Cortical dysplastic lesions in children with intractable epilepsy: role of complete resection

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Object. The authors conducted a study to determine seizure-related outcomes in a group of pediatric patients with pathologically proven focal cortical dysplasia (FCD) treated by focal cortical resections and multiple subpial transections (MSTs).

Methods. The authors performed a retrospective review of pediatric patients in whom surgery was conducted to treat medically refractory epilepsy secondary to cortical dysplasia between April 1989 and January 2001. Diagnostic studies included preoperative scalp electroencephalography (EEG), magnetic resonance (MR) imaging, positron emission tomography (PET), and magnetoencephalography (MEG). Intraoperative electrocorticography (ECoG) or extraoperative subdural grid EEG monitoring was performed in all patients. Seizure outcome was classified using the Engel scheme. The authors analyzed nine data points and compared these with seizure outcome, including seizure semiology, MR imaging, PET and MEG data, as well as location of resection, intracranial video-EEG findings, MSTs, postresection ECoG data, and histological findings.

The authors analyzed data obtained in 39 children in whom the follow-up interval after epilepsy surgery was at least 18 months. Patients had suffered epilepsy for a mean of 7.7 years prior to surgical intervention and their mean age at treatment was 9.6 years (range 2 months–18 years). A good seizure-related outcome was demonstrated in 28 patients (72%), including 21 (54%) who were free of seizures (Engel Class I) and seven (18%) in whom seizures were rare (Engel Class II). In 11 patients seizure-related outcome was less favorable, including six (15%) with worthwhile improvement involving some seizures (Engel Class III) and five (13%) with no postoperative seizure improvement (Engel Class IV). There was no significant correlation between seizure outcome and data related to seizure characteristics, MR imaging, PET scanning, MEG, location of resection, intracranial video-EEG, postresection ECoG, and histological findings. Eight (50%) of 16 patients who underwent MSTs in addition to incomplete resection of FCD experienced a good outcome (Engel Class I and II). Twenty (87%) of 23 patients in whom resection of FCD was complete and in whom MSTs were not performed experienced a good seizure outcome (p < 0.05).

Conclusions. Complete resection of FCD results in good seizure outcome in a majority of children. When conducted in conjunction with incomplete cortical resection, MSTs do not improve seizure outcome in patients with FCD. Focal cortical dysplasia located outside of eloquent cortex and complete excision of the lesion are the most important predictors of seizure outcome.

Key Words • Epilepsy surgery • Focal cortical dysplasia • Seizure outcome • Resection • Multiple subpial transections

Focal cortical dysplasia has been increasingly recognized as the cause of seizures in patients undergoing surgery for intractable epilepsy. It has been identified in 26% of pediatric patients in one surgical series compared with 10 to 12% in combined series of pediatric and adult patients. The majority of studies of outcome after epilepsy surgery for cortical dysplasia involve small numbers of cases and few series involve children. Cortical dysplasia is often identified as a cause of intractable epilepsy on neuroimaging studies prior to surgical intervention; however, the diagnosis may not be established until the time of pathological examination in up to 34% of cases. An inability to identify FCD preoperatively may reflect the spectrum of the disease, which varies from mild microdysgenesis to severe focal dysplastic lesions with significant cortical disorganization and bizarre balloon cells.

The authors of studies involving outcome after surgery for cortical dysplasia have reported that the completeness of resection is a significant predictor of postoperative seizure outcome. Seizure recurrence in patients with a near-complete excision was thought to be related to the extension of dysplastic cortex beyond the visible abnor-

Abbreviations used in this paper: ECoG = electrocorticography; EEG = electroencephalography; FCD = focal cortical dysplasia; FDG = 18F deoxyglucose; MEG = magnetoencephalography; MR = magnetic resonance; MST = multiple subpial transection; PET = positron emission tomography; 3D = three-dimensional.
Complete resection of cortical dysplastic lesions

mality. Epileptogenic areas in and around dysplastic cortex have been described, which, if completely resected as demonstrated by their disappearance on postexcision EC0G, result in a statistically significant better outcome than in cases in which they persisted. Cortical dysplastic lesions commonly involve regions of eloquent brain. Consequently, strategies regarding resection of both the obvious lesion and epileptogenic areas that may contain microscopic dysplastic elements have been limited.

