(Submitted to Neurocomputing)

Localization of Epileptic Foci by Means of Cortical Imaging using a Spherical Head Model

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Abstract

We have applied a cortical imaging technique (CIT) with a three-sphere head model to estimate cortical potentials from scalp EEG recordings during interictal spikes in a pediatric epilepsy patient. The CIT analysis was performed during the ascending limb of interictal spikes and localized areas of activity were observed, overlying the epileptogenic zone, as being confirmed by the ECoG recordings and neurosurgical resections of the patient. The present study suggests that CIT may provide a useful alternative for noninvasive localization of intracranial sources generating epileptiform activity from pre-operative scalp EEG recordings.

Key word: cortical imaging technique, source localization, epilepsy, EEG

1. Introduction

Long-term electroencephalogram (EEG) and video monitoring of epileptic patients is a well-established procedure in the diagnosis and management of epilepsy. Due to the volume conduction effect of the skull, the scalp EEG is severely smeared, thus not being able to provide spatial details on the underlying brain electrical activity [4, 11]. It is important to accurately localize the sites of seizure onset to improve the surgical outcome and avoid neurologic deficits from surgical resections. Thus, electrocorticography (ECoG) has been employed for the direct inspection of the epileptogenic zone on the cerebral cortex and has become a kind of "golden standard" for defining epileptogenic brain regions. However, invasiveness, risk of morbidity, limited availability, and the high cost of this technique limit its use in the clinical routine. Therefore, it is highly desirable to significantly enhance the spatial resolution of the scalp EEG, thus enabling a better prediction of the location of epileptic foci from noninvasive scalp EEG monitoring.

A recently developed cortical imaging technique (CIT) [5] can link the cortical potentials with scalp potentials by a lead field matrix. By solving the EEG inverse problem, the cortical potentials can be estimated from the scalp potentials with enhanced spatial resolution, by reducing the blurring effect of the head volume conductor. Compared with the 3-D inverse solutions [3, 8, 10, 14, 15, 16], the CIT approach has the unique feature that it can be compared directly with the ECoG recordings. In the present study, we examine the feasibility of applying the previously developed CIT for noninvasive localization of epileptic foci from pre-operative EEG measurements.

2. Methods

2.1 Data Acquisition

A pediatric patient with medically refractory seizures was included in the present study according to a protocol approved by the IRB of The University of Illinois at Chicago and the University of Chicago. The long-term video EEG monitoring was conducted in the Pediatric Epilepsy Center at the University of Chicago Children's Hospital. Pre-operative scalp EEG (24 channels) was sampled at 400Hz and band-pass filtered from 1-100Hz. The scalp electrodes were uniformly distributed over the scalp according to the 10-10 system. The intracranial electrode pads were placed directly on the surface of brain, and post-operative ECoG was recorded for intracranial monitoring [13]. The artifact-free interical spikes from pre-operative EEG data were visually detected. CIT analysis was applied to time points from 20 ms before to 5 ms after the largest negative peak.

2.2 Data Analysis

The previously developed CIT algorithm was detailed in [5]. Briefly, the head volume conductor was approximated using an inhomogeneous three-concentric-sphere model, in which the radii of the brain, the skull, and the scalp spheres were taken as 0.87, 0.92, and 1.0, respectively (Fig.1). The normalized conductivity of the scalp and the brain was taken as 1.0, and that of the skull as 1/80. Each surface of the three spheres was discretized uniformly into 1280 triangle elements. The cortical potential $\boldsymbol{F}$ and measured scalp potential $\boldsymbol{U}$ can be directly connected by lead field matrix $\boldsymbol{A}$ as $\boldsymbol{U} = \boldsymbol{AF}$. By solving the inverse problem using zero-order Tikhonov regularization [12], the cortical potentials can be estimated from the scalp potentials with enhanced spatial resolution as

$$\boldsymbol{F} = \boldsymbol{A}^{+} \boldsymbol{U} = (\boldsymbol{A}^{T} \boldsymbol{A} + \boldsymbol{l}\, \boldsymbol{I})^{-1} \boldsymbol{A}^{T} \boldsymbol{U}$$

where $^{+}$ represents pseudoinverse, ^{T} represents matrix transpose, and I represents identity matrix.

The regularization parameter *ë* which is used to suppress the effect of noise, is determined by the L-curve approach [2].

