Hemispherectomy is a surgical procedure used to treat unilateral medication-resistant epilepsy in diffuse hemispheric conditions such as Sturge-Weber syndrome, cortical dysplasia, hemimegalencephaly, or Rasmussen encephalitis.7-9,14,21 Described by Dandy in 1928, and first applied by McKenzie in 1938 to intractable epilepsy, hemispherectomy consists of a complete resection of a hemisphere. Multiple modified techniques, known as functional hemispherectomies, were subsequently developed to avoid potential complications related to the empty cavity after the resection. Hemispherotomy, the latest development of the disconnection procedures, involves the resection of a variable amount of cerebral cortex, and the disconnection of the hemisphere including the corona radiata, resection of the medial temporal structures, transventricular corpus callosotomy, and disruption of the frontal horizontal fibers.23,27,30 There are 2 main variations to the hemispherotomy technique including a perinsular (lateral) approach and a transventricular, transcallosal (vertical or parasagittal) approach.
The isolation of the hemisphere by disconnection of the neural fibers achieves significant seizure control in the majority of patients, leading to improvement in developmental outcomes.\textsuperscript{6,21} Despite the effectiveness of these procedures, there are patients who do not improve with surgery and have residual seizures after surgery. Possible causes of suboptimal clinical outcomes include incomplete resection (especially the presence of residual frontal basal cortex), incomplete section of the corpus callosum, and bilateral independent epileptogenic foci.\textsuperscript{8}

Different strategies and techniques are used to identify the epileptogenic zone in children. An initial evaluation by an experienced pediatric epileptologist, neuropsychological and neuropsychiatric evaluations, EEG, MR imaging, video-EEG, SPECT, FDG-PET, and functional MR imaging are used in the majority of the centers.\textsuperscript{29} Intracranial monitoring with subdural grid placement over the suspected area is helpful in locating the seizure focus, but it is invasive and may not uncover all epileptogenic areas. For patients in whom current strategies fail to identify the epileptogenic zone, new noninvasive tools to improve patient selection would be highly desirable. Improved patient selection would enable a greater number of patients to be considered surgical candidates.\textsuperscript{7–4,7}

Magnetoencephalography is a technique that uses a superconducting quantum interference device (SQUID) and multiple detector coils over the skull to amplify small magnetic fields generated by intracranial neuronal activity. Magnetoencephalography allows for the combination of structural and functional information, achieving high spatial resolution (several millimeters comparable to subdural electrodes) and temporal resolution (less than a millisecond similar to invasive EEG) to localize epileptic activity.\textsuperscript{3,16,18,34,40} Moreover, MEG may be superior to EEG in locating the residual epileptogenic area after an operation, since magnetic fields are theoretically not distorted by the tissue conductivity of the scalp, skull, CSF, and brain. It can further be used to map eloquent cortex involved in speech, motor, sensory, visual, and auditory stimuli\textsuperscript{14,16,17,36,40,42}, which allows for improved presurgical planning and risk assessment. When combined with MR imaging, its utility is especially high in stereotactically guiding the surgeon to the epileptogenic zone, particularly in nonlesional cases. Magnetoencephalography has important advantages over EEG in neonates, because EEG waveforms can be distorted by open fontanelles and sutures, whereas MEG waveforms are not. Also, MEG systems do not require the use of gels that may cause allergies or skin irritation, as patients are in direct contact with leads or wires from the device.\textsuperscript{31,37,39} Despite these advantages of MEG, its sensitivity and specificity in the assessment of patients with drug-resistant epilepsy has not yet been completely elucidated. Magnetoencephalography is most sensitive to tangentially oriented cortical sources, along the walls of a sulcus, and least sensitive to cortical activity from radially oriented cortical sources such as on the crown of a gyrus.\textsuperscript{33,34} Other pitfalls of MEG include its reliance on the patient’s cooperation, its high cost, and limited access to the device worldwide.