In an effort to treat lesions surgically in unresectable or eloquent cortex, Morrell, et al., developed the technique of MSTs. Vertical cuts through eloquent cortex are believed to disrupt spread of epileptic activity in a horizontal direction while allowing preservation of functional vertical columns. Multiple subpial transections have been reported to be both safe and effective for the control of focal epilepsies involving eloquent cortex in adults and as well as children. They provide the surgeon with the ability to treat dysplastic lesions and epileptogenic areas in eloquent cortex that otherwise may have been left untreated.

The purpose of this study was to determine the seizure outcome in children with intractable epilepsy who participated in a study involving a comprehensive surgical strategy for pathologically confirmed FCD.

Clinical Material and Methods

We performed a retrospective review of patients who underwent surgery for intractable epilepsy and in whom there was evidence of FCD on pathological examination at the Hospital for Sick Children. All cases were treated between January 1, 1989, and January 1, 2001. Patients with hemimegalencephaly, bilateral cortical dysplasia, schizencephaly, or dysembryoplastic neuroepithelial tumor, or those in whom follow up was shorter than 1 year, were not included in the analysis. We identified 39 patients (16 boys and 23 girls) in whom the mean age at the time of epilepsy surgery was 9.6 years.

Presurgical Evaluation

All children with medically refractory epilepsy underwent a comprehensive presurgical evaluation. We performed prolonged video-EEG in which the international 10-20 scalp–electrode placement system was used with a single reference electrode (BMSI System 4000 and 5000; Nicolet, Madison, WI). Patients were grouped according to epilepsy syndromes (frontal, parietal, temporal, and occipital lobe) based on seizure history, and results of scalp-based video-EEG and neuroimaging studies (assessed using the International League Against Epilepsy classification). Magnetic Resonance Imaging

In all cases, preoperative MR studies were performed using a 1.5-tesla imager. Prior to November 1998, our standard epilepsy protocol included the following sequences: sagittal T1-weighted images; axial and coronal dual-echo T2-weighted images; and coronal volumetric 3D Fourier transform gradient-echo sequences. In children younger than 2 years of age, longer echo times (50–100 msec) were used on proton density and T2-weighted images to improve evaluation of myelination. If a neoplasm was suspected, Gd-based contrast was injected intravenously. Magnetic resonance imaging–demonstrated features suggestive of FCD in this study included increased signal intensity, poor gray–white matter differentiation, polymicrogyria, thickened cortex, or the presence of abnormally deep sulci.

Positron Emission Tomography Scanning

We studied interictal PET scans by using FDG. In children in whom sedation was not used, the interictal FDG PET scans were obtained using a GEMS 2048 system (Scanditronix, Essex, MA). We analyzed a set of 15 slices (6.5-mm slice thickness, spaced by 3.5 mm with a spatial resolution of 5 mm). In younger children who required sedation, interictal FDG PET scanning was conducted using an ECAT ART system (CTI-Siemens, Knoxville, TN). We analyzed a set of 47 continuous slices (3.5-mm slice thickness). The intravenous dose of FDG was 0.07 mCi/Kg. Scanning of the brain was undertaken 40 minutes after the injection.

Magnetoencephalographic Studies

Magnetoencephalographic studies were performed at the Scripps Clinic and Research Foundation (San Diego, CA) by using a Magnes II (74-channel) or a whole-head Magnes 2500 WH (148-channel) biomagnetometer (4D Neuroimaging, San Diego, CA). Since February 2000, MEG studies involving a whole-head gradiometer Omega system (151-channel; CTF, Port Coquitlam, BC, Canada) have been performed at The Hospital for Sick Children in Toronto. The details of MEG reported in this study, including methods of detection, localization, and analysis of sources of interictal MEG spikes, have been previously published.

