Multimodality imaging in the surgical treatment of children with nonlesional epilepsy

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ABSTRACT

Objectives: To evaluate the diagnostic value of individual noninvasive presurgical modalities and to study their role in surgical management of nonlesional pediatric epilepsy patients.

Methods: We retrospectively studied 14 children (3–18 years) with nonlesional intractable focal epilepsy. Clinical characteristics, surgical outcome, localizing features on 3 presurgical diagnostic tests (subtraction peri-ictal SPECT coregistered to MRI [SISCOM], statistical parametric mapping [SPM] analysis of [18 F] FDG-PET, magnetoencephalography [MEG]), and intracranial EEG (iEEG) were reviewed. The localization of each individual test was determined for lobar location by visual inspection. Concordance of localization between each test and iEEG was scored as follows: 2 = lobar concordance; 1 = hemispheric concordance; 0 = discordance or nonlocalization. Total concordance score in each patient was measured by the summation of concordance scores for all 3 tests.

Results: Seven (50%) of 14 patients were seizure-free for at least 12 months after surgery. One (7%) had only rare seizures and 6 (43%) had persistent seizures. MEG (79%, 11/14) and SISCOM (79%, 11/14) showed greater lobar concordance with iEEG than SPM-PET (13%, 3/14) ($p < 0.05$). SPM-PET provided hemispheric lateralization (71%, 10/14) more often than lobar localization. Total concordance score tended to be greater for seizure-free patients (4.7) than for non-seizure-free patients (3.9).

Conclusions: Our data suggest that MEG and SISCOM are better tools for lobar localization than SPM analysis of FDG-PET in children with nonlesional epilepsy. A multimodality approach may improve surgical outcome as well as selection of surgical candidates in patients without MRI abnormalities. *Neurology*® 2011;76:41–48

GLOSSARY

ECoG = electrocorticogram; **FCD** = focal cortical dysplasia; **iEEG** = intracranial EEG; **MEG** = magnetoencephalography; **MSI** = magnetic source localization; **SISCOM** = subtraction peri-ictal SPECT coregistered to MRI; **SPM** = statistical parametric mapping.

Children with medically intractable epilepsy have been considered for epilepsy surgery if the epileptogenic zone is reasonably localized with noninvasive presurgical evaluation.^{1–3} Among available noninvasive tests, the most accurate and reliable tool for identification of seizure focus remains MRI. Presence of visible MRI lesion not only warrants surgical candidacy, but also predicts a favorable surgical outcome.^{4–7} Recent advances with high-resolution MRI may reveal the presence of brain lesions not previously detected. However, some patients continue to have no detectable lesions on MRI, despite the suggestion of a focal epileptogenic zone on seizure semiology and scalp EEG.

When no lesion is seen on MRI, other noninvasive functional imaging modalities have been employed: peri-ictal SPECT and subsequent subtraction image coregistered to MRI (SISCOM) may visualize increased blood flow at the time of seizure^{8,9}; 2-deoxy-2-(18 F)fluoro-D-glucose PET (FDG-PET) and subsequent voxel-based analysis using statistical parametric mapping (SPM) may visualize the areas of decreased metabolism¹⁰; and magnetoencephalography (MEG)/magnetic source localization (MSI) may reveal the source of interictal/ictal epileptic discharges.¹¹ Although

Supplemental data at
www.neurology.org

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Study funding: Supported in part by the NIH (R01NS062756).

Disclosure: Author disclosures are provided at the end of the article.

Figure 1 Flow diagram of patient selection

F/U = follow-up; iEEG = intracranial EEG.

the diagnostic sensitivity and specificity of these individual modalities have been studied separately in various epilepsy groups,¹² there have been few studies on the diagnostic yield of individual noninvasive modalities and the value of combined multimodality imaging in the nonlesional epilepsy population. The purpose of this study is to evaluate the localization agreement of individual noninvasive presurgical modalities with intracranial EEG (iEEG) as a gold standard, and to study whether a multimodal approach contributes to improved surgical outcome in nonlesional pediatric epilepsy.