We have used MEG in more than 600 patients who have been evaluated for epilepsy surgery at the Hospital for Sick Children. Of these, more than 200 patients have ultimately undergone surgery. Although MEG has predominantly been used for the localization of interictal epileptic discharge, there have been several reports confirming its utility in ictal events.\textsuperscript{2,11,33,37} We have shown that when MEG interictal spike clusters (≥ 20 spikes in a 1-cm area) correlate with electrocorticographic data, complete resection of the epileptogenic zone will result in seizure freedom in a very high percentage of cases.\textsuperscript{21} Coexisting scatters (small clusters [6–19] within 1 cm of each other, or < 6 sources or sources > 1 cm apart) remote from the clusters do not require excision as they are nonepileptogenic.\textsuperscript{21} In addition, MEG has been found to be useful in the management of lesional and nonlesional epilepsy in patients with nonlocalizing video-EEG.\textsuperscript{34–29}

To our knowledge, there are no studies investigating the role of MEG in patients undergoing hemispherectomy. The object of this study is to establish the relative contribution of MEG to the management of patients with drug-resistant epilepsy caused by hemispheric syndromes and in patient selection for hemispherectomy. We hypothesized that MEG localization to 1 hemisphere was a favorable prognostic indicator for seizure freedom in patients who underwent ipsilateral hemispherectomy.

**Methods**

The records of patients undergoing a functional hemispherectomy at the Hospital for Sick Children in Toronto were retrospectively reviewed, and patients who underwent MEG as part of the preoperative evaluation were selected. Thirteen patients met these criteria.

The information acquired for each case included patient demographics, clinical history, preoperative studies, surgical records, histopathology, complications, and outcome. Patients were each assessed individually based on their clinical presentation and findings from diagnostic test results. All patients underwent extensive neurological and neuropsychological examinations, MR imaging studies, and interictal and ictal scalp video-EEG. The video-EEG was performed using International 10–20 scalp electrode placement system with a single reference electrode (BMSI System 4000 and 5000, Nicolet). The MR imaging technique used volumetric acquisition and 3D reconstruction in multiplanar cuts of T1-weighted, T2-weighted, and FLAIR sequences using a Siemens 1.5-T/64-MHz MR imaging system (Siemens Medical Solutions USA, Inc.). Intracarotid injection of amobarbital sodium (the Wada test) for the lateralization of cerebral speech function and for testing of memory was performed in 1 patient, and another patient required invasive intracranial monitoring with subdural grid to further delineate the epileptic zone. All patients underwent MEG with a whole-head gradiometer using an Omega system (151 channels, VSM MedTech Ltd.). During MEG, they also underwent simultaneous EEG that was recorded from 19 electrodes (International 10–20 system). We recorded 2-minute periods of spontaneous MEG data 15 times. The sampling rate for data acquisition was 625 Hz. The MEG spike dipole sources were mapped onto the MR imaging (T1-weighted...
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ed, 2 mm slice thickness, no skip) pixels by using the MARK VOXEL program (VSM MedTech Ltd.). Patients who were unable to tolerate the test were placed under propofol and remifentanil general anesthesia.

Three patients had undergone a previous biopsy, and 1 patient had undergone 2 previous biopsies on separate occasions. Four patients had undergone a previous resection for cortical dysplasia, and 1 patient underwent 2 resections on separate occasions. The patients were discussed at a multidisciplinary epilepsy conference and those deemed suitable candidates went forward with surgery for periinsular hemispherectomy.

Magnetoencephalography spike sources were classified according to their number and spatial density: “clusters” (Class I) consisted of 20 or more MEGSSs with adjacent sources located within 1 cm of one another; “small clusters” (Class II) consisted of 6–19 MEGSSs within 1 cm of one another while “scatters” (Class III) consisted of fewer than 6 MEGSSs or sources more than 1 cm apart. No MEGSSs were classified as Class IV.

The hemispherotomy technique performed in all patients was a PIH, as described elsewhere.21,40 The Engel classification system was used to evaluate postoperative seizure outcome at 2 years after surgery.11,42

Results

Tables 1 and 2 summarize the demographics, brief seizure history, diagnosis, MR imaging findings, MEG findings, operative procedure, and seizure outcomes.

Patient Characteristics

Between 2002 and 2007, 13 patients underwent PIH and MEG at our institution. Some of these cases are highlighted in Figs. 1–5. Nine patients were boys. The mean age at onset of seizures was 25 months (range 0–84 months). The mean age at the time of surgery was 66 months (range 10–149 months). Patients had an average of 2.8 (range 1–5) seizure types that included complex partial, simple partial, absence, myoclonic, tonic-clonic, and epilepsy partialis continua. The average number of seizures per day was 12 (0.05–50). Three patients experienced status epilepticus.

