Localization of the epileptogenic focus is a rate-limiting factor in evaluating patients with medically uncontrolled partial seizures for epilepsy surgery. Considerable delay, expense, and possible morbidity are incurred if intracranial electroencephalographic (EEG) monitoring becomes necessary. Accordingly, improving noninvasive presurgical localization has become an area of considerable interest. Although structural brain imaging such as magnetic resonance imaging (MRI) has contributed much, functional localization of epileptogenic foci remains essential. None of the new “functional” imaging techniques, such as positron emission tomography (PET), single photon emission computed tomography (SPECT), or functional MRI (fMRI), has sufficient temporal resolution, however, to distinguish the origin of spike or seizure activity, as opposed to that which results from propagation. We continue to rely, therefore, on the analysis of interictal spikes and ictal rhythms recorded by scalp EEG for noninvasive functional localization.

Unfortunately, traditional EEG analysis by visual inspection is simplistic at best and misleading at worst. Characterization of an epileptogenic focus has in the past been limited to identifying the electrode recording the maximum negative potential. Such localization is based on the inaccurate assumption that the cortical generator must underlie the scalp EEG field maximum. In order to advance our use of EEG, we must progress beyond simple description of waveforms and pursue the activity and location of underlying cerebral sources. Computer-assisted EEG analysis greatly aids this effort. Voltage topography of spike and seizure potentials is the basis for epileptogenic focus localization with biophysical source models, such as the equivalent dipole or current source density (CSD). These models are more correctly based on the assumption that it is the relative location of both voltage maxima (negative and positive) and the contours of the voltage fields between them that convey information concerning source location, orientation, and propagation.

EEG Voltage Topography
EEG brain mapping, the display of voltage, spectral, or other processed EEG data on a schematic of a head, has been popular for more than 20 years; however, the spatial mapping of spike and seizure voltage fields in order to localize and characterize epileptogenic foci for clinical purposes is barely a decade old. During this decade, before I came to the University of Chicago in January 2000, my colleagues and I at Yale University studied EEG spike/seizure foci from more than 200 patients with complex partial epilepsy of temporal lobe origin. We observed three major patterns of voltage topography that could distinguish spike/seizure foci with sublobar precision: temporal base versus temporal tip versus lateral temporal foci (Figure 1). This distinction was clinically important because those patients with spike or seizure fields suggesting temporal basal or tip cortex foci had far better surgical outcomes following temporal lobe resections than those with fields suggesting lateral foci.

Dipole Source Modeling
Although mapping spike and seizure voltage fields on schematic heads clearly was worthwhile and an improvement over traditional EEG interpretation, my colleagues and I sought a means to predict the location and activity of an epileptic focus in three-dimensional terms. This would offer easier interpretations and provide a means to coregister EEG with other anatomical and functional data. To accomplish this we turned to a mathematical technique called dipole source modeling, which was developed years earlier to study normal evoked potentials but had not been applied clinically. Although the real generators of scalp spikes and seizures are areas of cortex that extend over several square centimeters,
the activity of such a region may be computer modeled by one or more dipoles. In general, the equivalent dipole model will reside close to the center of the real generator area, have an orientation that is orthogonal to the net orientation of this cortex, but be located slightly deep to the cortex.

In several studies, we noted that dipole orientation provided an essential clue to distinguishing foci in different temporal lobe regions.9-12 Equivalent spike or seizure dipoles with a horizontal and radial orientation suggest sources in the lateral temporal cortex, while dipoles with a more vertical and tangential orientation suggest an inferior and basal temporal cortex source. Finally, model dipoles that are horizontal but tangential and with a distinct anterior-posterior direction, suggest temporal tip cortex sources (Figures 1 and 2).

Several other laboratories in Europe have confirmed our findings regarding the utility of EEG dipole modeling in the evaluation of patients with focal epilepsy.13-17 There is a consensus that most spikes (and seizures) are well modeled by equivalent dipoles. These European researchers, too, have found that dipole orientation, rather than strictly dipole location, more clearly differentiates among possible cortical foci.

In our recent clinical series using dipole modeling of scalp EEG spikes and seizures, 12 of 12 patients whose epileptogenic focus was predicted to be in the basal temporal lobe, and 3 of 4 patients whose focus was predicted to be in the temporal lobe tip became seizure free after standard temporal lobectomy.18,19 We believe that such patients may be able to undergo surgery without invasive intracranial EEG monitoring. On the contrary, those patients whose EEG dipole analysis pointed to a lateral temporal focus required a more tailored cortical resection that needs invasive EEG data for its formulation. It is our belief that all patients who are candidates for epilepsy surgery will benefit from these state-of-the-art types of scalp EEG analysis.

NEW DEVELOPMENTS IN ANATOMICAL COREGISTRATION AND REALISTIC HEAD MODELS

Traditional EEG interpretation does not take advantage of the wide variety of anatomical information that is now available in most patients from CT, MRI, or other imaging studies. The clinically important information provided by spike or seizure voltage topography or dipole modeling now can be displayed on or in three-dimensional reconstructions of the patient’s own head and brain. Interpreting these functional data becomes both improved and easier for both the neurologist and neurosurgeon. The anatomical data obtained from three-dimensional reconstructions also can
be used to make true-to-life models of the patient’s head shape. Using realistic head shapes, rather than the customary spherical head model, has been shown to make dipole and other forms of EEG source modeling more accurate by up to 3 cm in focus localization²⁰,²¹ (Figure 2).

**EEG Current Source Density**

Currently there is much interest in producing images of brain function or dysfunction superimposed on the actual cortical surface. Although dipole models provide clinically useful localization of brain sources, they do not realistically depict the size and shape of the epileptogenic focus. For example, CSD analysis is one mathematical tool that can be used to estimate the extent of cortical activity involved in generating an epileptic spike or seizure. Estimated cortical currents associated with the abnormal discharges can be displayed on three-dimensional reconstructions of the patients’ brains. We have shown that these CSD models reflect the location and extent of cortical activity with surprising accuracy by validating the predictions with subsequent intracranial EEG recording in the same patients²²,²³ (Figure 2). Spike and seizure propagation also could be clearly identified. Although continued investigations will be necessary to refine CSD modeling for routine clinical purposes, we believe that soon it will be a useful adjunct to voltage topography and dipole modeling.

**Conclusions**

EEG voltage topography, equivalent dipole modeling, and CSD analysis are new neurophysiological tools that provide significantly improved localization of spike and seizure foci over traditional EEG interpretation. By using them routinely and properly at the University of Chicago Hospitals, the number of patients requiring long-term intracranial EEG monitoring before epilepsy surgery will be reduced, and the accuracy and utility of intracranial electrode placement will be improved in those patients who still need invasive recording.

**References**