Yield of MRI, high-density electric source imaging (HD-ESI),

SPECT and PET in epilepsy surgery candidates

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Abstract

Objective: Preoperative workup aims at localizing the epileptogenic focus to achieve postoperative seizure-freedom. We studied the predictive value of non-invasive techniques, i.e. structural magnetic resonance imaging [MRI], high-density electric source imaging [HD-ESI] and metabolic imaging (positron emission tomography [PET]; single-photon emission computed tomography [SPECT]), in surgically treated patients.

Methods: A prospective study of 190 epileptic operated patients, with >12 months follow-up and analyzed with state-of-the-art algorithms. 58 patients underwent all techniques. We computed sensitivity, specificity, predictive value and diagnostic odds ratio (OR) in relation to postoperative outcome.

Results: Of 190 patients, 148 (77.9%) were seizure-free at follow-up. Resection of the epileptogenic focus was associated with favorable postsurgical outcome ($p<0.05$). Among 58 patients who underwent all tests, only MRI and HD-ESI were favorable outcome predictors (MRI: OR 10.9, $p=0.004$; HD-ESI: OR 13.1, $p=0.004$). Patients with concordant structural MRI and HD-ESI results had 92.3% (24/26) probability of favorable outcome. When both results were negative, probability was 0% (0/5); and when they disagreed, it was 63.0% (17/27).

Conclusions: Combination of MRI and HD-ESI offered the highest predictive value for postoperative seizure-freedom.

Significance: This finding highlights the added value of HD-ESI in the presurgical workup, in particular in combination with an informative MRI.

Keywords: Presurgical evaluation; temporal lobe epilepsy; drug-resistant epilepsy; seizure-freedom; non-invasive procedures.

Abbreviations

EEG = Electroencephalography; SPECT = Single-photon emission-computed tomography; PET = Positron emission tomography; MRI = Magnetic resonance imaging; ESI = Electric source imaging.

Introduction

Evaluation and management of drug-resistant seizures remains a challenging clinical problem in epilepsy. Notwithstanding the advent of new antiepileptic drugs, nearly one-third of patients with recently diagnosed epilepsy will not achieve seizure remission with pharmacological therapy (Kwan and Sander, 2004). On the other hand, epilepsy surgery in suitable candidates can eradicate or markedly reduce the frequency of seizures in about ~60-70% of patients (Engel, 1993; Wiebe et al, 2002; Kwan and Sperling, 2009) and, therefore, should be considered early in the disease. Epilepsy surgery requires precise estimation of the epileptogenic zone to be removed in order to obtain seizure-freedom, while preserving the eloquent cortex (Rosenow and Luders, 2005). This is achieved by adding different non-invasive exams (e.g.: video-electroencephalogram [EEG], magnetic resonance imaging [MRI], positron emission tomography [PET] and single-photon emission computed tomography [SPECT]) (Knowlton et al, 2008; Schramm and Clusmann, 2008). In some patients, intracranial EEG monitoring is necessary (Rosenow and Luders, 2001; Knowlton et al., 2008; Schramm and Clusmann, 2008; Yuan et al., 2012).

Few studies including large cohorts (i.e. > 50-60 patients) have compared the contribution of non-invasive neurophysiologic techniques in the presurgical work-up. A study of 62 patients undergoing intracranial EEG identified a positive predictive value of 78% for preoperative magnetic source imaging based on magnetoencephalography (Knowlton et al., 2006), with a sensitivity of 55%. A recent prospective study compared electric source imaging (ESI) in a group of 152 operated patients with a follow-up period of >1 year and found highest sensitivity and specificity (> 80%) for ESI based on EEG with high-density electrode recordings (HD-ESI) (Brodbeck et al., 2011).

The aim of the present study, which is an extension of the prospective and methodological study performed by Brodbeck et al. (2011), was to determine which procedure *or combination of procedures* is the most predictive of seizure-free outcome in patients undergoing epilepsy surgery. Secondly, we consider only HD-ESI, given that its superiority over ESI with low electrode counts has been already shown (Brodbeck et al., 2011).

Methods

Patient population

This study was based on a prospectively collected database, including 190 patients who underwent surgery for medically intractable epilepsy at the University Hospitals of Geneva, Switzerland, between 1995 and 2012. All patients had a postsurgical follow-up period of at least 12 months. This study was approved by the local Ethics Committee, in agreement with the Declaration of Helsinki.