Seizure etiology was Rasmussen encephalitis in 6 patients, hemimegalencephaly in 2, and cortical dysplasia in 4. All patients except one had preoperative hemiparesis, and 11 patients had developmental delay. The average time from seizure onset to surgery was 42 months. Seven procedures were performed on the right side.

Twelve of the 13 patients underwent successful MEG; in the remaining patient, MEG was unsuccessful due to technical reasons related to general anesthesia. Four patients had Class I MEGSS distributions, 5 had Class I coexisting with Class III MEGSS, 2 had Class II coexisting with Class III MEGSS, and 1 patient had only Class III MEGSS distributions. Eight patients had scattered MEGSS distributions in the contralateral nonepileptogenic hemisphere.

The patients in Cases 1, 4, 5, 7, 8, 9, 12, and 13 had unilateral EEG findings and clusters of spikes on MEG that identified the primary epileptogenic hemisphere, and the MR imaging findings were suggestive of a unilateral diffuse hemispheric condition. The patient in Case 1 had undergone a previous temporal lobectomy, and the postoperative video-EEG and MEG studies showed the epileptogenic zone in the right frontocentrotemporal area, with rare independent focus in the left frontal area. The patient in Case 7 underwent a right posterotemporal, parietal cortical resection; the postoperative electrocorticography, video-EEG, and MEG studies showed spikes and waves in the anterior margin of the inferior frontal cortical excision and from superoanterior frontal regions a distance from the cortical excision. The patient in Case 8 had undergone

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age at Op, Sex</th>
<th>Age at Onset</th>
<th>Seizure Type</th>
<th>No. of Diff Types of Seizure</th>
<th>Frequency</th>
<th>Pathology</th>
<th>FU (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 yrs, M</td>
<td>22 mos</td>
<td>CPSG</td>
<td>1</td>
<td>1–2/mo</td>
<td>RE</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>1 yr, M</td>
<td>2 mos</td>
<td>GTC</td>
<td>2</td>
<td>1–2/day</td>
<td>HM</td>
<td>78</td>
</tr>
<tr>
<td>3</td>
<td>5 yrs, M</td>
<td>2 yrs</td>
<td>PS, GTC</td>
<td>5</td>
<td>5/day</td>
<td>RE</td>
<td>57</td>
</tr>
<tr>
<td>4</td>
<td>2 yrs, M</td>
<td>21 mos</td>
<td>CPS, GTC</td>
<td>2</td>
<td>2/mo</td>
<td>RE</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>9.5 yrs, F</td>
<td>2 yrs</td>
<td>CPSG</td>
<td>3</td>
<td>5/day</td>
<td>CD</td>
<td>70</td>
</tr>
<tr>
<td>6</td>
<td>11 mos, F</td>
<td>3 wks</td>
<td>CPS, CPSG</td>
<td>5</td>
<td>1–10/day</td>
<td>CD</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>2 yrs, F</td>
<td>12 mos</td>
<td>PS, CPCG</td>
<td>3</td>
<td>13/day</td>
<td>CD</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>3 yrs, M</td>
<td>1 day</td>
<td>CPS, CPSG</td>
<td>2</td>
<td>50/day</td>
<td>CD</td>
<td>48</td>
</tr>
<tr>
<td>9</td>
<td>5 yrs, M</td>
<td>5 yrs</td>
<td>CPS</td>
<td>3</td>
<td>45/day</td>
<td>RE</td>
<td>62</td>
</tr>
<tr>
<td>10</td>
<td>10 mos, M</td>
<td>3 mos</td>
<td>CPS, CPSG</td>
<td>2</td>
<td>20–25/day</td>
<td>HM</td>
<td>24</td>
</tr>
<tr>
<td>11</td>
<td>8 yrs, M</td>
<td>1 day</td>
<td>PS, CPSG, G</td>
<td>4</td>
<td>2/wk</td>
<td>CD</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>12 yrs, F</td>
<td>7 yrs</td>
<td>PS, CPS, CPSG</td>
<td>3</td>
<td>3/day</td>
<td>RE</td>
<td>24</td>
</tr>
<tr>
<td>13</td>
<td>7 yrs, M</td>
<td>5.5 yrs</td>
<td>PS, PSG</td>
<td>2</td>
<td>epilepsy partialis continua</td>
<td>RE</td>
<td>12</td>
</tr>
</tbody>
</table>

* CD = cortical dysplasia; CPS = complex partial seizure; CPSG = complex partial with secondary generalization; Diff = different; FU = follow-up; G = generalized; GTC = generalized tonic-clonic; HM = hemimegalencephaly; PS = partial seizure; PSG = partial with secondary generalization; RE = Rasmussen encephalitis.