Subdural Grid EEG

Intracranial video-EEG was performed in patients with FCD and an epileptogenic zone adjacent to or within eloquent cortex, as well as in patients in whom MR imaging documented no abnormal findings. The subdural grid electrodes allowed us to localize precisely the primary epileptic foci and functional cortex. Coverage of the medial temporal structures was achieved using either subtemporal strip electrodes or depth electrodes placed into the anterior and posterior segments of the hippocampus.

We constructed subdural grid arrays (up to 128 contacts) based on MR images, interictal and ictal scalp-based EEG results, MEG spike sources, MEG sensory evoked fields, and clinical symptoms. We determined the grid size on the basis of 3D MR imaging involving 1.5-mm, thin-slice T1-weighted images (ISG Allegro 3D imaging software; Sedara Systems, Inc., Mississauga, ON, Canada). This software was also used in cases in which intraoperative neuronavigation was applied to help determine extent of resection of the lesion.
Seizure activity was monitored and functional mapping was performed using the subdural grid array in the intensive care unit. During the period of invasive monitoring, seizures were recorded using time-locked video-EEG (BMSI 5000; Nicolet). We determined the epileptic region from the ictal-onset zone and the prominent interictal zone on the extraoperative subdural grid–based EEG recordings by using a computerized topography technique. On the 3rd or 4th day after subdural grid placement, we recorded somatosensory evoked potentials and electrically stimulated the electrodes on the subdural grid array while the patient was awake; this was conducted to localize the primary motor, language, and somatosensory areas. We created a map of epileptic and functional regions on the digital image on which the subdural recording data were overlaid to generate a plan of subsequent cortical resection.

Patients were then returned to the operating room to undergo cortical resection and MSTs through regions of FCD, zones of epileptogenesis, and eloquent areas of brain if they involved prominent ictal and interictal spikes. Electrocntorography involving a 4 x 5 surface electrode array (Ad-Tech Medical Instrument Co., Racine, WI) was used to monitor the residual epileptic discharges after cortical resection and MSTs.

Completeness of resection of FCD was determined by assessing results of intraoperative image guidance, MEG, intracranial video-EEG, or intraoperative ECoG.

Postexcision ECoG

Postexcision ECoG was completed and the results were classified into the following five grades: A, no residual epileptiform discharges; B, mild residual discharges; C, moderate residual discharges; D, no change from preexcision ECoG findings; and E, indeterminate grade because of the presence of artifacts or drug effects.

Pathological Examination

Pathological examination of surgically obtained tissue specimens was reviewed by a single neuropathologist (L.B.). Those patients in whom balloon cells were suggestive of a forme fruste of tuberous sclerosis underwent further investigation to rule out this diagnosis. Dual disease was determined on the basis of mesial temporal (hippocampal) sclerosis and a cortical dysplastic lesion within the same biopsy specimen.

Seizure Outcome Classification

Postoperative classification of seizure outcome was based on the Engel scheme (Class I, absence of seizures and auras only or seizures only during drug withdrawal; Class II, rare disabling seizures or nocturnal seizures only; Class III, worthwhile improvement; and Class IV, no improvement) after a minimum 1.5-year follow-up period.

Patients were divided into two groups based on seizure outcome: good seizure outcome included Engel Classes I and II cases and a less favorable outcome group consisted of Engel Classes III and IV cases.

Statistical Analysis

The Fisher paired exact t-test was conducted to compare the two seizure outcomes with the following: 1) seizure characteristics including patient age at the time of seizure onset and duration of seizures; 2) presence of FCD on preoperative MR images; 3) correlation of PET findings with resection; 4) MEG spike sources in relationship to regions of resection; 5) location of resection (for example, temporal lobe compared with extratemporal lobe); 6) cases requiring or not requiring intracranial video-EEG; 7) cases with and without MSTs; 8) postexcision ECoG grade; and 9) histological feature (presence or absence of balloon cells).