Presurgical workup included a thorough neurological examination, a neuropsychological assessment, a psychiatric evaluation, a high-resolution MRI, and in most cases PET. Ictal SPECT and ESI was added whenever possible. Forty-three patients underwent additional intracranial EEG recordings prior to surgical resection, if seizure onset zone could not be determined by non-invasive methods and/or to localize eloquent cortex. Out of those patients who underwent all non-invasive imaging exams (N=58), 23 were implanted with intracranial electrodes.

Surgery

Surgical decision-making was carried out on an individual basis at our weekly epilepsy surgery consensus conference. Resection was based on concordant

information provided by EEG, neuroimaging techniques, observation of ictal semiology and neuropsychological tests. No rules were applied in prioritizing a certain modality. Whenever possible, surgery was performed with the aid of imaging guidance.

Surgical treatment included the resection of the temporal lobe (n=125; 66%), the extra-temporal structures (n=60; 31.5%) and, in a single case, a cerebellar lesion (n=1; 0.5%). Transventricular hemispherotomy was applied in four cases (2%). Out of the 125 patients who underwent temporal lobe surgery, n=21 were limited to the medial temporal lobe only, n=20 to the lateral temporal lobe only, and n=84 included both regions. Extra-temporal lobe surgery comprised unilobar (n=31; out of which 52% targeted the frontal lobe) or multilobar (n=29; 48%) resections. MRI was abnormal in 174 patients.

Study variables

The outcome variable was the postoperative seizure outcome as determined by the neurosurgeon, neurologist or neuropsychiatrist on the last follow-up, according to Engel's classification (Engel et al., 1993). Table 1 provides information on the operated site and the postoperative outcome in 190 patients. Predictor variables were the results of preoperative imaging procedures described below.

High Density Electric Source Imaging (HD-ESI)

ESI based on EEG with a high number of electrodes was obtained in 85 patients by recording for 2-24 hours with 64 (n=2 infants), 128 (n=44) or 256 electrodes (n=39) using HydroCel Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR, USA). EEG was continuously recorded (1-2 h sessions) at a sampling rate of 1 kHz and

band-pass filtered between 0.1–400 Hz. The Vertex (Cz) electrode was used as recording reference and the data were referenced offline to the average reference. EEG was analyzed by means of a semi-automatic procedure composed by several steps described in Brodbeck et al. (2011).

The most dominant and isolated IEDs (i.e. spikes or sharp waves), with similar localisation and morphology, were visually detected by a blinded board certified EEG reader [A.M.L.]. Results were compared to those obtained by two unblinded authors in charge of the patients [M.S. and S.V.]. Numbers of averaged spikes in high-density EEG were on average 27 spikes (SD 34.26).

Interictal epileptic discharges (IED) were averaged across epochs of 500ms using the free academic software Cartool (D. Brunet, Geneva University Medical Center, Center for Biomedical Imaging, Geneva, Switzerland; <http://sites.google.com/site/fbmlab/cartool>). A band-pass filter of 0.1-30Hz was applied to the on-going EEG. The EEG map at the 50% rising phase of the averaged IED was selected for further source localization.

A local autoregressive average (LAURA) distributed linear inverse solution (Grave de Peralta Menendez et al., 2001; Michel et al., 2004) was applied to estimate the intracranial 3D current density distribution of the averaged IED. We applied a simplified realistic head model based on the individual MRI which constraints the solution space to the grey matter (for methodological details see (Michel et al., 2004; Spinelli et al., 2000)).

Magnetic Resonance Imaging

MRI was acquired either with a 1.5T Achieva (Phillips Healthcare, Netherlands) or a 3T Trio scanner (Siemens AG, Germany) and performed according to a standardized

state-of-the-art epilepsy protocol (Vargas et al., 2013) using a 32-channel brain coil: a) coronal T₂-weighted fast spin-echo repetition time (TR) 7520ms; echo time (TE) 114ms; voxel size 0.5 × 0.4 × 3 mm (slice thickness); b) sagittal 3D FLAIR (fluid-attenuated inversion recovery) TR 5000; TE 419; inversion time (TI) 1800; isotropic voxel size 0.9 × 0.9 × 0.9 mm); c) sagittal 3D gradient echo T₁ TR 1750ms; TE 2.29ms; isotropic voxel size 0.7 × 0.7 × 0.7 mm); d) diffusion-weighted imaging (DWI) TR 8000ms; TE 84ms; 30 directions; e) and arterial spin labelling (ASL) TR 4000ms; TE 12ms; voxel size 3.4 × 3.4 × 4 mm (slice thickness). MRIs were described by a board-certified neuroradiologist with long experience in epilepsy imaging [MIV]. In those patients who had no visible lesion on the MRI, voxel-based comparison with a healthy control group was carried out, as described elsewhere (Huppertz et al., 2009).