METHODS **Standard protocol approval, registration, and patient consent.** The study was approved by the institutional review board at Cincinnati Children's Hospital Medical Center. Patient consent was not required in this retrospective clinical study.

Subjects. We retrospectively reviewed medical records of children with medically intractable focal epilepsy who underwent presurgical evaluation in the comprehensive epilepsy center at the Cincinnati Children's Hospital Medical Center between October 2006 and October 2009. Our standard presurgical evaluation included detailed history and clinical examination, scalp video-EEG monitoring, MRI with dedicated high-resolution imaging for epilepsy patients, FDG-PET scans, ictal/interictal SPECT, and MEG/MSI. Invasive EEG was recommended for further localization of ictal onset zone or to map eloquent cortices. Of 256 patients with presurgical evaluation during the study period, we identified 46 patients who had normal or nonspecific MRI. Of these 46, 25 patients underwent iEEG and subsequent resective epilepsy surgery. Fourteen of the 25 patients met the inclusion criteria as follows: 1) were 18 years of age or younger at time of surgery; 2) had normal or nonspecific findings on preop-

erative MRI; 3) underwent all multimodality evaluations including SISCOM, SPM-PET, and MEG; 4) had iEEG and subsequent resective epilepsy surgery; and 5) had follow-up of at least 12 months postsurgery (figure 1). Eleven patients were excluded because they failed ictal SPECT (n = 2), MEG (n = 2), or had a short follow-up duration without test failures (n = 7) (table e-1 on the *Neurology*® Web site at www.neurology.org).

Presurgical evaluation: Noninvasive functional imaging studies. Imaging protocols. MRI was performed at 3 T (10 patients) or 1.5 T (4 patients). The details used for the MRI protocols are included in the supplementary data. Imaging studies were assessed by a neuroradiologist (A.B.R. certified with added qualification in neuroradiology) with 15 years of experience in epilepsy imaging (J.L.L.). Analysis of imaging was performed in a 2-step process. Initially, the imaging studies were reviewed blinded to clinical history (other than intractable epilepsy), results of other tests, and to resection location. The studies were then re-reviewed with knowledge of all additional clinical history, EEG results, additional imaging results, and resection location (by analysis of resection location on postoperative imaging studies). No subject had a clearly defined lesion on MRI. Examinations were classified (after final review) as normal (10 patients), nonspecific findings (volume loss or small regions of white matter increased signal, not related to subcortical regions or clear gyral malformation, 2 patients), or questionable but nondiagnostic (subtle gyral morphology asymmetry on same side as surgery, but without clear focal cortical thickening, altered cortical signal, or gray matter white matter blurring, 1 patient; subtle subcortical white matter increased signal without cortical thickening or cortical increased signal seen only on final imaging review, 1 patient). One patient had postsurgical changes in the region of a prior right temporal lobectomy, but no imaging abnormality in the region of the new resection site (right temporal and parietal lobes). The methodology for each functional imaging test is included in the supplementary data (appendix e-1: Methods).

Neuropsychological evaluation. Neuropsychological evaluation was done preoperatively, as well as 12 months postoperatively, by a board-certified pediatric neuropsychologist, and included the Bayley Scales of Infant and Toddler Development,

third edition,¹³ for the youngest patient. For the other patients, either the Wechsler Intelligence Scale for Children (fourth edition) or the Wechsler Adult Intelligence Scale (third or fourth edition) were used, based upon the age of the patient.^{14,15}

Invasive video/EEG monitoring. Following a multidisciplinary surgical conference in which all noninvasive evaluation data were reviewed, extraoperative iEEG monitoring was recommended if the noninvasive data were incongruent or divergent, no causative lesion was seen on MRI, or eloquent cortex was involved. Extraoperative monitoring was performed using subdural strip and grid electrodes. Placement of intracranial electrodes was guided by noninvasive localization and further tailored by intraoperative electrocorticogram (ECoG). Continuous video iEEG was recorded using the Stellate systems (128-channel 16-bit A/D and sampling frequency 2 KHz; Natus Medical Inc., San Carlos, CA). Primary ictal onset zone included the area covered by the first electrodes that showed an EEG onset pattern preceding clinical behavior. Secondary spread zone was defined as the area neighboring the primary ictal onset zone which showed an EEG spread pattern during a seizure.