Results

We identified 39 patients who underwent epilepsy surgery for FCD and in whom the minimum follow-up period was at least 1.5 years. There were 16 male and 23 female patients whose mean age at the time of operation was 9.6 years (range 2 months–18.5 years). The time of seizure onset ranged from newborn to 12 years (mean 2.3 years), and the duration of epilepsy prior to surgery ranged from 4 months to 16.8 years (mean 7.7 years). A total of eight patients had previously undergone operations, including seven who underwent cortical resections and one who underwent an anterior two-thirds corpus callosotomy.

Seizure Outcome

In 28 patients seizure outcome was good (Engel Classes I and II) including 21 (54%) who were seizure free at last (mean 3.6 years) follow-up examination and seven (18%) who experienced only rare seizures. In 11 patients seizure outcome was less favorable (Engel Classes III and IV) including six (15%) in whom the frequency of seizures was significantly reduced and five (13%) in whom the frequency was unchanged. There was no difference in seizure outcome when patients with longer follow up (> 2 years) were compared with those in whom it was shorter (< 2 years). Fifty-eight percent of patients in whom follow up was less than 2 years experienced a good outcome (Class I or II), whereas 75% of those in whom follow up was 2 years or more experienced a good outcome (p = 0.7). The seizure-related profiles and outcomes in the 39 patients with FCD are summarized in Table 1.

Seizure-Related Characteristics

There was no significant difference with respect to age of seizure onset (p = 0.4) or duration of seizure history (p = 0.6) between the two groups stratified by the different seizure outcomes. Temporal lobe epilepsy was identified in 11 patients, frontal lobe epilepsy in 12, occipital lobe epilepsy in three, parietal lobe epilepsy in two, and multiple-lobe epilepsy in 11 patients.

Magnetic Resonance Imaging Studies

Preoperative MR imaging was performed in all patients and in 32 (82%) there was evidence of FCD. In seven patients (18%) there was no MR imaging–documented evidence of FCD. In two patients, MR imaging revealed normal findings. In four patients there was evidence of localized atrophy, and in one patient there were nonspecific white matter changes only. Twenty-four patients...
Complete resection of cortical dysplastic lesions

TABLE 1
Summary of seizure profiles and seizure-related outcomes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Engel Class (%)</th>
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<tbody>
<tr>
<td></td>
<td>I/II</td>
</tr>
<tr>
<td>age at seizure onset</td>
<td></td>
</tr>
<tr>
<td>&lt;24 mos</td>
<td>20 (77)</td>
</tr>
<tr>
<td>≥24 mos</td>
<td>8 (62)</td>
</tr>
<tr>
<td>duration of seizures</td>
<td></td>
</tr>
<tr>
<td>&lt;100 mos</td>
<td>14 (67)</td>
</tr>
<tr>
<td>≥100 mos</td>
<td>14 (77)</td>
</tr>
<tr>
<td>FCD on MRI</td>
<td></td>
</tr>
<tr>
<td>yes</td>
<td>24 (75)</td>
</tr>
<tr>
<td>no</td>
<td>4 (57)</td>
</tr>
<tr>
<td>location of resection</td>
<td></td>
</tr>
<tr>
<td>temporal lobe</td>
<td>8 (67)</td>
</tr>
<tr>
<td>extratemporal region</td>
<td>20 (74)</td>
</tr>
<tr>
<td>EEG recordings</td>
<td></td>
</tr>
<tr>
<td>intraop ECoG</td>
<td>18 (75)</td>
</tr>
<tr>
<td>intracranial video-EEG</td>
<td>10 (67)</td>
</tr>
<tr>
<td>MSTs w/ cortical resection*</td>
<td></td>
</tr>
<tr>
<td>yes</td>
<td>8 (50)</td>
</tr>
<tr>
<td>no</td>
<td>20 (87)</td>
</tr>
<tr>
<td>presence of balloon cells</td>
<td></td>
</tr>
<tr>
<td>yes</td>
<td>11 (92)</td>
</tr>
<tr>
<td>no</td>
<td>17 (63)</td>
</tr>
</tbody>
</table>

* Statistically significant (p < 0.05).

