Epileptic Source Localization from MEG data: Local maxima of 2DII current density solutions compared to ECD locations of spike events

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Abstract

The Equivalent Current Dipole (ECD) technique is limited to imaging sources for brief time windows when source amplitude is high and other activity low. Two Dimensional Inverse Imaging (2DII) [1] is a current density technique capable of imaging multiple source activity, and allowing the study of source activity time evolution. One would expect that 2DII solutions would contain ECD results as a subset in which the ECD locations correspond to local maxima of 2DII source solutions. Using a 148 channel MEG, interictal spikes were acquired from eight patients with complex partial seizures. Dipole selection criteria were: correlation coefficient > 0.95, goodness of fit > 0.95, Q >400 nAm, RMS >800 fT, and confidence region < 1mm^3. 2DII current density source solutions were generated for seven to fifteen spike events per patient. The distance between 2DII maximum and corresponding ECD peaks was used to quantify solution difference between the two imaging techniques. The average difference between 2DII and ECD source locations for individual spike events across all patients was 1.0 cm. This study demonstrates that 2DII imaging is useful in verifying ECD results with the added ability to study the interaction of an epileptic focus with other brain structures. The advantage of ECD is rapid calculation and quantification of final results with minimum number of parameters, (location, amplitude, quality of fit). The 2DII technique allows the observation of the dynamics of individual spike events and, when combined with the ECD technique, the correspondence of source location serves as a crosscheck on the validity of the results of each technique.

1 Introduction

ECD source localization is both useful and appropriate for imaging the location of a high amplitude source that dominates MEG data [2]. However, because of the requirement for a high amplitude source, the ECD technique is limited to accurately imaging sources for extremely brief windows of time in which the source amplitude is high and other source activity low. The 2DII technique is a current density technique capable of imaging multiple source activity and allowing the time evolution of source activity to be studied. However, to quantify significantly active sources, local maximum amplitude locations of the 2DII solution must be examined at each time slice, or from average 2DII source solution of multiple time slices. One would expect that these 2DII solutions would contain the ECD results as a subset in which the ECD location corresponds to a local maximum of the 2DII source solution.

The present study was performed to determine if the ECD source locations of an interictal spike would be consistent with the local source amplitude maxima of the corresponding Two Dimensional Inverse Imaging (2DII) solution of the same interictal spike.

2 Methods

2.1 Patient studies

Eight patients (male = 4; female = 4) with histories of localization-related epilepsy (complex partial seizures) were monitored with 148-channel Neuromagnetometer (4-D Neuroimaging Magnes WH2500) and 32 channels of EEG (Neuroscan synamps using the 10-20 system).

Each subject changed into a hospital gown and removed all metal articles from his/her body, except for dental work, which was demagnetized with a commercial videotape eraser. Three small electrode coils, used to transmit subject location information to the neuromagnetometer probe, were taped onto the subject's forehead with two-sided tape. Disposable ear molds of the correct size were placed in the ears and an additional localization coil was attached to each ear mold. The subject then lay comfortably on the bed inside of the magnetically shielded room, and automatic probe position routines were used to locate the head with respect to the neuromagnetometer detector coils. The neuromagnetometer helmet containing the detector array was then placed over the subject's head in close proximity to most of the cortical surface. The subject was asked to avoid both eye and body movements during data collection. Changes in the subject's position during the study were detected by changes in magnetic field locations from the coils on the forehead and ears. Runs during which the subject moved were repeated.

2.2 Data collection

MEG and EEG data were digitized at 508.63 samples per second from 0.1 Hz to 100 Hz. Three ten-minute continuous acquisitions were collected.

2.3 Analytical Technique

ECD [4] is a modeling technique used to model the direction and strength of neuronal current flow. The ECD technique is limited to imaging sources for brief time windows in which source amplitude is high and other activity low. Most studies use four parameters to determine if a dipole fit is reliable: the single current dipole moment, Q (strength of the dipole vector in nAm), the correlation coefficient, R (the degree of association between the actual measured magnetic field data and the estimated forward solution data), the goodness of fit, GoF (the measure of how well the measured magnetic field agrees with the estimated field from an assumed dipole), the root mean square magnetic field value of waveforms across all channels, RMS (measure of magnetic signal strength of the data at the latency for which the dipole is computed).

2DII [1] is a current density source imaging technique. The 2DII technique transforms random initial amplitudes of a 3,000-point cortical structure, extracted from the patients MRI into a source structure corresponding to the magnetic field data utilizing an iterative algorithm. For robustness, 20 solutions are used to create the images.

2.4 Data Analysis

Data were forward and backward filtered using a 3-100 Hz bandpass with a 60 Hz notch filter. All data were visually inspected for epileptic spike activity. A small interval of time encompassing the spike was selected and a ECD fit was performed using the Magnetic Source Imaging software (MSI) [4] algorithm based on a group of 35-40 channels over the area of interest. A short segment of quiet activity was used as baseline noise data for computing the confidence region. Selection criteria for dipole fits: Correlation coefficient > 0.98, goodness of fit > 0.95, Q values > 400 nAm, RMS > 800fT and confidence regions < $1mm^3$; then the mean average was calculated for each subject's spikes.

2DII current density source solutions were generated for seven to fifteen of these spikes per patient. For the time series of 2DII source solutions of each spike event, an average source amplitude solution was calculated and the location of 5 to 10 local source peak amplitudes were determined using a multiple seed point gradient search algorithm, followed by a clustering technique to merge sources with insignificant location differences. The ECD location was compared to the location of these local 2DII source solution maxima. The distance between the two imaging techniques was used to quantify the solution differences.