Surgical resection. The resection margin was determined using iEEG ictal onset zone (primary ictal onset zone plus secondary spread zone) sparing eloquent cortex (language and motor). If indicated, facial motor cortex or primary sensory cortex was included in the resection margin after extensive discussion with the patients and their parents. Multiple subpial transection was performed on the primary motor or language cortex when the area was clearly included in the epileptogenic zone. Postresection

intraoperative ECoG was performed in all cases to assess residual epileptiform discharges at the resection margins. Further resection was recommended only when we identified burst of repetitive spikes longer than 5 seconds, high frequency oscillations, or frank electrographic seizures.

Evaluation of surgical outcome. Postoperative seizure outcome was evaluated by review of outpatient visits or telephone contacts. Seizure outcome was classified based on the system proposed by Engel et al.²: Class I = seizure-free; Class II more than 90% reduction; Class III more than 50% reduction; and Class IV less than 50% reduction or unchanged. Seizure outcome data were reported as of the date of latest available follow-up.

Pathology. Pathology was initially reviewed by several pediatric pathologists, and then it was blindly reviewed by a single pediatric neuropathologist (L.M.) specifically for this study. Histopathology of focal cortical dysplasia (FCD) was classified using Palmini's classification¹⁶ as follows: 1A, architectural abnormality only; 1B, architectural abnormality plus giant or immature neurons; 2A, architectural abnormality with dysmorphic neurons without balloon cells; 2B, architectural abnormality with dysmorphic neurons and balloon cells.

Analysis and statistics. Localization of individual presurgical tests including SISCOM, SPM-PET, and MEG was determined for lobar location by visual analysis. Comparison of localization between each test and primary ictal onset area on iEEG led to concordance scores as follows: 2 = lobar concordance; 1 = hemispheric concordance; 0 = discordance or nonlocalization.

Table 1 Clinical characteristics and surgical outcome of 14 patients

Patient	Sex/age, y	Seizure semiology	Ictal scalp EEG	Operation	Follow-up duration, mo	Surgical outcome	Pathology	Complication
1	F/16	Tingling sensation in R arm, head, eye deviating to L	L H	L frontal corticectomy + MST	22	I	FCD 1A	SMA syndrome
2	F/14	Staring, head turning to R, L hand automatism	L H	L frontal corticectomy	15	I	FCD 1B	SMA syndrome
3	M/8	Staring followed by GTC	Not lateralizing	R frontal corticectomy + temporal lobectomy	17	II	Frontal: FCD 1B; temporal: FCD 1A; hippocampus: NL	—
4	F/9	Tonic, atonic, myoclonic	Not lateralizing	R frontal corticectomy + MST	28	IV	FCD 1A	Transient motor weakness
5	F/18	Staring, speaking incoherently	L temporal	L lateral temporal corticectomy	23	I	NA	Transient naming difficulty
6	M/14	Head turning to R	Not lateralizing	L frontal corticectomy	15	I	FCD 1B	—
7	M/17	Numbness on L forearm, head turning to L	R H	R frontal corticectomy	21	III	FCD 1A	—
8	F/14	Staring, followed by GT (R > L)	Not lateralizing	L parietal corticectomy	14	I	NA	—
9	F/14	Myoclonic (R > L)	L H	L frontal corticectomy	12	I	FCD 1B	—
10	M/3	Staring, turning to R	R H	R temporal lobectomy	24	III	FCD 1B; hippocampus: NL	—
11	F/13	GTC	R H	R frontal lobectomy	25	III	FCD 1B	—
12	F/11	Staring with R hand automatism	R H	R parietal corticectomy + temporal lobectomy	15	IV	FCD 1B; hippocampus: NA	—
13	M/11	Nocturnal hypermotor seizure	Not lateralizing	L frontal corticectomy	32	III	NA	—
14	M/14	Staring, head and eyes version to R	L H	L frontal corticectomy + anterior temporal lobectomy	12	I	FCD 2A; hippocampus: NL	—