(75%) with preoperative evidence of FCD experienced a good outcome whereas four (57%) without obvious FCD on preoperative imaging experienced a good outcome (p = 0.6).

Positron Emission Tomography Scanning

Thirteen patients underwent preoperative interictal PET scanning, in 12 of whom hypometabolism was demonstrated. In 10 patients the region or lobe of hypometabolism corresponded with the cortical resection, and of these patients eight experienced a good outcome (Engel Class I or II). In two patients, the area of hypometabolism did not correlate with resection; in one patient, no focal PET-documented abnormality was identified. Two of these three patients experienced a good outcome. In eight of the 12 patients with PET-documented hypometabolism preoperative MR imaging confirmed cortical dysplasia. There were areas of PET hypometabolism in four patients, with no cortical dysplastic lesion identified preoperatively on MR imaging; in three of whom resections involved PET-demonstrated abnormalities. In two of these patients, seizure outcome was good.

Magnetoencephalography Studies

Fifteen patients underwent preoperative MEG. Fourteen patients underwent resections that encompassed at least a portion of the spike sources, and of these, nine (60%) experienced a good seizure outcome. In 10 patients there was evidence of FCD on MR imaging and in nine (90%) there were MEG spikes and resections that correlated with the abnormality on MR imaging (Fig. 1). Three involved temporal resections; four, frontal; two, parietal; and one, occipital. Seven (70%) of these 10 patients experienced a good outcome. In five patients in whom MR imaging revealed no abnormality or atrophy only, four cases involved resections that encompassed at least some of the MEG spikes sources. Two (40%) of five patients experienced a good outcome.

Location of Resection

There was no significant correlation between the location of resection and the seizure outcome. Twelve patients (31%) underwent temporal lobe surgery alone and 27 (69%) underwent surgery in the extratemporal areas. Good seizure outcome was achieved in eight patients (67%) in whom temporal lobe resection was performed and in 20 (74%) of those in whom extratemporal lobe resection was performed (p = 0.7).

Intracranial Video-EEG

Fifteen patients underwent chronic intracranial video-EEG recordings: 14 patients with extratemporal lobe epilepsy (12 frontal, one parietal, and one occipital) and one with temporal lobe epilepsy. There was no significant difference in seizure outcome between the 15 patients who underwent intracranial video-EEG (10 patients [67%] with good outcome) and the 24 who underwent intraoperative ECoG (18 patients [75%] with good outcome) (p = 0.72).

Multiple Subpial Transections

We performed MSTs in addition to lesionectomy and cortical excision in 16 patients (intracranial video-EEG in 15 and intraoperative ECoG in one). In 12 patients MSTs were performed through motor areas and in nine through extratemporal regions, including five patients in whom MSTs involved both motor and language areas (Fig. 2). Of the 16 patients who underwent MSTs, eight (50%) experienced a good outcome, whereas 20 (87%) of 23 patients in whom MSTs were not performed experienced a good outcome. In patients not requiring MSTs, seizure outcome was better than that in those requiring MSTs (p = 0.03). In the eight MST-treated patients who experienced a good seizure outcome, the MSTs involved 33% of the total area treated surgically. In contrast, in the remaining eight MST-treated patients in whom seizure outcome was less favorable, the MSTs involved greater than 56% of the total area treated surgically. The ECoG-documented discharges in 12 of these 16 patients were either Grade A or B.

Postexcision ECoG

Twenty (69%) of 29 patients with ECoG-documented Grade A or B experienced a good seizure outcome compared with five (71%) of seven patients with Grade C or D. Postexcision ECoG data were unavailable for three patients. No significant difference in seizure outcome was found based on the results of postexcision ECoG (p = 1).

Outcome and Histological Analysis

The results of biopsy specimen evaluation indicated that FCD was present without balloon cells in 27 patients, whereas in 12 patients dysplastic lesions were characterized by the presence of balloon cells. Eleven (92%) of 12 patients in whom pathological examination demonstrated balloon cells experienced either Engel Class I or II outcome. Seventeen (63%) of 27 patients without balloon cells experienced a good outcome. Intergroup comparison
showed no statistical significance (p = 0.12). Dual disease consisting of cortical dysplasia and mesial temporal sclerosis was found in seven patients.