3. Results

The patient is a 16-year-old male with intractable seizure. His intracranial monitoring suggested that the epileptogenic zone was in the left frontal lobe. Neurosurgical resection of a large portion of his left frontal lobe reduced this patient's seizure from many times per day to occasional once per week or per two weeks. One typical waveform segment of interictal spike and the scalp potential distributions at three time points are shown in Fig. 2. The largest negative peak was recorded at Fz, and was marked by black dot in Fig 2 (a). Notebly, the scalp EEG maps showed a widely distributed pattern, and did not reveal the spatial details on the underlying epileptogenic zone. The CIT analysis results are shown in Fig. 3. At the correspondent time points with those in Fig. 2, the estimated cortical potentials were obtained with enhanced spatial resolution. It also clearly revealed that the activity was originated from the left superior frontal lobe, and propagated toward midsaggital line, and spread there. The CIT results are consistent with the intracranial ECoG recordings, and are confirmed by the surgical resection.

4. Discussion

In this pilot study, we have applied the cortical imaging technique [5] to estimate the cortical potentials during interictal spikes from pre-operative EEG recordings in a pediatric epilepsy patient. Enhanced spatial resolution was achieved in the estimated cortical potential maps as compared to the blurred scalp potential maps, thus fascilitating noninvasive localization of the intracranial sources of epileptiform activity. Promising results have been obtained in the present study, in that the estimated cortical potential maps revealed localized area of activity overlapping with the cortical region displaying epileptiform activity, as being confirmed by the surgical resection of the patient. In comparison with the cortical current imaging [1,9], the present CIT analysis allows estimation of cortical potentials [4,5,6,7], thus providing a means of comparison with the ECoG [7]. More accurate inverse estimation would be expected to be achieved by employing more scalp recording electrodes, and by using the realistic geometry head model constructed from the patient's magnetic resonance images [7]. In summary, the present promising results suggest that the CIT approach merits further investigation for its application to non-invasive localization of epileptic foci from pre-operative EEG monitoring.

Acknowledgment

This work was supported in part by NIH EB00178, NSF CAREER Award BES-9875344 and a Falk grant.

References:

[1]. A.M Dale., and M.I. Sereno, Improved localization of cortical activity by combining EEG and MEG with MRI cortical surface reconstruction: a linear approach. J. Cog. Neurosci., 1993, 5: 162-176.

[2]. P.C. Hansen, Analysis of discrete ill-posed problems by means of the L-curve, SIAM Rev., 1992, 34: 561-580.

[3]. B. He, T. Musha, Y. Okamoto, S. Homma, Y. Nakajima, and T. Sato, Electrical dipole tracing in the brain by means of the boundary element method and it's accuracy. IEEE Trans. Biomed. Eng. 1987, 34:406-414.

[4]. B. He, Brain electric source imaging - Scalp Laplacian mapping and cortical imaging, Critical Reviews in Biomedical Engineering, 1999, 27, 149-188.

[5]. B. He, Y. Wang, D. Wu, Estimation cortical potential from scalp EEG's in a realistically shaped inhomogeneous head model by means of the boundary element method, IEEE Trans. Biomed. Eng., 1999, 46, 1264-1268.

[6]. B. He, J. Lian, K.M. Spencer, J. Dien, E. Donchin, A cortical potential imaging analysis of the P300 and novelty P3 components, Human Brain Mapping, 2001, 12: 120-130.

[7]. B. He, X. Zhang, J. Lian, H. Sasaki, D. Wu, V.L. Towle, Boundary element method based cortical potential imaging of somatosensory evoked potentials using subjects' magnetic resonance images, NeuroImage, 2002, 16: 564-576.

[8]. B. He, D. Yao, J. Lian, D. Wu, An equivalent current source model and Laplacian weighted minimum norm current estimates of brain electrical activity, IEEE Trans. on Biomedical Engineering, 49: 277-288, 2002.

[9]. H.J. Huppertz, S. Hoegg, C. Sick, C.H. Lücking, J. Zentner, A. Schulze-Bonhage, R. Kristeva-Feige, Cortical current density reconstruction of interictal epileptiform activity in temporal lobe epilepsy. Clinical Neurophysiology, 2001, 112: 1761-1772,

[10]. J.C. Mosher, P.S. Lewis, and R.M. Leahy, Multiple dipole modeling and localization from spatio-temporal MEG data. IEEE Trans. Biomed. Eng., 1992, 39: 541-557.

[11]. P. Nunez, Electric Field of the Brain. London, Oxford University Press, 1981.

[12]. A.N. Tikhonov, and V.Y. Arsenin, Solutions of ill-posed problems. Wiley, New York, 1977.

[13]. V.L. Towle, S. Cohen, N. Alperin, K. Hoffmann, P. Cogen, J. Milton, R. Grzeszczuk, C. Pelizzari, I. Syed, and J.P. Spire, Displaying electrocorticographic findings on gyral anatomy. Electroenceph. Clin. Neurophysiol., 1995, 94: 221-228

[14]. R.D. Pascual-Marqui, C.M. Michel, and D. Lehman, Low resolution electromagnetic tomography: a new method for localizating electrical activity in the brain. Int. J. Psychophysiol., 1994, 18: 49-65.

