Parameters for Clinical Evaluation of Interictal Epileptic Spikes

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1 Introduction

Analysis of MEG data for presurgical localization of epileptic tissue from interictal spikes involves the time and the ability to discern the epileptic spikes from other neuronal events occurring in the cortex [1,2,3]. Current software (4D Neuroimaging) for Magnetic Source Imaging (MSI) includes as parameters:

1) The single current dipole moment [strength of the dipole vector in nAm (Q)]
2) The correlation coefficient [the degree of association between the actual measured magnetic field data and the estimated forward solution data (R)]
3) The goodness of fit [the measure of how well the measured magnetic field agrees with the estimated field from an assumed dipole (GoF)]
4) The root mean square (RMS) field value of waveforms across all channels.

Siedenberg et al. performed a localization study on noise to determine if the dipole selection criteria were able to discard events in which no sources are involved [4]. Epoch data of 410 trials were collected and the output averaged. Then a dipole fit routine was applied to the entire epoch. Correlation coefficients in the unfiltered data never reached a value of 0.70 or better and the goodness of fit (GoF) were less then 0.85. However, when filtered, (1-20Hz) this same data had maximum correlations of 0.93 and maximum GoFs of 0.98. In all cases the dipole locations for these solutions were in, or very near, a spherical head model.

MEG has been used extensively in the localization of epileptic spike activity. Most studies use the four parameters listed above to determine if a dipole fit is reliable. Kirchberger et al. [5] found that the MEG showed dipole localizations adjacent to the borders of previous dissection, in ten of seventeen patients. Single equivalent current dipoles (ECD) were calculated. Their measure of the reliability of the dipole fit was correlation coefficient of 0.98 or greater and confidence region of less than 3 cm^3 [confidence region (CR) is the volume of tissue that encompasses the 95% probability that the spike is located there]. Their results were supported by the findings of ECoG studies in all 5 patients undergoing this invasive procedure.

In the present study we also look at the calculated parameter for confidence region for both epileptic spike activity in a human subject and epoch noise data without a subject under the MEG probe

2 Methods

2.1 Patient studies

Six patients (male = 3; female = 3) with histories of complex partial seizures were monitored with 148 MEG channels (4D Neuroimaging Magnes WH2500), and 21 channels of EEG (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. Subjects with metallic or electrical device implants were excluded. Three small electrode coils, used to transmit subject location information to the neuromagnetometer probe, were taped to the subject's forehead with two-sided tape. One coil was located in the center of the forehead and one coil on each side, approximately 2 cm apart. 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 (MSR), 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 the 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 Subject Data - Epilepsy

Data were digitized at 508.63 samples per second from 0.1 Hz to 100 Hz. Three ten-minute continuous acquisitions were collected. Data were forward and backward filtered using a 3-100 Hz bandpass with a 60 Hz notch filter. All data was visually inspected for epileptic spike activity. A small interval of time encompassing the spike was selected and a single equivalent current dipole fit (ECD) was performed using the MSI 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. MSI software then localized the source of activity for each interictal spike. Correlation coefficients, goodness of fit, and RMS parameters were calculated along with confidence regions by dipole fit routine for 156 spikes, which met MSI selection criteria, then the mean average was calculated for all spikes and each individual subjects spikes were averaged.

2.3 No Subject Data – Noise

Continuous noise data was collected exactly as the epilepsy protocol, but without a subject under the probe. Data were digitized at 508.63 samples per second from 0.1 Hz to 100 Hz, for ten-minute of continuous acquisitions. Data were forward and backward filtered using a 3-100 Hz bandpass with a 60 Hz notch filter. Visual inspection was used to locate any area where a dipole may be fit. Then a single ECD was fit to selected latencies.

Epoch Noise data without a subject was also collected. Data were digitized at 290.64 samples per second from 0.1 Hz to 50 Hz. Three epoch data sets were collected (512 epochs; epoch duration of 0.4 seconds), while the sensor was in the same location as our data collection during subject studies. This protocol was similar to that used by Siedenberg et al. [4]. Data was forward and backward filtered using an 8-40 Hz bandpass with a 60 Hz notch filter. All data was visually inspected for maxima and minima. This visual inspection of the data and the contour plot of the magnetic field suggested that the activity would found in the posterior regions. The time interval from 1-180 msec was selected and single equivalent current dipole fits (ECD) were performed using the MSI algorithm based on a group of 58 channels over the left posterior hemisphere (LP) and then again over the right posterior hemisphere (RP).