Positron Emission Tomography

PET acquisition was performed on a BiographHiRez Sensation 16 (Siemens Healthcare, Erlangen, Germany) using a standard protocol recommended by the manufacturer. PET scans were carried out in 185 patients, during the interictal state, using [¹⁸F]-labeled fluorodeoxyglucose (FDG). The administered activity was 250 MBq for adults and was adapted to body weight for children. Images were acquired approximately 30 min after tracer administration.

FDG-PET images of a subgroup of adult patients (58 subjects who underwent all four imaging techniques) were also analyzed by voxel-wise comparison with a normal database using *BRASS*[™] automated functional brain analysis software (Hermes *BRASS* software, Nuclear Diagnostics AB, Sweden) (Slomka et al., 2001). Each

individual FDG-PET image was warped to the reference template and a threshold of 2 SD was set to identify deviations from normal distribution (Radau et al., 2001).

Areas with minimal-to-low grade FDG uptake were visually identified by a board-certified nuclear medicine specialist [V.G.], who interpreted also the SPECT studies (see below).

Ictal Single-photon Emission-Computed Tomography

Ictal SPECT scans were performed using a single bolus injection of 740 MBq (20 mCi) ethlenecysteinate dimer labeled with [99mTc] during seizure. The administered activity was 740 MBq for adults and adapted to body weight for children. Scans were acquired 20–60 min after the radioisotope injection using a three-head gamma camera (Toshiba CGA-9300, Tokyo, Japan). A total of 137 patients were scanned. Focus localization was determined by visual analysis of the ictal exam. Ictal/Interictal SPECT were analyzed by subtraction ictal SPECT coregistered to MRI (SISCOM).

Test Scoring

After data acquisition and processing of all four modalities (MRI n=190, PET n=185, ictal SPECT n=163, HD-ESI n=82), localization findings were defined at a sublobar level. A visual selection method was equally applied across all four techniques. A score was established to assess the degree of localization of the probable seizure-onset zone (Luders et al., 2006): 1) Localized within the resected lobe; 2) Localized both within and outside boundaries of the operated lobe; 3) Localized outside the resected lobe; 4) Normal/No pathology detected; 5) Exam not performed. For statistical analysis, patients from group 2), 3) and 4) were considered together and

compared to group 1 (Table 2). Consensus was reached by a reviewer who was blinded to the final diagnosis [A.M.L.].

Statistical analysis

We defined a test as being positive if it placed the epileptogenic focus within the resection zone (i.e.: with no activity outside this area). For each test, we computed the proportion of seizure-free patients (Engel Class I) among those with a positive and a negative result, and obtained sensitivity (Sn), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and prognostic odds ratio

(OR) with its p-value. The prognostic OR can be defined as either $\frac{Sn \cdot Sp}{(1 - Sn) \cdot (1 - Sp)}$ or

$\frac{PPV \cdot NPV}{(1 - PPV) \cdot (1 - NPV)}$; it provides a summary assessment of the predictive ability of a

test. We repeated test comparisons in a subset of 58 patients who had available results for the four imaging methods (HD-ESI, MRI, PET and ictal SPECT). Table 3 details the clinical characteristics on that group of patients.

Regarding EEG recordings in the group of 58 patients: n=2 were recorded with 64 electrodes, n=31 using 128 channels and n=25 with 256 electrodes.

We also examined the performance of different tests combination; where having two positive results was compared to any other combination (e.g., comparison of both positive HD-ESI and MRI versus 1/2 or both tests negative). Finally, we used multiple logistic regressions to identify test results that best predicted a seizure-free outcome.

The analyses were conducted using IBM SPSS software version 18.

Results

Patients

Of 190 patients, 91 (47.9%) were women. The median age at epilepsy onset was 7.0 +/- 10.8 years (range 0-54), and age at surgery was 25.3 +/- 15.3 years (range 0.6-60). Fifty-seven (30.0%) patients were <16 years at time of surgery (median age: 8.6 +/- 4.6 years).