[15]. M. Scherg, and D. Von Cramon, Two bilateral sources of the AEP as identified by aspatio-temporal dipole model. Electroenceph. Clin. Neurophysiol., 1985, 62: 32-44.

[16]. W. Van Drongelen, M. Yuchtman, B.D. Van Veen, B.C. Van Huffelen, A spatial filtering technique to detect and localize multiple sources in the brain. Brain Topogr., 1996, 9: 39-49.

Figure Captions

Fig. 1 Schematic diagram of the cortical imaging technique (CIT).

Fig. 2 (a) Waveforms of an interictal spike in an epilepsy patient. The largest negative peak is marked by the black dot and set to be 0 ms. (b) Top view of the scalp potential distributions at different time points (from top to bottom, -10 ms, -5 ms and 0 ms). (c) Left-side view of the scalp potential distributions at corresponding time points.

Fig. 3 Cortical potential imaging results. (a) Top view of the estimated cortical potential distributions by CIT at different time points (from top to bottom, -10 ms, -5 ms, 0 ms). (b) Left-side view of the estimated cortical potentials at the correspondent time points. The negative activity overlies with epileptogenic zone on the left frontal lobe.

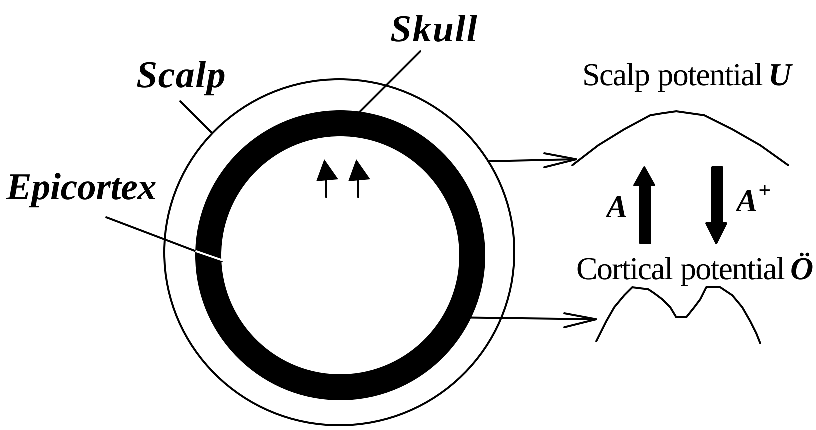


Fig. 1 Zhang X, et al.

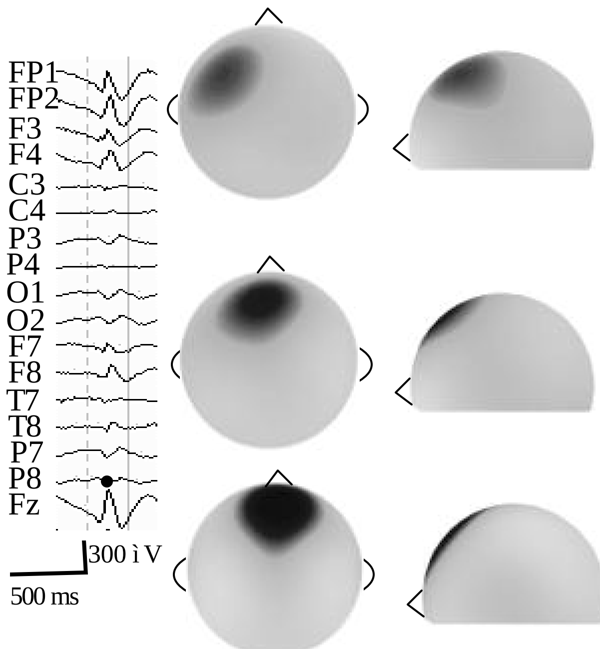
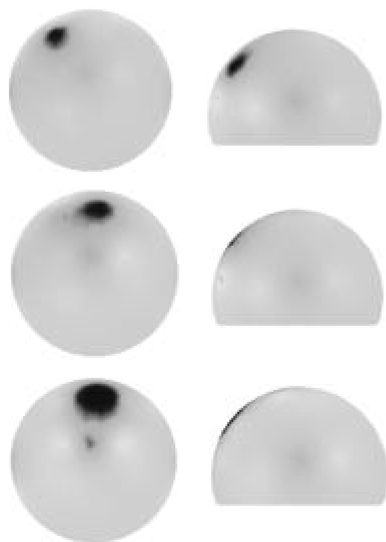


Fig. 2 Zhang X, et al.



(a) (b)

Fig. 3 Zhang X, et al.