Integration of Dipole Model and Current Density Reconstruction towards 3-D Source Localization using EEG and MRI

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1 Abstract

This study adapted the CURRY program and assessed the relationship of the 3-D spike-source to local lesions evident on the patient's clinical history. Dipole and Current Density Reconstruction (CDR) simulations were performed using realistic head models and using the boundary element method (BEM). This represents an initial step in developing the techniques for the pre-surgical evaluation of children. The integration of dipole and CDR models will then provide accurate 3D localization of brain lesions and tumors in 3-D images. This would consequently enhance the data analysis, signal interpretation, diagnosis, and validation of previous results, which are especially welcome in safety critical procedures.

2 Introduction

3-D source localization integrating EEG and MRI modalities can serve as a powerful tool for determining accurately the 3-D location of an epileptogenic event. To estimate the location of such an event, one must first correctly model the dipoles, as well as the volume conductor in which the resulting currents flow. Dipoles arise from extracellular sites and are related to a malformed pathologic substrate that is more extensive than the lesion evident on MRI scans. Pre-operative evaluation is therefore more difficult in adults and relies heavily on EEG data including interictal spike discharges. The spikes recorded on the scalp can be processed using specialized software such as CURRY to define their source in 3-D that can then be superimposed on the patient's MRI scan to further facilitate surgical planning. A detailed review of the different source reconstruction methods can be found in [1]. While source reconstruction methods have been successfully used in adults being evaluated mainly for temporal lobe epilepsy, that applications have been limited in the pediatric population.

Dipole models converge with other localizing information such as the CDR since as an effective tool in determining if a patient can go to surgery directly without invasive EEG monitoring. Dipole algorithms require a prior knowledge of the number of active sources. They rely on the assumption that the most actively involved cortical areas are well represented by their centers of mass. Therefore, the need for the development of source models such as the current density reconstruction has been growing. The results of a CDR method represent more realistically active brain regions. They provide extra information needed of the source such as extension, number of higher activated areas in the brain and prior knowledge of the number of sources is not required.

3 Methods

Participants

Ten children with medically refractory partial seizures undergoing pre-surgical evaluation have been analyzed in this study. The EEG data was recorded using XLETek Neuroworks Ver.3.0.5 (by Lotus Tech Ltd. Ontario, Canada). The standard international 10-20 system with four extra temporal electrodes was used. Sampling frequency of 500Hz with 0.1-70 Hz band-pass filter settings and 12 bits A/D conversion were used to obtain the digital EEG recordings. MRI images were created using the Sigma Horizon LX 1.5 Tesla MRI scanner (manufactured by General Electric, Medical Systems, Wisconsin, USA). High resolution T1 weighted spoiled GRASS (Gradient Recalled Acquisition in the Steady State) images were obtained.

Implementation Steps

To identify the location of the epileptic sources, a source localization program was developed using the Neuroslicer software CURRY V.5.0. Input data in this study were EEG signals and MRI brain images of epileptic patients. The first step in the localization procedure involved identifying the pertinent time intervals in the overall EEG recordings in which the interictal spikes occurred. The physicians performed this task by visual inspection of the recorded data. Those portion of EEG data were of 4.5 seconds of duration and during the spike interval the source localization analysis was performed.

In the preprocessing step, DC and high frequency components were removed from the data using a 0-1.3 Hz band-pass filter. To reduce the configuration space and to extract the dominant EEG patterns, the EEG data is first decomposed into signal and noise subspaces using Principal Component Analysis (PCA) decomposition. After PCA, we apply Independent Component Analysis (ICA) on the signal subspace. MRI brain spaces were used to construct realistic subject dependent head models. The model derived was a Boundary Element Method (BEM). After obtaining the final coordinates of the calculated dipole through a digital pen that is applied to the patients, the electrode positions were imported to the CURRY software for co-registration with the MRI.

The method applied for source localization integrated the rotating dipole solution and a CDR-based method. A rotating dipole can depict the location of a given source accurately and CDR can provide the extent of that given source, thus defining fully the source of the event. The time interval during which the source localization was performed was a 200 ms maximum time range, which is a typical duration of an epileptic spike [2]. The most important subintervals interval that was analyzed was the upslope phase of the spike since it is related to the actual seizure onset. The results obtained by implementing the dipole method in the calculated location of the dipole in the form of a point in Cartesian coordinates and the strength of the dipole moment at the selected time interval [3].

In this study the CDR method, which is a distributed source model, calculates the amplitude of a large set of dipoles. No assumptions on the number of dipoles in the brain are considered. The number of calculated dipoles is always much larger than the number of electrodes used on the EEG. In our studies we used the ALORETA method. sit ALORETA does not require spatial resolution in sight. Instead, the variance of the estimated current is used. 3D ALORETA method is fast in terms of processing time while it still yields high localization accuracy [4].

4 Results

The source localization analysis was performed during the 200ms interval in which the spike occurred. This interval analysis allowed us to track the propagation of the source of epileptic activity from the onset of the spike to the generation of the slow wave representing the end of the spike. Since the whole spike duration was monitored over one or two intervals, the analysis yields one or two source locations per interval [5, 6]. It is important to note that the 10 participating patients underwent successful surgical interventions and our results did confirm the clinical findings. The results for one given patient are illustrated in Figure 1.

Quantitative EEG morphology showed the source located in the left frontal and temporal lobe, with an orientation suggesting left frontal and temporal. These findings suggest that the center of interictal epileptic activity is situated in the left region of the brain. A thorough analysis was performed with the CDR method and the results show that there is also an indication of frontal and temporal activity in the left side.

5 Discussion

This preliminary study was aimed at localizing cortical generators of interictal epileptiform activity in patients by means of dipole and CDR analysis. The full process integrated the PCA and the ICA methods in the analysis of EEG data, using the multimodal neuroimaging software named CURRY to optimize the accuracy of the 3-D localization results. The results of the dipole and CDR methods showed that the calculated 3-D sources were closest to the lesions. Interval analysis using rotating dipole and CDR models provide a powerful tool for studying spikes propagation and have important pathophysiological implications. The results are most encouraging, considering that the 3-D sources were computed using only 23 electrodes. The use of closely spaced electrode array and averaging of multiple spikes in each subject will likely enhance the precision of 3-D localization. The results of this integrated technique will benefit from another research endeavor that consists including diffusion tensor imaging (DTI) to the current source localization of the EEG MRI integrated platform. This constitutes our next research step.

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7 References


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