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<table>
<thead>
<tr>
<th>Case No.</th>
<th>Interictal</th>
<th>Ictal</th>
<th>MRI Finding</th>
<th>Other Tests</th>
<th>Localization of Hemisphere</th>
<th>No. of MEGSSs in Contralat Hemisphere</th>
<th>Engel Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rt</td>
<td>no ictal events recorded</td>
<td>rt hemiatrophy</td>
<td>—</td>
<td>although no ictal epileptiform activity was recorded, interictal slowing, neurological deficit, &amp; MRI corresponded to the rt side</td>
<td>61 T (59) — — 2</td>
<td>I</td>
</tr>
<tr>
<td>2‡ rt</td>
<td>rt</td>
<td>HM, rt hemisphere CD w/ rt F predominance</td>
<td>PET: decreased perfusion in rt hemisphere, sparing rt T region</td>
<td>MRI &amp; VEEG lateralized to the rt side</td>
<td>0 — — — 0</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>bilat</td>
<td>lt</td>
<td>lt hemisphere atrophy</td>
<td>—</td>
<td>MRI &amp; VEEG corresponded to lt side, although some interictal bilat discharges</td>
<td>65 T (10) — PO (11) 44</td>
<td>I</td>
</tr>
<tr>
<td>4</td>
<td>lt</td>
<td>lt</td>
<td>lt FT atrophy progression</td>
<td>—</td>
<td>MRI &amp; VEEG lateralized to lt side</td>
<td>9 — F (7) F (2) 0</td>
<td>I</td>
</tr>
<tr>
<td>5</td>
<td>UND</td>
<td>lt</td>
<td>lt FTP CD (pachygyria)</td>
<td>—</td>
<td>VEEG, &amp; MRI corresponded to lt side</td>
<td>160 F (157) — F (3) 0</td>
<td>II</td>
</tr>
<tr>
<td>6</td>
<td>lt</td>
<td>lt</td>
<td>extensive lt CD, polymicrogyria</td>
<td>—</td>
<td>MRI &amp; VEEG lateralized to lt side</td>
<td>86 T (38) — F (19) 29</td>
<td>I</td>
</tr>
<tr>
<td>7</td>
<td>rt</td>
<td>rt</td>
<td>rt parasylvian cortical malformation extending to parasagittal region of rt T lobe</td>
<td>subdural grid: rt superior T gyrus &amp; central cortex, interictal discharges localized to rt pst T &amp; R regions</td>
<td>VEEG, subdural monitoring, &amp; MRI to rt side</td>
<td>53 P (48) 5</td>
<td>I</td>
</tr>
<tr>
<td>8</td>
<td>rt</td>
<td>rt</td>
<td>CD in rt hemisphere</td>
<td>PET: hypermetabolic regions in pst &amp; medial lt O lobe</td>
<td>physical exam, VEEG &amp; MRI corresponded to rt side</td>
<td>16 F (12), P (4) — — 0</td>
<td>II</td>
</tr>
<tr>
<td>9</td>
<td>rt</td>
<td>rt</td>
<td>progression of vol loss in both hemispheres but mainly in rt, rt dural enhancement, RE</td>
<td>—</td>
<td>VEEG &amp; MRI corresponded to rt side</td>
<td>94 F (94) — — 0</td>
<td>I</td>
</tr>
<tr>
<td>10</td>
<td>lt</td>
<td>lt</td>
<td>lt partial HM involving lt TO regions</td>
<td>—</td>
<td>VEEG, PET, &amp; MRI corresponded to lt side</td>
<td>115 TO (81) — F (6), C (1) 27</td>
<td>I</td>
</tr>
<tr>
<td>11</td>
<td>rt</td>
<td>bilat</td>
<td>rt hemiatrophy</td>
<td>—</td>
<td>MRI corresponded to rt side; although VEEG was bilat, it had a subtle predilection to rt side</td>
<td>57 R (25) — T (4) 28</td>
<td>IV</td>
</tr>
<tr>
<td>12</td>
<td>rt</td>
<td>rt</td>
<td>increased signal intensity in the F lobe</td>
<td>—</td>
<td>VEEG &amp; MRI correspond to the rt side</td>
<td>13 P (7) F (4), T (1), P (1) 1</td>
<td>I</td>
</tr>
<tr>
<td>13</td>
<td>lt</td>
<td>lt</td>
<td>thickening &amp; blurring in lt precentral gyrus consistent w/ CD</td>
<td>—</td>
<td>VEEG &amp; MRI correspond to lt side</td>
<td>6 F (8), R (1), T (2) 0</td>
<td>I</td>
</tr>
</tbody>
</table>