Abbreviations: FCD = focal cortical dysplasia; GT = generalized tonic seizure; GTC = generalized tonic-clonic seizure; H = hemispheric; MST = multiple subpial transection; NA = not available; NL = normal; SMA = supplementary motor area.

Table 2 Localization concordance between each functional imaging test and intracranial EEG

Patient	Subdural grid location	No. of subdural electrodes	iEEG	SPM-PET	EEG-PET score ^a	SISCOM	EEG-SISCOM score ^a	MEG	EEG-MEG score ^a	Total sum ^b	Outcome (Engel)
1	LF, T	72	LF	LT	1	LF	2	LF	2	5	I
2	LF, T, P	88	LF	LT	1	LF, P	2	LF	2	5	I
3	Bi-RF, T	82	RF, T	LF, T, RF	0	Both O, R, P	0	Both T, O	0	0	II
4	RF, T, P	100	RF	LP	0	RF, P	2	RP	1	3	IV
5	LF, T	76	LT	Both F, LT	1	LT	2	LT	2	5	I
6	LF, T, P	112	LF	LT, both F	1	LT, F	2	LF	2	5	I
7	RF	128	RF	LF, T	0	RF	2	RF	2	4	III
8	LF, T, P	122	LP	Both F, T	0	RF, T, LP	0	LP	2	2	I
9	LF, T, P	92	LF, P	LF, T	1	LF, P	2	LF, P	2	5	I
10	RF, T	78	RT	RF, T	1	RT	2	RF	1	4	III
11	RF	62	RF	RF	2	RF	2	RF	2	6	III
12	LF, T, P	86	RF, P, T	RF, P	2	RT, O	1	RF, T	2	5	IV
13	LF	102	RF	RT	1	RF	2	RF	2	5	III
14	LF, T, P	104	LF, T	LF, T	2	LF	2	LF	2	6	I
Total sum ^c					13		23		24		

Abbreviations: Bi = bilateral hemispheric; F = frontal; iEEG = intracranial EEG; MEG = magnetoencephalography; O = occipital; P = parietal; SISCOM = subtraction peri-ictal SPECT coregistered to MRI; SPM = statistical parametric mapping; T = temporal.

^a Comparison of localization between each test and intracranial EEG led to concordance scores as follows: 2 = lobar concordance; 1 = hemispheric concordance; and 0 = discordance or nonlocalization.

^b Total concordance score in each patient was measured by the summation of concordance scores for all 3 tests.

^c Total concordance score in each test was measured by the summation of concordance scores for all 14 patients.

Lobar concordance was present if the test localization indicated the same lobar region as iEEG; hemispheric concordance if the same hemisphere; otherwise, the findings were considered discordant or nonlocalizing. Total concordance score in each patient was measured by the summation of concordance scores for all 3 tests.

Fisher exact test was used to evaluate the relationship between total concordance score and postsurgical seizure outcome. For the purpose of the statistical analysis, outcome was dichotomized as seizure-free (Class I) or non-seizure-free (Class II, III, and IV) and the total concordance score was classified as low (0–2), medium (3–4), or high (5–6).

RESULTS Patients. Fourteen patients met the inclusion criteria for this study. Their clinical characteristics and surgical outcomes are summarized in table 1. The mean age at surgery was 12.6 years (3–18 years). The mean duration of epilepsy was 7.3 years (2.5–13 years). Based on ictal scalp EEG and clinical semiology, we were able to localize the possible epileptogenic zone in only 1 of 14 patients (7%) and to lateralize the epileptogenic hemisphere in an additional 8 patients (57%). The mean length of postoperative follow-up was 20 months (12–32 months).

