Modeling of Skull and Brain Defects in the EEG Inverse Problem with the Boundary Element Method

C.G. Bénar, J. Gotman

Montreal Neurological Institute, Montréal, Canada

Introduction

Techniques solving the EEG inverse problem can be used clinically in order to find the generators of interictal epileptic spikes (Ebersole, 1994). Recent methods are based on realistic head models comprising three layers (skin, skull and brain), which can be represented by the boundary element method (BEM) (Cuffin, 1995). Nevertheless, patients who have undergone brain surgery challenge these models. Indeed, these patients present skull defects as well as a resected brain area, both of which affect the propagation of electrical currents (van den Broeck, 1998). In this study, we evaluate the importance of these defects by quantifying their influence on dipole localization.

Background

Burr holes: In the typical protocol of temporal lobe epilepsy surgery used at the Montreal Neurological Institute, four burr holes and some bone removal are performed in order to create a bone flap (Fig. 1a). When closing the flap, three burr holes are filled with methacrylate, and one is left open for drainage. The open burr hole is filled with soft tissues, which are hyperdense on MRI images. The burr hole filled with methacrylate is hypodense (Fig. 1b).

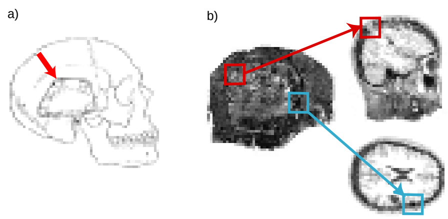


Figure 1: a) Temporal craniotomy (modified from Appuzzo, "Brain surgery); red arrow: open burr hole b) Burr holes as seen on MRI (left: curvilinear reconstruction using the Brainsight software; upper right: open hole; lower right: hole filled with methacrylate)

Brain resection: The extent of resection in a temporal lobectomy is shown in Fig. 1a. Resections are filled with CSF and are hypodense on T1-weighted images (Fig. 1b)

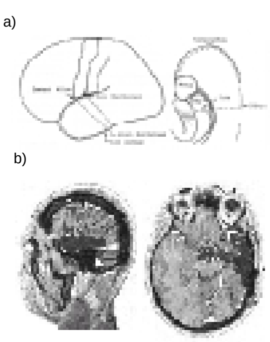


Figure 2: a) Extent of resection in dominant and non-dominant temporal resection (From Olivier, 1987); b) A temporal lobe resection as seen on T1-weighted MRI images

Methods

Conductivity of methacrylate: We measured the conductivity of a sample of methylmethacrylate bathed in a physiological solution. We found that it is inferior to $4 \cdot 10^{-8}$ S/m, and can therefore be considered as a perfect insulator in our study.

Open burr hole: We modeled the hole as a depression in the skull BEM surface (Fig. 5). A local mesh refinement was performed (Fig. 6). For all our models, we used the Curry software (Philips Labs, Germany).

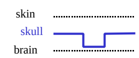


Fig. 5: Schematic view of a detail of the BEM surfaces that were used in the open burr hole model

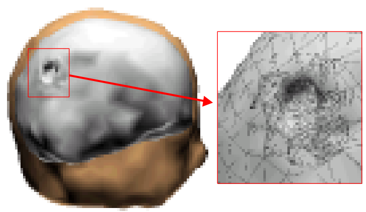


Fig. 6: Skin and skull BEM surfaces of the open burr hole model

Burr hole filled with methacrylate: We modeled the methacrylate plug as a bounded surface with zero conductivity (Fig. 7).

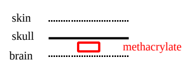


Fig. 7: Schematic view of a detail of the BEM surfaces that were used in the filled burr hole model

Resection: We modeled a temporal resection as a closed surface enclosing a volume of CSF-like conductivity (Fig. 8).

Fig. 8: Skin, skull and resection BEM surfaces of the temporal resection model

Quantification of the influence of the defects: We placed several dipoles in the vicinity of the defects (Fig. 9 and 10), and computed the corresponding scalp potentials at 71 locations (10/10 system). We used a head model that included the defect of interest. Dipoles were then fitted on these potentials, but this time using a defect-free head model. This enabled us to measure the error in dipole localization, amplitude and orientation that results from not including the defects in the head model.

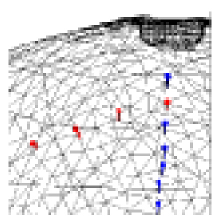


Fig. 9: Radial dipoles below (blue) and lateral to (red) the burr hole

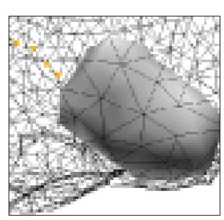


Fig. 10: Dipoles behind the temporal resection

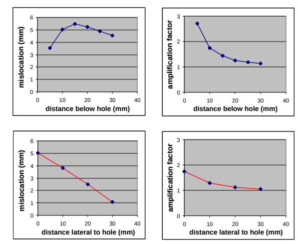
Results

These graphs represent the error in dipole parameters that result from not including the defect in the head models

Open Burr hole

Radial dipoles below the open burr hole

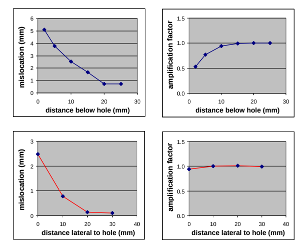
Radial dipoles lateral to the open burr hole



Burr hole filled with methacrylate

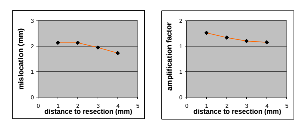
Radial dipoles below the burr hole filled with methacrylate

Radial dipoles lateral to the burr hole filled with methacrylate



Brain resection

Dipoles behind temporal resection



Conclusion

Our results show that not including open burr holes in realistic head models can lead to significant errors in EEG dipole modeling. We also demonstrated that the methacrylate plug used to fill the other burr holes has a measurable influence. However, a cavity the size of a typical anterior temporal lobe resection does not have a significant effect. The BEM can be used in a clinical setting to model skull defects in post-operative patients. Nevertheless, this method can not fully model these defects, because there is a residual space between the skull boundary and the hole. Therefore, further tests need to be done in order to assess the advantages of the more computationally-demanding finite element method (FEM) (Buckner et al., 1997).

References

Buckner H., Knoll G., Fuchs M., Rienacker A., Beckmann R., Wagner M., Silny J., Pesh J., Electroenceph. Clin. Neurophys. 1997 102: 267-278

Cuffin BN., 1995, IEEE Trans on Biomed Eng, vol. 42, No 1, pp 68-71

Ebersole JS., 1994, Acta Neurol Scand, suppl. 152: 20-28

Olivier A., 1987, in "Surgical treatment of the epilepsies", J. Engel Ed., Raven press, New York

Van den Broeck SP., Reinders F., Donderwinkel M., Peters MJ., 1998, EEG Clin Neurophys 106, 522-534

contact: cbenar1@po-box.mcgill.ca
www.bic.mcgill.ca/~benar