Post-surgical outcome

At 12-months follow-up, seizure outcome was Engel Class I in 148 (77.9%) out of the 190 patients, Engel Class II in 17 (8.9%), Engel Class III in 19 (10.0%) and Engel Class IV in 6(3.2%) (Table 1). Mean follow-up duration was 26.6 +/- 27 months. In our sample, patients suffering from extra-temporal lobe epilepsy presented a less favorable postoperative outcome (14/60 were Class III and 3/60 were Class IV), than patients with a temporal lobe intervention ($p = 0.0002$).

Performance of individual tests

All 190 patients had preoperative EEG recordings and standard MRI data. The number of patients with unavailable results was five for PET scan, 53 for ictal SPECT and 108 for HD-ESI (Table 2). If we detail the test scoring outcome per technique: a) MRI presented 132/190 results with score 1, 38/190 with score 2 and 20/190 with score 3+4; b) PET had 120/185 results with score 1, 45/185 with score 2 and 20/185 with score 3+4; c) Ictal SPECT presented 75/137 with score 1, 41/137 with score 2 and 21/137 with score 3+4; d) HR-ESI had 68/82 with score 1 and 14/82 with score 3. In the whole sample, all tests performed were associated ($p < 0.05$) with complete seizure control, defined as Engel Class I. The contrast was strongest for MRI, PET

and HD-ESI ($p < 0.01$). No imaging technique had both high sensitivity and high specificity.

We then compared test performance indicators among the group of 58 patients who had all tests available (Table 4, upper half). Among these patients, 35 (67.3%) were seizure-free. Only MRI and HD-ESI had prognostic OR greater than 5, and both were statistically significant even in this subsample ($p = 0.016$ and $p = 0.011$, respectively).

Performance of test combinations

As expected, the combination of two positive tests identified fewer seizure-free patients than each positive test alone. Therefore, this resulted in lower values of sensitivity and negative predictive value, and higher values of specificity and positive predictive value (Table 4, lower half). The highest prognostic OR was obtained for the combination of positive results on the HD-ESI and the MRI.

Logistic regression modeling among the 58 patients with all tests confirmed that only MRI and HD-ESI were independent predictors of favorable outcome. Once these two predictors were included in the model, none of the other tests were statistically significant. The adjusted prognostic OR was 13.1 for HD-ESI and 10.9 for MRI (both $p = 0.004$).

The combination of MRI and HD-ESI provided clinically useful results in more than half of the patients (Table 5). In a minority of patients (5/58), both tests were negative, and none of them experienced a favorable clinical outcome (i.e. NPV of 100%). In about half of the patients (26/58), both tests were positive, and 92.3% (24/26) were seizure-free at follow-up. If only one of them was positive and the other negative (27/58), the proportion of seizure-free was 63.0% (17/27).

We attempted to identify additional predictors of excellent outcome among the 27 patients with contradictory results on the MRI and HD-ESI. None of the nuclear imaging modalities (PET, SPECT) were associated with a favorable postoperative outcome ($p>0.4$).

Discussion

In this study, all preoperative imaging exams were associated with favorable postoperative outcome, but the strongest independent indicators were MRI and HD-ESI (independently or in combination; Figure 1).

MRI is capable of providing very high spatial resolution, and it is well known that the presence of a lesion is related to better outcome compared to non-lesional epilepsy. The definition of “non-lesional” varies across studies, and may refer either to imaging or histopathological results (Tellez-Zenteno et al., 2010), or may even include patients with hippocampal sclerosis (Lowe et al., 2010). In the present study, we adopted the very conservative and clinically practical definition of “non-lesional”; referring to the absence of a lesion in a high-resolution MRI obtained with an established “epilepsy protocol” including negative findings in a voxel-based comparison with a data set of >300 healthy subjects (Huppertz et al., 2005). Using this definition, MRI rendered a 70% sensitivity and specificity in the subset of 58 patients in whom all tests were performed. This may appear low, but in our population, many patients had multifocal, bilateral or no MRI lesion. Furthermore, even when MRI depicts a unifocal abnormality, the true epileptogenic zone may be more complex. A recent study on 158 patients with frontal lobe epilepsy, of which 76% were lesional cases, only 44% were postoperatively seizure-free (Simasathien et al., 2013). While incomplete resection is foreseeable when the lesion/focus is too

close to eloquent cortex; in many cases, like in dysplastic lesions, the epileptogenic focus may not necessarily overlap with the visible structural anomaly. Interestingly, in all 158 patients, intracranial exploration was carried out indicating once more that the use of intracranial EEG is no guarantee of success.