Clinical outcome. Overall seizure-free outcome in the 25 patients with negative MRI who had resective surgery during the study period was 48% (12/25). Among 14 patients who met the study inclusion criteria, 50% (7/14) were seizure-free: 1 (7%) had rare seizures (Engel Class II) and 6 (43%) had persistent

seizures (Class III and IV). No patient experienced permanent neurologic deficit (table 1).

There was no significant difference between preoperative and postoperative neuropsychological test scores on a population basis (table e-2). Four patients demonstrated improvements of 12 to 25 points in full-scale IQ at follow-up than at presurgical examination. Two patients demonstrated scores that were 12 and 13 points lower. The remainder of the patients was either not assessed on both presurgical and postsurgical occasions or demonstrated changes of less than 10 points.

Level of concordance with iEEG: SISCOM, SPM-PET, and MEG. Details of localization of each test and their concordance scores compared with iEEG are listed in table 2. SISCOM and MEG each showed lobar concordance (score = 2) with iEEG in 11 (79%) patients, and both SISCOM and MEG showed lobar concordance with iEEG in 9 (64%) patients. SPM-PET showed lobar concordance with iEEG in 3 (21%) patients, but there was concordance in lateralization with iEEG in an additional 10 (71%) patients. MEG and SISCOM showed higher lobar concordance with iEEG than SPM-PET ($p < 0.05$, sign test). The sum of concordance scores across all 14 patients was 24 for MEG, 23 for SISCOM, and 13 for SPM-PET.

Relationship between test concordance and surgical outcome. The total concordance scores for individual patients and their surgical outcomes are also shown

Figure 2 Patient 14 with all concordant presurgical tests (total sum = 6) and seizure-free outcome

A 14-year-old boy with focal epilepsy since age 4 years. Scalp EEG disclosed frequent interictal spikes in left hemisphere, especially in left anterior temporal areas. MRI was normal. (A) Magnetoencephalography showed maximal source activity in left inferior frontal region. (B) Subtraction peri-ictal SPECT coregistered to MRI demonstrated increased perfusion in left frontal region. (C) Statistical parametric mapping-PET showed hypometabolism involving left frontal and temporal region. (D) Intracranial EEG revealed ictal onset in left lateral temporal and inferior frontal areas (red circles). The patient became seizure-free following left frontal corticectomy and left anterior temporal lobectomy at 12 months of follow-up. Pathology revealed type IIA focal cortical dysplasia in both frontal and temporal lobes without hippocampal sclerosis.

in table 2. Total concordance score tended to be greater for the seizure-free group compared with the non-seizure-free group (Class II, III, IV): the average of total concordance scores was 4.7 in the seizure-free group, while the score was 3.9 in the non-seizure-free group. The difference did not reach significance.

When both SISCOM and MEG showed lobar concordance with iEEG (SISCOM + MEG = 4), seizure-free outcome was 67% (6/9), while that of the rest (SISCOM + MEG < 4) was 20% (1/5) ($p = 0.27$, Fisher exact test). If SPM-PET showed at least lateralization in addition to the lobar concordance between SISCOM and MEG (SISCOM + MEG + SPM-PET ≥ 5), the surgical outcome increased to 75% (6/8), while that of the rest (SISCOM + MEG + SPM-PET < 5) was 17% (1/6) ($p = 0.10$, Fisher exact test). Two illustrative cases were described in figures 2 and 3.

Pathology. Pathology was available in 11 patients and FCD was found in all 11 patients. Ten patients were classified as Palmini type I (3 IA/7 IB); one patient was classified as IIA. There were 2 cases where the reviewers disagreed: the blinded reviewer identified FCD type IA and the other review diagnosed subpial gliosis. In 3 patients, the volume of specimen was not sufficient for pathologic diagnosis.