**Discussion**

In this series, the surgical treatment of intractable epilepsy in children with pathologically proven malformations of cortical development resulted in good seizure outcome in 28 (72%) of 39 patients. In surgical series involving intractable epilepsy secondary to FCD based on pathological evidence alone, investigators have reported seizure-free status in as few as 8% to 18% of treated patients. In both of these series, however, preoperative evaluation was limited to CT scanning in nearly half of the cases. In a summary of all series of patients who underwent surgery for FCD, the author documented seizure-free outcome in 42% of patients in whom the minimum follow-up period was 1 year. In contemporary series of surgery for FCD in which MR imaging was conducted in the majority of patients, improved outcome was demonstrated. In a comprehensive series involving epilepsy surgery in children, Wyllie, et al., reported that 31 treated patients (26%) suffered from FCD, and a seizure-free outcome was achieved in 16 (52%), which was similar to results reported by Kloss, et al., and Paolicchi, et al. In a combined series of pediatric and adult patients with intractable epilepsy and MR imaging–proven malformations of cortical development, 49% were seizure free and another 23% suffered rare seizures. A similar seizure outcome was reported by Hong, et al., whose series included both patients with FCD detected preoperatively by MR imaging or postoperatively by histological examination. In our series, we used a multimodality approach of MR imaging, PET, and MEG, with or without intracranial EEG, to identify the cortical dysplastic lesion, epileptogenic region, and eloquent cortex. Although an observation in each modality does not significantly correlate with seizure outcome, complementary diagnostic techniques of FCD may allow for the best possible seizure outcome in children.

Evidence derived from several series has suggested that complete resection of cortical dysplastic lesions and epileptogenic areas around FCD are important predictors of seizure outcome. In patients in whom a near-complete excision was achieved, seizure recurrence has been thought to be related to the extension of dysplastic cortex beyond the visible abnormality. The reasons for incomplete resections of obvious lesions are not well detailed; however, extension of the dysplastic cortex into eloquent areas of brain may have restricted the extent of the resection. A comprehensive surgical strategy followed in our series included MSTs performed through visible dysplastic regions identified preoperatively as well as the epileptogenic areas identified by subdural grid evaluation when found in eloquent cortex. In addition to cortical resections, MSTs were conducted in 16 patients in our series, and these procedures correlated significantly with a less favorable outcome (Engel Class III or IV). In the majority of these patients postresection ECoG demonstrated either no or only mild residual discharges. The location of focal cortical dysplastic lesions and epileptogenic zones outside of essential cortical areas in patients in this series, which allowed for their complete removal, remains the most important predictor of outcome. In future studies, the use of postoperative MR imaging supplemented with surface coil detection of residual FCD may also help predict which patients will do well postoperatively.

It has been difficult to assess the effectiveness of MSTs in the treatment of focal epilepsy because most reports often included small numbers of patients with diverse pathological entities, and surgical treatment usually involved an additional cortical resection. In the present series of patients with FCD in whom MSTs...
were conducted in addition to cortical resections, seizure outcomes were similar to those documented in recent series in which cortical resections alone were undertaken for FCD.8,14,30,45 Reports involving the use of MSTs and cortical resection for FCD have been limited to selected patients within larger series.11,22 In a review of larger series of patients treated with MSTs, Polkey31 showed that 42% of patients became seizure free when MSTs were used in conjunction with cortical resections compared with only 15% of patients who had undergone MSTs alone. Outcome was better in patients with pathologically proven lesions. In a different series in which MSTs alone were performed, the authors reported a good seizure outcome in nine (45%) of 20 patients; however, Engel Class III was considered to reflect a good outcome.34 Early enthusiasm for MSTs as a supplementary treatment to cortical resections may be a reflection of short follow up. In a meta-analysis of MSTs, Spencer, et al.,38 documented an increase in simple partial seizures in 15 to 20% of patients regardless of whether they had undergone cortical resection. Orbach, et al.,23 reported the late recurrence of seizures (2–5 years postoperatively) in 10 patients (18.5%) after undergoing either MSTs alone or in conjunction with cortical resection. The increase in seizure frequency was attributed to the transections as increases in seizure frequency are believed not to occur after resection alone.38

