An Experimental Study on BEM-Based Cortical Imaging of Human SEP Activities

X Zhang[1], VL Towle[3], H Sasaki[1], J Lian [1], GL Li[2], and B He[1-2*]
Departments of Bioengineering[1] & EECS[2],
University of Illinois at Chicago, 851 S. Morgan St., Chicago, IL 60607, USA
[3]Department of Neurology, University of Chicago
*Email: bhe@uic.edu

Abstract: *The boundary element method (BEM) based cortical imaging technique (CIT) has been applied to an experimental study on human somatosensory evoked potentials (SEPs) recorded from a patient. The accuracy of the analysis was determined by comparing SEPs recorded from the scalp with those recorded directly from the patient's cortex. The results indicate that the CIT improved the spatial resolution of the scalp potentials, and the reconstructed cortical potential maps are consistent with the direct cortical recordings.*
Keyword – EEG, cortical imaging, SEP, BEM

I. Introduction

Brain activation is a spatio-temporally-distributed process. Although the conventional electroencephalogram (EEG) offers excellent temporal resolution, it has limited spatial resolution in localizing brain electrical sources. Tremendous effort has been made to improve the spatial resolution of EEG by solving the EEG inverse problem. Of particular interest is the recent development of BEM-based cortical imaging technique (CIT) [1-2], which offers a much-enhanced spatial resolution in estimating the cortical potentials as compared to the scalp potential, without assuming intermediate source layers. The present study reports a pilot experimental study of BEM-based cortical imaging of a patient's scalp-recorded SEP, and compared with the directly recorded cortical potentials.

II. Methods

1. CIT in a RG Human Head model

A BEM-based CIT algorithm has been developed in our laboratory at the University of Illinois at Chicago [1-2]. BEM is used to construct the multi-layer realistic geometry head model from MR images, and the potentials over the scalp and cortical surfaces are linked directly by means of Green's Theorem, in the multi-layer piece-wise homogeneous medium. An adaptive algorithm is used to accurately calculate the transfer function relating cortical potentials with scalp potentials [2]. By solving the linear inverse problem, the cortical potential is then noninvasively estimated from the measured scalp potential (SP) with much enhanced spatial resolution.

2. Realistic Geometry BEM Head Modeling

A Matlab-based software package has been developed for image segmentation and construction of BEM head model (Fig. 2). The contours of the scalp, the skull and the epicortical surfaces are edge-detected, and manually adjusted if necessary. Nodal points representing the contours of the three layers are extracted and downsampled. The surface between two adjacent slices is constructed by connecting the corresponding nodal points to generate the triangle mesh. Each of the triangles is constructed by connecting two adjacent contour nodes in one slice with a third contour node in its adjacent slice, under the constraint that the normal direction of the constructed triangle satisfies the right-hand-rule. Assume $\{Z_n\}$ and $\{Z_{n+1}\}$ are two node sets that represent digitized contours in two adjacent slices (Fig. 1), and the k_{th} node in $\{Z_n\}(Z_{n,k})$and the j_{th} node in $\{Z_{n+1}\}(Z_{n+1,j})$ are connected to form one edge of the triangle. To choose either the $(k+1)_{th}$

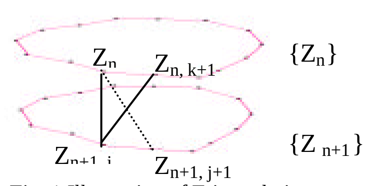

Fig. 1 Illustration of Triangulation

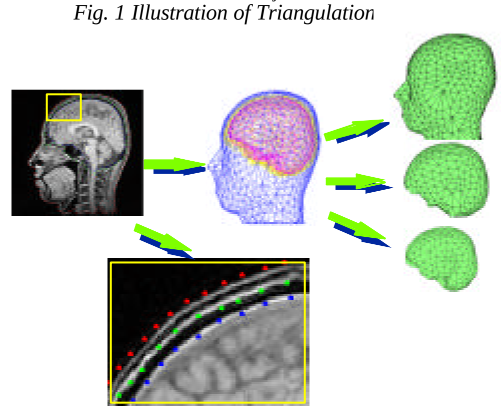

Fig. 2 BEM head modeling

node in $\{Z_n\}(Z_{n,k+1})$, or the $(j+1)_{th}$ node in $\{Z_{n+1}\}(Z_{n+1,j+1})$ to form another two edges, a combined criterion — minimize both the sum of edge lengths, and its standard deviation — was used. Repeat this step for all the slices, then the nearly uniformly distributed triangle mesh can be generated automatically. The realistic geometry (RG)

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle An Experimental Study on BEM-Based Cortical Imaging of Human SEP Activities	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Departments of Bioengineering & EECS University of Illinois at Chicago 815 S. Morgan St Chicago, IL 60607	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 2	

BEM head model of the patient in the present study was constructed by using this software [3].