* C = central; F = frontal; FTP = frontal temporoparietal; O = occipital; P = parietal; PO = parietooccipital; pst = posterior; R = rolandic; T = temporal; TO = tempororooccipital; VEEG = video-EEG; — = none; UND = undeterminable.
† The numbers in parentheses indicate the number of MEGSSs.
‡ The general anesthesia used in this patient to obtain the MEG precluded recording of any interictal activity.
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2 previous temporooccipital resections for cortical dysplasia; the last resection consisted of a complete temporal lobectomy and a partial parietal occipital lobectomy. The postoperative electrocorticography study showed intermittent spike discharges around the margin of the occipital lobectomy, and the postoperative video-EEG demonstrated right frontotemporal and occipital onset of seizures. Magnetoencephalography yielded 48 spikes in the right hemisphere and 5 in the left hemisphere. The majority of the MEG spike clusters were medial to the area of the cortical resection in the rolandic region, suggesting residual cortical malformation in the perisylvian region.

The MR imaging findings in the patient in Case 2 were consistent with hemimegalencephaly, and video-EEG localized the seizure onset to the right side. The PET study showed a decreased perfusion in the right hemisphere. There were no spike waves on MEG. The patient in Case 3 had imaging findings and a biopsy result suggestive of Rasmussen encephalitis and multiple seizure types, and video-EEG studies showed an ipsilateral ictal onset but bilateral interictal discharges. There were scattered bilateral spike sources on MEG. This patient was deemed a surgical candidate to achieve better seizure control. Although there was no expectation of complete seizure control, he ultimately demonstrated an Engel Class I outcome.

The patients in Cases 6 and 10 had hypsarrhythmia and a lateralizing video-EEG. The patient in Case 6 had left hypsarrhythmia predominancy, a slowed background
with a larger amplitude in the left hemisphere, and a focal abnormality in the left frontocentral region on EEG. Ictal events were related to left central parietotemporal rhythmic discharges. The patient in Case 10 had ictal events suggesting a left posterior head region onset. However, MEG showed bilateral dipoles in both patients. The patient in Case 6 had temporal and frontocentral spikes bilaterally (57 in the left side, 29 in the right side); the temporal discharge was more significant in the left hemisphere. The patient in Case 10 had 81 dipoles forming a cluster in the left temporooccipital region, some scattered spike waves in the left frontal operculum, and 24 spike waves forming a cluster in the right temporooccipital region. Based on the seizure semiology and imaging, video-EEG, and MEG imaging, these patients were considered candidates for hemispherectomy.

The patient in Case 11 had right brain hemiatrophy. Seizure onset was bilateral on video-EEG. Magnetoencephalography identified bilateral dipoles (28 on the left and 29 on the right). Compared with the left hemisphere, the right dipoles had a very low amplitude and were unstable. These findings were found to be highly indicative of a localized epileptogenic network in the atrophic hemisphere, which was not detected on the ictal scalp EEG.