DISCUSSION Absence of an MRI lesion not only discourages consideration of a patient for surgical candidacy, but is also associated with poor surgical outcome. In our study, the overall seizure-free outcome was 50% when all 3 noninvasive modalities were used. This seizure-free outcome compares well with other published series of nonlesional epilepsy.^{6,11,17-21} Although seizure-free outcome in these challenging patients is still lower than in the

An 8-year-old boy with focal epilepsy since 1 year of age. Scalp EEG disclosed consistent focal slowing over right temporal area with multifocal interictal spikes. The patient had 3-step surgery including bilateral subdural grid placement as the first step, because of discordant test results. (A) Magnetoencephalography showed maximal source localization in both temporal lobes. (B) Subtraction peri-ictal SPECT coregistered to MRI showed increased perfusion in multifocal areas. (C) Statistical parametric mapping-PET demonstrated multifocal areas of hypometabolism. (D) Ictal onset zone was found in right frontal and temporal areas (red circles), which lead to multiple corticectomy involving both frontal and temporal lobes. The patient achieved more than 90% of seizure reduction following surgery at 17 months of follow-up. Pathology revealed type IB FCD in right frontal lobe and type IA FCD in right temporal lobe.

lesional focal epilepsy group, high seizure burdens and frequently associated cognitive dysfunction should be weighed in favor of surgical consideration.

There are several noninvasive localization tests available to help detect epileptogenic foci in nonlesional epilepsy. Most recently, SISCOM, MEG, and FDG-PET have become more widely available. However, most epilepsy centers may not have access to all of these modalities, therefore, there are few studies directly comparing all 3 tests with iEEG and surgical outcome in the same patients. The current study shows that both SISCOM and MEG have better lobar concordance with iEEG than SPM-PET. This is consistent with recent studies showing that SISCOM and MSI had a high predictive value for localizing seizures with iEEG.^{22,23} Although FDG-PET has been shown to be useful in temporal lobe

epilepsy,²⁴ its diagnostic value in nonlesional neocortical epilepsy is less clear.^{25,26} We used SPM analysis in an attempt to eliminate some of the subjectivity required with visual analysis and to control for differences in expertise and experience between readers.²⁷ Using SPM analysis of FDG-PET, the lobar concordance rate with iEEG was lower for FDG-PET than the other modalities. The extent of hypometabolism on FDG-PET is often larger than the true epileptogenic zone, and often extends beyond one lobe into an adjacent lobe. In addition, the epileptogenic zone is often observed in the periphery of hypometabolism rather than in the center.²⁸ As a result, FDG-PET may be more often lateralizing than localizing to a single lobe. In fact, FDG-PET successfully lateralized seizure onset zone in 71% (10/14) of our patients. PET and iEEG lateralization disagreed in 4 patients;

3 had a Class III or IV outcome. Therefore, discordant FDG-PET with other noninvasive tests may be associated with poor surgical outcome in nonlesional epilepsy. Similar findings have been reported in adult temporal lobe epilepsy.²⁹

Our data support the role of multimodal approach in presurgical evaluation of nonlesional epilepsy. First, multimodality imaging allowed us to extend the surgical treatment to patients who could not be considered good candidates without the tests. Based on ictal scalp EEG and clinical semiology, we were able to localize the possible epileptogenic zone in only 1 out of 14 patients (7%, 1/14) and to lateralize the epileptogenic hemisphere in an additional 8 patients (57%, 8/14). Without multimodality approach, 36% of patients (5/14) with poor lateralization may have been discouraged from epilepsy surgery. Second, we were able to refine the hypothesis on the possible epileptogenic zone and therefore to reduce the size of craniotomy and number of subdural electrodes. In our series, 57% of patients with lateralizing but nonlocalizing seizure onset may have required diffuse hemispheric iEEG coverage without the multimodal tests. Third, high concordance score across these tests tended to be associated with favorable surgical outcome even though it did not reach statistical significance, probably due to small sample size. This agrees with a previous study demonstrating that positivity of all tests including MSI, FDG-PET, and ictal SPECT predicts increased odds for seizure-free outcome after surgery.²²

Histologic examination revealed that all 11 patients with available pathology had focal cortical dysplasia. FCD type I was noted in 91% (10/11) of patients in this study. In previous reports, type I FCD was often associated with negative MRI and poor surgical outcome while type II FCD was associated with more visible MRI findings and better outcome.³⁰ Higher incidence of FCD in our series than previous series of nonlesional epilepsy¹⁷ and the presence of disagreement between the initial and second reviewer (18%, 2/11) suggest that there exists some variability of diagnostic threshold for FCD.