Confidence regions, goodness of fit, correlation coefficients, and RMS were calculated by dipole fit routine, these values were then averaged for the filtered epoch and the unfiltered epoch. Only correlations with a fit of 0.80 or better were included in this analysis.

3 Results

3.1 Epileptic Subjects

Our results show that the mean average correlation coefficients were 0.99, average GoFs were 0.97, and the average RMS were 823 nAm, which was over twice the value of the average Q values, 260nAm. The mean average confidence region was 1.08 $cm^3 \pm 1.05$ for all 156 epileptic spikes. Table 1 shows the mean average calculated parameters for each individual patient's epileptic interictal spike activity. Table 2 is the overall mean average parameters of all 156 spikes.

Table 1: *The average dipole fit parameters for epileptic spikes from each of the 6 subjects.*

	N	GoF	R	CR (cm^3)	RMS (fTesla)	Q (nAm)
1	75	0.95	0.98	1.1 ±1.0	838 ±244	273± 209
2	29	0.97	0.99	0.3 ±0.4	615 ±106	270±151
3	33	0.97	0.99	0.3 ±0.3	968 ±209	197± 98
4	40	0.96	0.99	1.5 ±0.8	707 ±148	214±117
5	26	0.97	0.99	1.8 ±1.0	1083 ±240	365±119
6	3	0.95	0.99	2.3 ±1.1	507 ±139	79± 32

Table 2: *The dipole fit parameters for all 156 epileptic spikes from 6 subjects.*

	GoF	R	CR cm^3	RMS fTesla	Q nAm
Mean	0.97	0.99	1.09	823.71	260.29
Standard Deviation	0.03	0.01	1.05	258.33	172.08

3.2 Noise - no subject

The single ECD fits to the continuous noise data had correlation coefficients and GoFs of less then 0.80. Therefore no further analysis was carried out on this set of noise data.

The average parameters calculated for the filtered and unfiltered epoch noise runs are shown in Table 3. The single ECD fit was performed on the unfiltered data using the 58-magnetometer channels in the left posterior area (LP) and again in the right posterior area (RP).

Table 3: *The dipole fit parameters for all filtered and unfiltered epoch noise data.*

	N	GoF	R	CR cm^3	RMS fTesla	Q nAm
Unfiltered						
LP	13	0.91	0.87	873	8.8 ± 1.9	6.0 ± 2.2
RP	34	0.91	0.92	492	10.1 ± 1.8	5.9 ± 1.6
Filtered 8-40Hz						
LP	3	0.89	0.83	507	4.0 ± 0.4	2.0 ± 0.1
RP	5	0.85	0.87	131	3.5 ± 0.6	2.2 ± 0.6

Only correlation coefficients and Goodness of Fits better than 0.80 were included in this analysis. The mean average GoF for the unfiltered data with both channel groups were 0.91, which were higher than the filtered data. The correlation coefficient (R) was 0.87 and 0.92 for the unfiltered data and lower for the filtered data. These findings contrast to those of Siedenberg, et al. [4]. The RMS values were not very large for the unfiltered data but larger for the filtered data, and they were larger than the Q values. The average confidence regions for all noise runs were over 100 cm^3. See Table 3 for these values.

See Table 4 for a comparison of the confidence region parameters between the runs where a subject was monitored (Epilepsy) and those were no subject was monitored (Noise).

Table 4: *The Confidence Region Values in cm^3.*

NOISE	EPILEPSY
873.33 ± 232.59	1.1 ± 1.0
491.60 ± 409.67	0.3 ± 0.4
506.72 ± 1798.88	0.3 ± 0.3
131.40 ± 82.82	1.5 ± 0.8
	1.8 ± 1.0
	2.3 ± 1.1

4 Discussion

By utilizing the parameter for confidence region (CR) in the determination of selecting epileptic spikes, the dipole fit suitability is efficiently found. When attempts to fit a dipole to epoch noise data, where no activity was occurring, correlation coefficients and GoFs could be calculated in the 0.80's. However the confidence regions for noise data were found to be very high over 100 cm^3. Confidence regions for all epileptic spikes used in the localization of epileptic activity were under 2 cm^3. Therefore by using this parameter in the analysis of epileptic spike activity, the reliability of the localization of the dipole fit was increased.

The confidence region of spontaneous spikes can be calculated and is an additional factor to consider when selecting representative

ECD localizations for interictal spikes. This will reduce the probability that the dipole is not localized to a 1cm^3 area or less. Consideration should be given to the possibility that spikes localized within the same confidence region arise from the same source.

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