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SEEG source analysis of intracranial stimulation with realistic head modeling: A validation study

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Introduction

Accurate source modeling relies on accurate models of the sensitivity distribution of EEG electrodes. Early models relied on simplified forward models with spherical heads, then later with tessellated boundary element models[1]. More recently, the finite element method (FEM) allows more detailed models to reflect more realistically the head geometry and anisotropic conductivity profiles[9]. Invasive SEEG electrodes allow more direct measurements of deep neural sources, yet their sensitivity distributions are less well characterized. In this study, to validate the sensitivity in the human brain, we collected the instantaneous response to intracranial single-pulse stimulation, where pairs of SEEG contacts were electrically stimulated. The pairs of contacts were modeled as ground truth dipolar sources, while potentials from these sources were measured at the other SEEG contacts. We used FEM modeling and an inverse dipolar model to locate these sources and therefore confirm the accuracy of the sensitivity distribution profiles.

Methods

The data used in this study were collected from 4 patients who have undergone SEEG implantation. Under approved and consented research protocols, we applied a 0.4mA-2ms wide square pulse for a given adjacent contact pair, and data were sampled at 2kHz across all remaining contacts. Our goal is to map passive conduction properties as measured at the center of this pulse. All the data, the forward computations, and inverse modeling are performed using the FEM package [3] in the Brainstorm software[8]. Briefly, the anatomical MRI data are segmented into the main brain tissues, and a tetrahedral mesh is generated throughout. Brainsuite[7] extracts the diffusion tensors from the DWI, and Brainstorm calculates the anisotropic conductivity via the effective medium approach[5]. The SEEG contact locations are obtained from CT images, and the brain volume is sampled uniformly on a 2.5mm 3D grid. **Fig1(a)** shows the FEM head model for one patient with anisotropic conductivity shown as ellipsoids, and **(b)** shows the SEEG implantation. FEM forward computation is performed in Brainstorm using a Continuous Galerkin approach from the DUNEuro library[6].

For each contact pair, the SEEG recordings were averaged at 1ms into the 2ms wide-pulse, to obtain an average stimulus-response at the center of the square pulse, and hence a direct measure of the sensitivity pattern of the SEEG array. Even with the low-amplitude stimulation designed to minimize neuronal responses and with averaging, we observed that the stimulus artifacts were still contaminated by some degree of neuronal activity. Therefore, we also used Independent Component Analysis (ICA)[2] to separate the (desired) stimulus artifact from neuronal activity. The resulting denoised artifact data then provide direct measures of lead-field sensitivity across the SEEG electrodes. For the inverse approach, we used the dipole scanning method of Brainstorm, ideal for focal sources of activity[4].

Results

We have processed the data from two of the four subjects in our preliminary investigation. S01 has 167 contacts with 42 stimulation sites; S02 has 158 with 31 resp. **Fig2(top)** shows an example of dipole localization adjacent to the right stimulation pair. The boxplots **(bottom)** show the localization difference between all dipoles and contact pairs. We notice the improvement in localization using ICA-preprocessed data. The mean localization errors are less than 4.5mm, which to our knowledge, are among the lowest yet reported.

Conclusion

Our approach gives a realistic insight into the accuracy of the brain source localization in a realistic experiment using the latest FEM approaches. Future studies will improve the sampling densities of our models, with calibrated tissue conductivity and more optimized inverse methods. Potential applications include improved identification of the epileptogenic zone in patients and localization of cortical targets for closed-loop neuronal monitoring and stimulation.

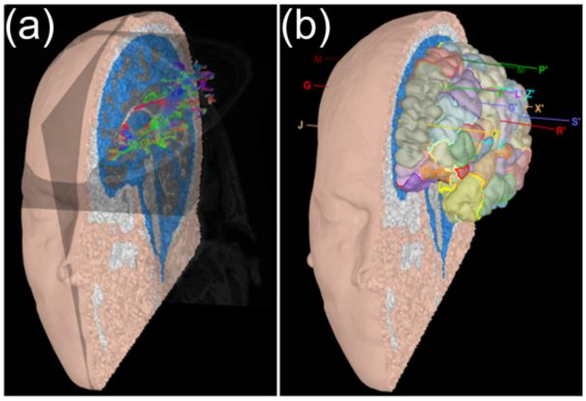

Figure 1:(a) The 3D MRI with tetrahedral FEM mesh and conductivity tensors as ellipsoids. (b) FEM head model with cortex, and location of SEEG electrodes.

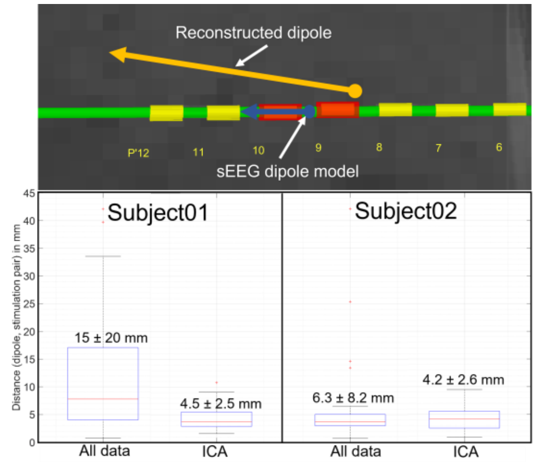

Figure 2: Top: illustration of SEEG dipole and the reconstructed dipole. Bottom: The boxplots of the localization error with mean and std for the two subjects

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