We recognize that there are limitations to this study. First, this is a single-center retrospective review, which is subject to selection bias given specific referral patterns. It is possible that more difficult cases of nonlesional epilepsy may have been discouraged from surgical consideration by the patients' primary neurologists. Second, our study did not analyze the cost-benefit aspect of this multimodality approach. With surging health care costs, many epilepsy centers may not offer all available noninvasive tests. However, considering the long-term financial burden of caring for intractable epilepsy patients, this

multimodality approach may be justified. Long-term follow-up of this patient population may provide further answers. Third, we applied SPM analysis of FDG-PET using a normal adult template. Even though SPM-PET has been reported to be useful in evaluating children over 6 years,³¹ small differences in the pattern of glucose metabolism may occur especially during late childhood and adolescence. Development of a normal pediatric template needs to be undertaken to apply SPM analysis more widely in the pediatric group, especially in children less than 6 years of age. Finally, we compared individual presurgical tests with iEEG to evaluate their diagnostic accuracy. Even though iEEG is considered the gold standard to map the ictal onset zone, sampling error is still possible, especially in nonlesional cases. Therefore, we tried to differentiate between the primary ictal onset zone vs the secondary spread zone based on iEEG pattern. Another shortcoming of using iEEG as the gold standard is that the placement of iEEG is to some degree influenced by the presurgical tests and thus the iEEG findings are not completely independent from the 3 presurgical tests.

Although combined multimodality imaging approach could enhance our ability to localize the epileptogenic zone in nonlesional focal epilepsy, extraoperative iEEG cannot be completely avoided presently. Aside from the exact localization of the epileptogenic zone, the extent of curative resection may not be accurately determined without proper iEEG monitoring and cortical stimulation mapping. A larger prospective study may be necessary to elucidate the role of multimodality imaging in this selected group of patients.

AUTHOR CONTRIBUTIONS

Statistical analysis was conducted by Dr. Paul Horn.

ACKNOWLEDGMENT

The authors thank Dr. Dong Soo Lee at Seoul National University for sharing the normal FDG-PET template acquired at his institution.

DISCLOSURE

Dr. Seo reports no disclosures. Dr. Holland-Bouley has received a speaker honorarium from Ortho-McNeil-Janssen Pharmaceuticals, Inc. and receives research support from the NIH/NINDS (R01NS062756 [PI]). Dr. Rose reports no disclosures. L. Rozhkov has 2 patents pending re: The technology of operating cylinder-rod kinematic couples by means of high-pressure gases. Dr. Byars receives research support from Novartis, the NIH (NICHHD 5R01HD38578 [coinvestigator] and NIDCD 5R01DC007186 [coinvestigator]), the US Department of Defense, and the US Department of Health & Human Services/National Institute of Child Health & Development. H. Fujiwara reports no disclosures. Dr. Arthur's spouse owns stock in General Electric. Dr. DeGrauw may accrue revenue on a patent re: Co-enzyme Q10 assay in blood; and receives research support from the FDA. Dr. Leach and Dr. Gelfand report no disclosures. Dr. Miles serves on the editorial board of *Pediatric and Developmental Pathology*. Dr. Mangano reports no disclosures. Dr. Horn serves on a scientific advisory board for the Cincinnati Children's Hospital Medical Center and receives royalties from the publication of *Reference Inter-*

Received March 2, 2010. Accepted in final form September 8, 2010.

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