Concerning the remaining techniques, sensitivity values for PET of 60-100% and ictal SPECT (with or without statistical analysis) of 66- 97% were reported (Knowlton, 2006; la Fougere et al., 2009). In the present study we obtained different results with ictal SPECT portraying the lowest sensitivity among all tests (48.6%), followed by PET (62.9%), maybe due to a higher percentage of patients with extratemporal foci as opposed to other studies. In MRI-negative temporal lobe epilepsy, a clear unilateral anterior temporal hypometabolism on PET has a similar high rate of postoperative seizure-freedom than hippocampal sclerosis (Carne et al., 2004).

HD-ESI represents focus localization in the 3-dimensional space within the individual patient's MRI. The combination of HD-ESI and MRI achieved a remarkable predictive capacity (i.e. seizure-free) in more than 90% of the patients (24/26, 92.3%) for whom results were concordant; but remained inconclusive for the remainder (17/32, 53%). When neither test was able to locate the epileptogenic zone within the resected area, the results were uniformly unfavorable (100% NPV).

Spatial precision of HD-ESI is in the cm-range. It has been shown that localization precision, to a sub-lobar level, can be obtained by using an electrode setup of more than 63 channels. Further increase from 64 to 128 electrodes showed very little improvement (Lantz et al., 2003). In addition, according to an earlier study from our group on 38 patients undergoing intracranial EEG monitoring, the median distance from the ESI maximum to the nearest electrode involved in the seizure onset was 15 mm, which in most patients co-localized with the intracranial ictal focus (Megevand et

al., 2014). This is relatively high, given that intracranial EEG alone is probably an imperfect “gold standard” due to potential spatial undersampling and an interelectrode distance of already 10 mm. These results as well as studies with simultaneous intra- and extracranial EEG recordings also suggest that ESI is capable to detect deeper sources (Kossler et al., 2015; Ramantani et al., 2014).

In patients with discrepant MRI and HD-ESI results, nuclear imaging techniques did not add additional outcome predictors. Further research should focus on this group of patients, perhaps by including HR ictal recordings or research on other epilepsy markers like high frequency oscillations (Jacobs et al., 2010) or imaging changes of ictal rhythmic discharges (Yang et al., 2011). As opposed to interictal discharges, ictal activity is supposed to correspond with the underlying seizure onset area, although our and others’ studies (Noe et al., 2013) point to an important role of correct and precise localization of interictal discharges. Systems allowing overnight long-term recordings with 128 or 256 channels maybe able to add HR-ictal recordings. Ictal or interictal, electromagnetic imaging offers a unique non-invasive opportunity to visualize neuronal discharges with both a high temporal and spatial resolution and thus, seems to be the most adequate technique in localizing the epileptogenic focus.

Conclusions

Our findings indicate that the use of MRI and ESI in the presurgical workup is associated with optimal seizure control, provided that both techniques concord and that the resection procedure takes the results into consideration. ESI together with MRI, predict the postoperative outcome.

Conflict of Interest

M.S. received speaker's fees from UCB, Eisai, EGI and GSK; S.V. from UCB and EGI. C.K. received research fees from UCB. All authors have directly participated in the planning, execution or analysis of the manuscript.

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Figure Legends

Figure 1. Localization of non-lesional frontal epilepsy in a child. From left to right: magnetic resonance imaging (MRI), high-resolution electric source imaging (HD-ESI), positron-emission tomography (PET) and single-photon emission computed tomography (SPECT) localizing an anterior left frontal lesion. Dysplasia was confirmed by histopathological analysis. HD-ESI, PET and SPECT's results are projected on the individual anatomic brain. Sagittal (a) and longitudinal (b) slices are presented. This patient who had all concordant examinations was seizure free (Engel Class I) postoperatively after 3 years.