In our series, patient-related factors, including age of seizure onset and the duration of epilepsy; preoperative factors such as the use of PET and MEG; surgery-related factors including location of resection and use of intracranial EEG; results of postexcision ECoG; and histological characteristics were not predictive of postoperative seizure outcome. A review of comprehensive surgical series for FCD has demonstrated similar results.8,14,28-30 In our series a trend toward improved seizure outcome was seen in patients in whom histological analysis showed balloon cells. Urbach, et al.,41 reported good seizure outcome in all 22 selected patients in whom balloon cells were identified on pathological examination. Patients were included only if high-resolution MR imaging studies were available. In all cases but one, the lesions were extratemporal, similar to our series in which all patients with balloon cells underwent extratemporal resection. Chassoux, et al.,6 reported seizure-free outcome in 64% of patients with FCD; in 24 of 28 patients balloon cells were demonstrated. Tassi, et al.,29 reported postoperative seizure-free status in 75% of patients with Taylor-type dysplasia, the specimens obtained in 12 of whom contained balloon cells. Although the authors of several series have suggested that resection of FCD associated with balloon cells may yield a more favorable postsurgical outcome,6,39,41 others have not supported this view.8,27 In an earlier publication16 we compared FCD with balloon cells and tuberous sclerosis and found a trend toward better postoperative seizure control in the FCDs associated with balloon cells. These two conditions were difficult to distinguish on the basis of MR imaging and histological appearances. We suggested that FCD associated with balloon cells likely represents a forme fruste of tuberous sclerosis, and as such, all patients with balloon cell dysplasias may require screening for other features of tuberous sclerosis to enable appropriate genetic counseling.

Magnetoencephalography has previously been shown to predict the epileptogenic zone in lesion epilepsy, including patients with FCD.15,25,37 Epileptic zones in patients with FCD were characterized by clusters of MEG spike sources within and extending from lesions identified on MR imaging.25 The majority of patients in whom preoperative MEG was performed underwent resections including the spike sources. In our patients in whom preoperative imaging revealed a cortical dysplastic lesion, resection of the MEG spikes and lesion resulted in a good seizure outcome.41

**Fig. 2.** a: Left parietal FCD. b: A cluster of MEG spike sources posterior to the central sulcus, extending inferiorly to lower rolandic cortex and supramarginal gyrus of language cortex, was confirmed by subdural grid recording. The RD1 space represents right-thumb somatosensory evoked potentials by tactile stimulation. Parietal cortical resection and MSTs of motor and language areas were completed. At last follow up, seizures were determined to be Engel Class III.
outcome in seven of 10 patients. Magnetoencephalography spikes have been shown to correlate with the ictal-onset zone confirmed by intracranial EEG. In nonlesional epilepsy, complete resection of the irritative MEG spike-delineated zone was highly predictive of good seizure outcome. No lesion was apparent on preoperative imaging in five patients. In these patients, MEG spike sources correlated with subdural grid–confirmed epileptogenic areas that were ultimately resected and proven pathologically to contain cortical dysplastic lesions. Therefore, MEG is useful in identifying some patients with cortical dysplasia in whom MR imaging demonstrates normal results. Even if not detected on MR imaging, characteristics of MEG spikes may indicate that surgery could be an option for those patients not formerly considered for resection.

Conclusions

Surgical treatment of intractable epilepsy in children with FCD resulted in a good seizure outcome in the majority of cases. Multiple subpial transections in eloquent areas in cases involving residual FCD and incomplete FCD resections do not contribute to improved outcome. The location of FCD outside of eloquent areas, which allows for complete resections of visible lesions and epileptogenic zones, is the most important factor in determining seizure outcome.

References

Complete resection of cortical dysplastic lesions


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