3 Results

The average difference between the locations of the underlying cortical sources for individual epileptic spikes across all eight patients from the two analytical methods was 1.3 cm.

For all spikes, the 2DII source locations and the ECD solutions were averaged to obtain an average 2DII and an average ECD spike location for each subject. The difference between these average 2DII and ECD locations was 1.0 cm. Table 1 displays the individual patient averaged x, y, z location component of the ECD and 2DII solution.

Table 1: *The distance between the individual average source location for the ECD vs. 2DII models.*

	Average ECD			**Average 2DII**			
Patient	X	Y	Z	X	Y	Z	Distance
1	2.30	1.65	10.59	1.91	1.60	10.26	0.51
2	-0.92	4.93	6.42	-0.83	4.20	6.51	0.74
3	5.88	-2.93	6.16	4.99	-2.02	5.20	1.59
4	-0.76	-5.03	5.40	-1.09	-5.18	5.37	0.37
5	2.95	-3.93	7.14	3.31	-4.14	6.7	0.62
6	5.14	2.33	5.24	3.26	3.36	3.28	1.93
7	6.34	1.75	6.60	6.68	-0.25	8.32	1.29
8	2.50	5.13	7.35	3.54	3.21	6.85	0.95
						Average Distance	**1.0**

In one subject the epileptic spike localizations for 5 spike events were displayed onto the patient's MRI slice. In figure 1 the localization solutions performed by ECD analysis are depicted as stars and the 2DII analysis are depicted as squares. For this subject the location distance between the ECD and 2DII source solutions was on the average 1.29 cm. The distance between the averaged ECD and the averaged 2DII solution location was 0.62 cm.

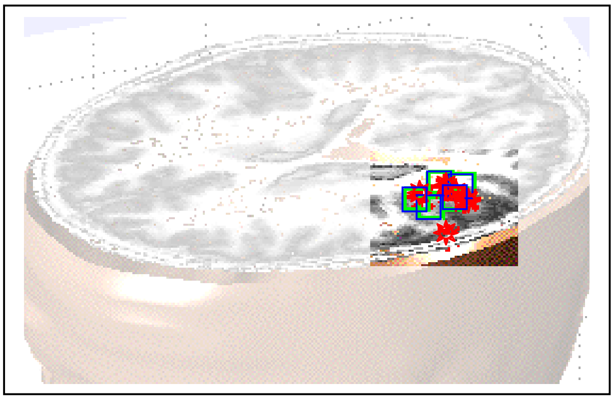

Figure 1 Source localizations of interictal spike activity by ECD (stars) and 2DII (squares) in one patient during an interictal spike event.

Figures 2 and 3 displays the different visualizations of each of these two analytical techniques. The 2DII image (fig. 2) displays the extended involvement of the tissue surrounding the focal location. The ECD (fig. 3) displays a point source location with the orientation of the current dipole vector.

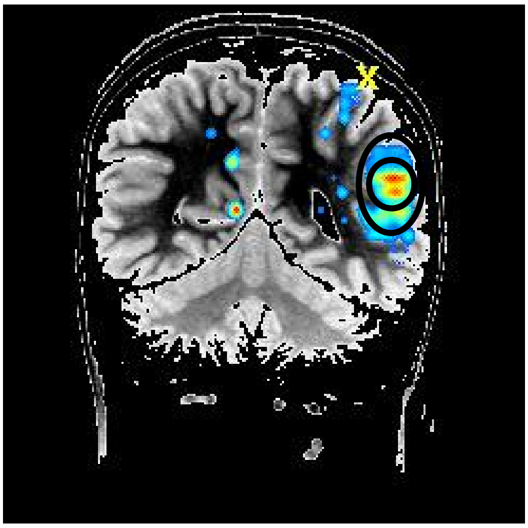

Figure 2 MRI Coronal slice with 2DII source localization of an interictal spike. Inner circle surrounds area of most intense cortical activity, outer circle encompasses moderate neuronal activity. Slice thickness 1.5mm. Gray scale is light for gray matter.

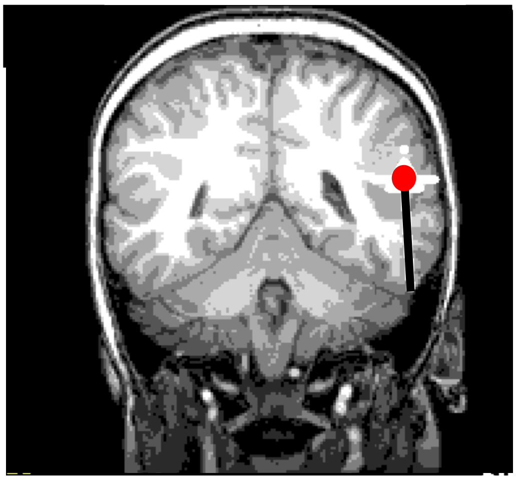

Figure 3 MRI coronal slice with ECD source localization of interictal spike in same patient. Black tail denotes orientation of the current dipole vector. Slice is 0.5mm thick. (Note that the gray scale's utilized for 2DII and ECD differ)

4 Discussion

ECD imaging, which characterizes epileptic activity in a very brief time window, has the advantage of quantifying source activity with a minimum number of parameters, (location, amplitude, quality of fit) for ease of interpretation, but this technique is limited to a very small time window within an epileptic event.

This study demonstrates how 2DII imaging can be used to verify ECD results with the added ability to study the whole brain and the relationships between neural networks (i.e. interaction of an epileptic focus with other brain structures) over the full time window of epileptic activity.

Acknowledgements

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