![Fig. 3. Case 5. Three-dimensional reconstructions of fine-slice T1-weighted MR images (superior [left] and posterior [right] views). The images were obtained as part of the presurgical evaluation for PIH, for drug-resistant epilepsy. The MEG findings are superposed on the reconstructed images. Magnetoencephalography demonstrated dense clusters of spikes in the posterosuperior perisylvian region and the anterior part of the parietal lobe, inferior to the left central gyrus. Scattered spikes are seen in the left pre- and postcentral gyri, and in the right inferior frontal gyrus, representing mirror spikes. Spikes are shown in green.](image)

![Fig. 4. Case 8. Three-dimensional reconstructions of fine-slice T1-weighted MR images (superior [left] and posterior [right] views). The MEG findings are superposed on the reconstructed images. Magnetoencephalography demonstrated 16 scattered epileptic spikes in the right middle frontal gyrus, paramedian region, and right occipital lobe. Spikes are shown in green.](image)
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due to the very low amplitudes. Based on the clinical, MR imaging, and MEG findings, the patient was deemed a candidate for surgery.

The disconnection was carried out uneventfully in all cases, as documented by the surgical reports. A postoperative CT scanning study was performed in all cases. In 10 cases, postoperative MR imaging was performed.

Clinical Outcomes

At the last follow-up (mean 30.6 months), 10 patients were seizure free or had no more than a few early, non-disabling seizures or seizures upon drug withdrawal only (Engel Class I), 2 patients rarely had disabling seizures, more frequently soon after surgery or nocturnal seizures (Engel Class II), and 1 patient had a worthwhile improvement with seizure reduction for prolonged periods, but for less than 2 years (Engel Class IV). At the 2-year follow-up most patients were able to decrease their number of medications. Those patients with outcomes different from Engel Class I were the patients in Cases 5 and 8 (Engel Class II) and 11 (Engel Class IV).

Perioperative and Postoperative Complications

No deaths were associated with the procedures. All patients had increased hemiparesis after surgery. Major complications included hydrocephalus in 1 patient, which was treated by placing a ventriculoperitoneal shunt; temporary dysphagia in 5 patients; 1 superficial wound infection that subsided with antibiotics; and episodes of thalamic storming in 1 patient. Another patient underwent an occipital lobe craniotomy due to an occipital infarction, and an evacuation of an acute subdural hematoma. The same patient had a sagittal sinus thrombosis. In long-term follow-up, 12 patients were ambulatory and only 1 patient was wheelchair bound.

Discussion

Thirteen patients with intractable epilepsy underwent a comprehensive presurgical evaluation and were candidates for functional hemispherectomy. The decision for hemispherectomy was made based on clinical, video-EEG, MR imaging, and MEG findings, and on additional tests (PET and subdural grid) in 3 patients. In 8 patients, video-EEG and MEG results were consistent to localize the primary epileptogenic hemisphere. In 2 patients (Cases 6 and 10), the video-EEG lateralized the ictal onset, but MEG showed bilateral spikes. Two patients had bilateral video-EEG and MEG spikes (Cases 3 and 11). Patients obtained good to excellent seizure control postsurgery, with 10 patients having Engel Class I, 2 patients having Engel Class II (Cases 5 and 8), and 1 patient having Engel Class IV (Case 11) outcomes. Fewer than 10 MEG spikes were seen in 3 patients; in 1 case, this was probably related to general anesthesia.

Hemispherectomy has been reported as an effective surgical treatment in select candidates, and our series outcome (77% Engel Class I and 92% Engel Class I or II) is comparable to previously published results (43%–90% Engel Class I and 61%–100% Engel Class I or II). Several studies compared the efficacy of the different hemispherectomy techniques in seizure control, and the differences have not been significant.

In this series, 10 patients were seizure free at 2 years of follow-up, and in these cases, the MEG spike discharge overlapped with the video-EEG findings. In 2 of the patients who had an outcome other than Engel Class I, the MEG clusters were concentrated in the disconnected hemisphere. The third patient had bilateral clusters and potentially independent epileptogenic foci from bilateral cortical dysplasia. Three patients had bilateral clusters on MEG and had excellent outcomes after disconnection. Thus, in our series MEG spike disconnection was not a predictor of seizure freedom, although MEG findings were consistent with video-EEG in the majority of cases.