TABLE 1: Postoperative outcome of all 190 epileptic patients

Operated Site	Engel Class I	Engel Class II	Engel Class III	Engel Class IV	TOTAL (%)
ETLE	36	7	14	3	60 (31.5)
TLE					
MTLE	16	4	-	1	21 (11)
LTLE	18	1	1	-	20 (10.5)
M/LTLE	73	5	4	2	84 (44.2)
Subcortical	1	-	-	-	1 (0.5)
Hemispherotomy	4	-	-	-	4 (2.1)
ALL PATIENTS (%)	148 (77.9)	17 (8.9)	19 (10)	6 (3.2)	190

Engel Class I: seizure-free; II: decrease >80%; III: decrease 50-80%; IV: decrease <50%; ETLE = Extratemporal lobe epilepsy; TLE = Temporal lobe epilepsy; MTLE = Mesiotemporal lobe epilepsy; LTLE = Latero-temporal lobe epilepsy.

TABLE 2: Test results and seizure-free outcome in 190 patients

	Result	N (%)	Seizure free, N (row %)	p-value
MRI	Within resection	132 (69.5)	116 (87.9)	<0.001
	Outside or normal	58 (30.5)	32 (55.2)	
PET	Within resection	120 (63.2)	102 (85.0)	0.006
	Outside or normal	65 (34.2)	42 (64.6)	
	Not done	5 (2.6)	4 (80.0)	
HD-ESI	Within resection	68 (35.8)	57 (83.8)	<0.001
	Outside or normal	14 (7.4)	5 (35.7)	
	Not done	108 (56.8)	86 (79.6)	
SPECT ictal	Within resection	75 (39.5)	60 (80.0)	0.042
	Outside or normal	62 (32.6)	42 (67.7)	
	Not done	53 (27.9)	46 (86.8)	

HD-ESI = Electric source imaging high-density; MRI = Magnetic Resonance Imaging; SPECT = Single-photon Emission Computerized Tomography ; PET = Positron Emission Tomography.

TABLE 3: Clinical characteristics of the subset of 58 patients

Sex ratio (M/F)	27/31
Mean age at disease onset	8.95
Mean age at operation	24.76
ETLE/TLE ratio	1:1
Aetiology/Syndrome	
Hippocampal Sclerosis	19
Developmental§	6
Tumor*	7
Lesional&	7
Gliososis	2
Tuberous sclerosis	7
Miscellaneous^	2
Non-lesional	8
Mean post-op follow-up period (months)	22.6
Post-operative outcome (Engel Class)	
I	40
II	9
III	7
IV	2
EEG	
Number of electrodes	
64 channels	2
128 channels	31
256 channels	25
Intracranial recordings	23

§Focal cortical dysplasia, heterotopia, schizencephaly, lissencephaly, polymicrogyria

*DNET, hamartoma, ganglioglioma, meningioma

&Aneurysm, cyst, stroke

^Head trauma, post-infection

TABLE 4: Test performance in 58 patients in whom all methods were performed, for single tests and for pairs of positive results

Test	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	OR
MRI	70.7	70.6	85.3	50	5.8
PET	65.9	58.8	79.4	41.7	2.8
SPECT	53.7	70.6	81.5	38.7	2.8
HD-ESI	87.8	47.1	80	61.5	6.4
HD-ESI + MRI*	58.5	88.2	92.3	46.9	10.6
HD-ESI + PET*	58.5	70.6	82.8	41.4	3.4
HD-ESI + SPECT*	43.9	82.4	85.7	37.8	3.7
MRI + PET*	56.1	76.5	85.2	41.9	4.2
MRI +SPECT*	48.8	88.2	90.9	41.7	7.1
PET + SPECT*	46.3	88.2	90.5	40.5	6.5

HD-ESI = Electric source imaging high-rdensity; MRI = Magnetic Resonance Imaging; SPECT = Single-photon Emission Computerized Tomography ; PET = Positron Emission Tomography. PPV = Positive predictive value; NPV = Negative predictive value; OR = Odds ratio.

* Both tests positive versus any other result

TABLE 5: HD-ESI and MRI in patients with all tests

Test results	Patients with all tests performed	
	N (%)	Seizure free (row %)
Both Negative	5 (8.6)	0 (0.0)
Only MRI positive	8 (13.8)	5 (62.5)
Only HD-ESI positive	19 (32.7)	12 (63.2)
Both positive	26 (44.8)	24 (92.3)
TOTAL	58 (100%)	41 (69.5)

HD-ESI = High density electric source imaging; MRI = Magnetic Resonance Imaging