3. Experimental Data Acquisition

A 26-yr old male patient with right frontal mass and frequent seizures participated in the study according to a protocol approved by the IRB. Both the 32-channel pre-surgical SEP and the epicortical SEP on a 4 x 8 grid during the surgery of mass resection were recorded. The location of the scalp electrodes was determined with a radio-frequency localizer and the location of the subdural grids was calculated from skull films. These were fit to the skin and cortex using a surface matching program, and compared with intraoperative photographs of the cortical surface to determine their accuracy. Ten replications (n = 500) of right median nerve scalp SEPs were obtained to assess the reliability of the recordings.

III. Results

Fig. 3 shows an example of the normalized scalp potential distributions at 20 ms after the onset of stimuli. In response to the right median nerve stimuli, N20/P20 map consists of a dipolar frontal positivity/parietal negativity over the left scalp. Note that the SP map is blurred due to the head volume conduction and interpolation between the widely-spaced scalp electrodes.

Fig. 4 shows the comparison between the normalized (a) directly recorded cortical potential (CP) map and (b) the CIT estimated CP map, which show similar spatial patterns. The correlation coefficient between the directly recorded and the estimated CP maps was 0.73 for N20/P20 component. Note that the central sulcus was clearly reconstructed in both the directly recorded and the estimated CP maps.

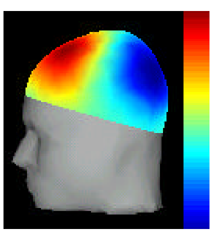

Fig 3 N20/P20 SP

IV. Discussion

In this pilot study, we have applied the BEM-based CIT algorithm [2] on the SEP data recorded from a patient. The estimated cortical potentials were compared with the SEP data directly recorded from the epicortex during the open-skull surgery in the same subject. The estimated CP maps show much more localized spatial pattern than the SP maps recorded prior to the operation at comparable latency after the right median nerve stimulation, and are consistent with the direct CP recordings [4-5].

Validation of the noninvasive EEG imaging techniques is of importance. Gevins et al. [6] reported the first experimental study in a human subject with direct cortical recordings, but did not formally compare them in a quantitative manner. Their results suggest the feasibility of the FEM-based deblurring technique they have developed. The present pilot study provides another well controlled experiment in assessing the feasibility of imaging noninvasively cortical potentials from scalp potentials and MR images of the subject, by means of BEM. The successful reconstruction of the central sulcus in the estimated cortical potential maps would facilitate the noninvasive diagnosis, and provides a feasible means to guide the clinical surgery.

The promising results of the present study suggest the feasibility of our BEM-based CIT algorithm. Further experimental studies are undergoing and will be reported in the future.

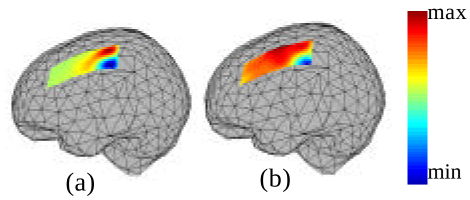

Fig. 4 N20/P20 comparison between
(a) direct CP (b) CIT estimated CP

Acknowledgment

This work was supported in part by NSF CAREER Award BES-9875344, NIH30094 and a grant from The Brain Research Foundation.

Reference

[1] He B: "Brain Electric Source Imaging: Scalp Laplacian Mapping and Cortical Imaging," *Critical Reviews in Biomedical Engineering*, 27: 149-188, 1999.

[2] He B, Wang Y, Wu D., "Estimating cortical potential from scalp EEG's in a realistically shaped Inhomogeneous Head model by means of the boundary element method," *IEEE Trans Biomed Eng.* 46: 1264-1268, 1999.

[3] Zhang X, Sasaki H, Towle V L, Alperin N, Lian J, He B, "Development of a MATLAB-based software system for realistic geometry head modeling," *Proc. APBME*, 682-683, 2000.

[4] Towle VL, Cohen S, Alperin N, Hoffmann K, Cogen P, Milton J, Grzesczcuk R, Pelizzari C, Syed I, and Spire J-P, "Displaying electrocorticographic findings on gyral anatomy," *Electroenceph. Clin. Neurophysi.*, 221-228, 1995.

[5] Cakmur R, Towle VL, Mullan JF, Suarez D, and Spire J-P, "Intra-operative localization of sensorimotor cortex by cortical somatosensory evoked potentials: From analysis of waveforms to dipole source modeling," *Acta Neurochirurgica*, 139: 1117-1124, 1997.

[6] Gevins A., Le J, Martin NK, Brickett P, Desmond J, and Reutter B, "High resolution EEG: 124-channel recording, spatial deblurring and MRI integration methods," *Electroenceph. Clin. Neurophysi.*, 90: 337-358, 1994.