical treatment. Epilepsia 1994; 35: 1130-1135.
16. Engel J. Outcome with respect to epileptic seizures. In: Engel J, ed. Surgical Treatment of the Epilepsies. New York: Raven Press, 1987: 553-571.
17. Hosain S, Nagarajan L, Fraser R, Van Poznak A, Labar D. Effects of nitrous oxide on electrocorticography during epilepsy surgery. Electroencephalogr Clin Neurophysiol 1997; 102: 340-342.
18. Gloor P. Contributions of electroencephalography and electrocorticography to the neurosurgical treatment of the epilepsies. In: Purpura D, Penry J, Walter R, eds. Neurosurgical Management of the Epilepsies. New York: Raven Press, 1975: 59-105.
19. Wennberg R, Quesney F, Villemure J-G. Epileptiform and non-epileptiform paroxysmal activity from isolated cortex after functional hemispherectomy. Electroencephalogr Clin Neurophysiol 1997; 102: 437-442.
20. Rasmussen T. Surgical treatment of complex partial seizures: results, lessons and problems. Epilepsia 1983; 24 (Suppl. 1): 65-76.
21. Penfield W, Jasper H. Epilepsy and the Functional Anatomy of the Human Brain. Boston: Little, Brown, 1954.
22. Echlin F. The supersensitivity of chronically "isolated" cerebral cortex as a mechanism in focal epilepsy. Electroencephalogr Clin Neurophysiol 1959; 11: 697-722.
23. Yeh H-S, Tew J, Gartner M. Seizure control after surgery on cerebral arteriovenous malformations. J Neurosurg 1993; 78: 12-18.

24. Dodick D, Cascino G, Meyer F. Vascular malformations and intractable epilepsy: outcome after surgical treatment. Mayo Clin Proc 1994; 69: 741-745.

25. Palmini A, Gambardella A, Andermann F, et al. Intrinsic epileptogenicity of human dysplastic cortex as suggested by corticography and surgical results. Ann Neurol 1995; 37: 476-487.

26. Morrell F. Secondary epileptogenesis in man. Arch Neurol 1985; 42: 318-335.

27. Palmini A, Costa J, Andermann F, et al. Surgical results and correlates of surgical outcome in epileptic patients with localized cortical dysplastic lesions. Epilepsia 1996; 37 (Suppl. 5): 208.

28. Morrell F, Whisler W, Bleck T. Multiple subpial transection: a new approach to the surgical treatment of focal epilepsy. J Neurosurg 1989; 70: 231-239.

29. Tran T, Spencer S, Marks D, et al. Significance of spikes recorded on electrocorticography in nonlesional medial temporal lobe epilepsy. Ann Neurol 1995; 38: 763-770.

30. Ebersole J. Magnetoencephalography/magnetic source imaging in the assessment of patients with epilepsy. Epilepsia 1997; 38 (Suppl. 4): 1-5.

31. Otsubo H, Hwang P, Elliot I, et al. Magnetoencephalography in children for extratemporal lobe epilepsy: surgical evaluation of epileptogenic zone. Epilepsia 1997; 38 (Suppl. 8): 151-152.