The factors influencing seizure outcome after hemispherectomy have not been completely elucidated. A lat-
eralizing EEG, such as unilateral background activity disorganization, and multifocal slow waves and spikes over the affected hemisphere, are predictors of a good outcome after surgery.\textsuperscript{1,10,44} Although abnormal EEG activity in the healthy hemisphere may represent secondary epileptogenesis, the chances of complete seizure control after surgery becomes less likely.\textsuperscript{23} The underlying brain pathology has been reported as the main factor in seizure outcome after hemispherectomy.\textsuperscript{3,18,21,32} Rasmussen encephalitis, porencephaly due to perinatal stroke, and Sturge-Weber syndrome are usually unilateral and achieve better rates of seizure freedom postoperatively (73\%–93\%) than multilobar malformative lesions such as hemimegalencephaly and cortical dysplasia (63\%–80\%), which usually present with bilateral electroencephalographic abnormalities\textsuperscript{4,5,9} and may be associated with some degree of contralateral brain involvement.\textsuperscript{5,21,23} Incomplete disconnection is associated with early recurrences that may disappear after reoperation.\textsuperscript{9,15,35}

In previous studies, MEG accuracy in predicting a good surgical outcome in temporal and extratemporal epilepsy was compared with previous techniques such as MR imaging, scalp video-EEG, and invasive EEG. In these studies, MEG was found to be second only to icctal subdural EEG.\textsuperscript{24,39} The correct localization by MEG of the epileptogenic zone was significantly better than localizations made based on the noninvasive video-EEG results.\textsuperscript{13,17,19,29} Magnetoencephalography has demonstrated utility in delineating the resection in nonlesional epilepsy, and the failure to resect brain regions containing the MEG dipole cluster leads to postoperative seizure recurrence.\textsuperscript{5,20,22,31} In cases of tumors with extramarginal MEG clusters, lesionectomy alone yields a favorable outcome.\textsuperscript{23,24,33,37} Although we expected that the lack of MEGSSs on the contralateral side would be a positive predictive factor for the success of hemispherectomy in providing a seizure-free outcome, this was not always found in this small patient cohort.

One issue to address when measuring MEG accuracy is the interpretation of the results. Bilateral independent MEG spike waves represent a frequent finding that raises the question of a differential diagnosis between secondary epileptogenesis versus bilateral seizure onset. This question is not always easy to answer without invasive monitoring. In fact, up to 25\% patients with focal epilepsies and unilateral interictal spikes show a bilateral seizure onset, and seizure onset occurs bilaterally in 70\% of patients with bilateral interictal spikes.\textsuperscript{12}

In our series, 10 patients were seizure free at 2 years of follow-up, and in these cases the MEG spikes overlapped with the video-EEG findings. In 2 of the patients who had an outcome other than Engel Class I, the MEG clusters concentrated in the disconnected hemisphere. The third patient had bilateral clusters and potentially independent epileptogenic foci from bilateral cortical dysplasia. Three patients had bilateral clusters on MEG and had excellent outcomes after disconnection. Thus, in our series, MEG findings were consistent with video-EEG in the majority of cases.

Some of the advantages of MEG over other procedures or tests performed in children with hemispheric malformations causing epilepsy include the short duration of the study (1–2 hours), the performance on an outpatient basis, and the ability to attain results even in infants. The results from MEG may be substituted by those obtained by video-EEG in many cases, as the two often provide a high rate of overlapping information. In our study, MEG did not alter the management of children with diffuse hemispheric epileptiform disturbances, although in the future a larger experience with MEG in more patients may offer insights into patient outcome after hemispherectomy.

Conclusions

Hemispherectomy is an effective surgical procedure for patients with unilateral intractable epilepsy related to widespread hemispheric diseases. A comprehensive assessment including neurological examination, video-EEG, and MR imaging is fundamental in identifying appropriate surgical candidates, since seizure recurrence seems to be related to bilateral involvement of the brain. The presence of unilateral MEG spike waves correlated with good outcomes after hemispherectomy. Magnetoencephalography is particularly advantageous in the pediatric population. If our results are confirmed in studies with greater numbers of patients, then it is possible that MEG could help in reducing the number of presurgical tests in select patients. Further studies with a greater number of patients are necessary to assess the role of MEG in the preoperative assessment of candidates for hemispherectomy.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Rutka. Acquisition of data: Torres, Fallah, Ibrahim, Otsubo, Ochi, Chuang, Snead. Analysis and interpretation of data: Torres, Fallah, Ibrahim. Drafting the article: Torres. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Rutka. Statistical analysis: Torres, Fallah. Administrative/technical/material support: Holowka.

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References

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