

Simulation of Electroencephalography (EEG) Using Abaqus

Summary

Electroencephalography (EEG) is used to obtain information about the electrical activity in the brain and is routinely used to diagnose neurological abnormalities. The inverse problem in EEG refers to the procedure of locating electrical sources in the brain from the extracranial electrical field measured on the scalp. The solution of the inverse problem requires the forward calculation of the electric field for a given source location. The significance of the inclusion of inhomogeneity and anisotropy in the electrical conductivity of the brain tissue in the forward solution is not well understood. In this Technology Brief we present examples that illustrate the use of the electrical analysis capability in Abaqus for calculating the forward solution based on the finite element method (FEM). The results from simulations in Abaqus can then be used to solve the inverse problem.

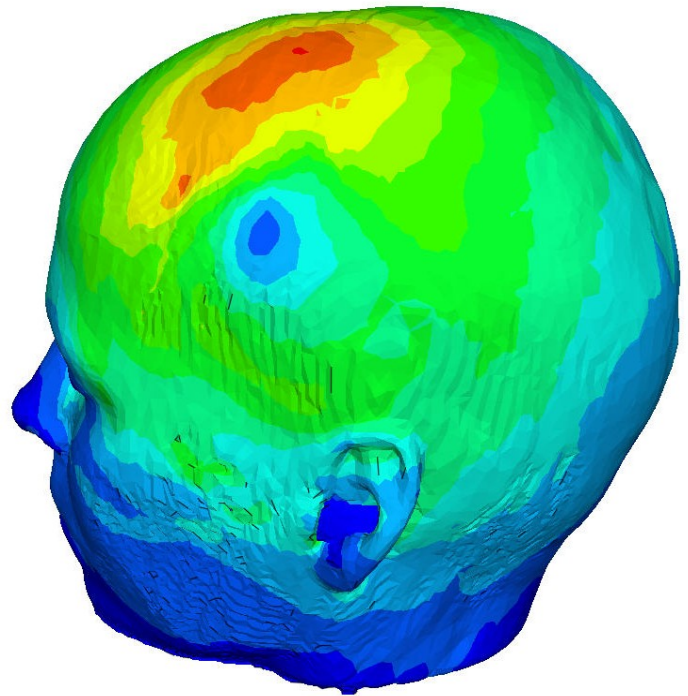
Background

To predict the locations of the sources of electrical activity within the brain, neurosurgeons currently depend on measurements of the brain's electrical fields using electroencephalography (EEG). Knowledge of the location of sources of seizure activity, such as in epilepsy, helps plan a course of treatment.

Currently, the ability to locate the sources of electrical activity is only moderately accurate [1]; increasing the accuracy will help neurosurgeons to better delineate the specific regions of the brain that need intervention. Subsequently, surgeries can be targeted to those regions, and unnecessary damage to healthy neural tissue will be reduced.

About 30% of the patient population suffering from epilepsy have medically uncontrollable seizures and may be considered for surgical therapy, based on scalp EEG monitoring. In some cases these patients undergo intracranial EEG monitoring for spontaneous seizures [2]. Localization of the seizure focus from intracranial EEG is critical for decreasing or eliminating seizure activity after surgery.

Studies have shown the clinical utility of advanced source imaging techniques in localizing epileptogenic loci using boundary element method (BEM) [1] and finite element method (FEM) models [3]. However, these methods are not yet routinely used in clinical settings due to their high computational cost and lack of direct validations with experimental data.



Key Abaqus Features and Benefits

- Coupled thermal-electrical analysis capability for the computation of electric field and current density
- Ability to include anisotropic and inhomogeneous electrical conductivity properties

Prediction of the locations of electrical sources using data obtained through EEGs is an inverse problem. The solution of the inverse problem requires the ability to calculate the electric field for a source at a given location; we refer to this as the forward problem. Reductions in forward model errors using FEM could lead to improved source localizations of seizures, with the eventual goal of surgery without the need for invasive intracranial EEG monitoring.

Because the electrical sources are deep inside the brain, the electrical current and potentials that get measured on the scalp during EEG are affected by the electrical conductivities of the intervening layers of tissues in the head.

To understand the influence of increasing the level of detail in the forward solution, the anisotropy and inhomogeneity of the electrical conductivity must be taken into account.

In this Technology Brief we present some results from simulations performed on a model of a human head [4]. The distributions of electrical potentials and currents within the model are calculated for known source locations in the brain. The electrical conductivity in the model is considered to be inhomogeneous as well as anisotropic.

Analysis Approach

The finite element mesh of a model of a head is shown in Figure 1. The head model is made up of different materials for different regions, such as gray matter, white matter, cerebrospinal fluid, scalp, cerebellum, ventricles, cerebrospinal fluid, optic chiasm, skull and scalp. Accurate segmentation of the brain tissue type is implemented using a semi-automatic method to segment multimodal imaging data from multi-spectral MRI scans (different flip angles) in conjunction with the regular T1-weighted scans and computed x-ray tomography images [4].

The electrical conductivity in the anisotropic white matter tissue is quantified from diffusion tensor MRI data [4, 5]. The finite element model is constructed using AMIRA [6],

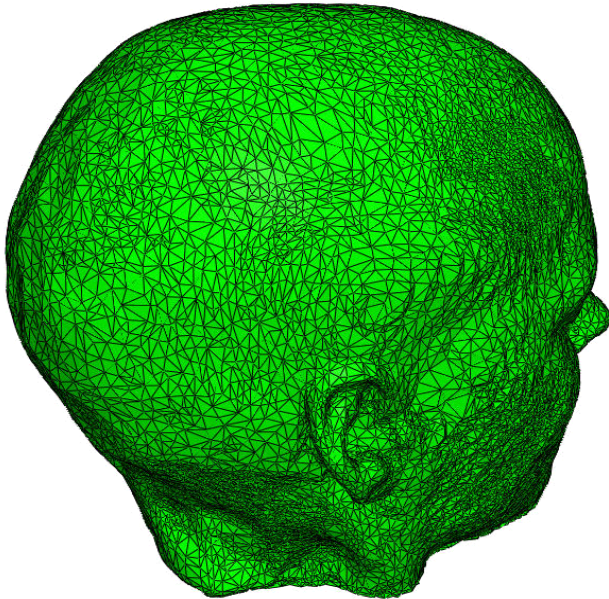


Figure 1: Finite element model of a human head

a commercial segmentation and visualization tool. The model is solved using the Abaqus coupled thermal-electrical analysis procedure. The analysis is driven by applied concentrated electrical currents at distinct nodes within the brain.

Results and Discussion

Values of electrical current density, electrical potential gradients, and electrical potentials are computed from the analysis. Figure 2 shows the distribution of electrical current density on the surface of the head, and Figure 3 shows the distribution of this quantity within the head. High values of current density are seen in the interior of

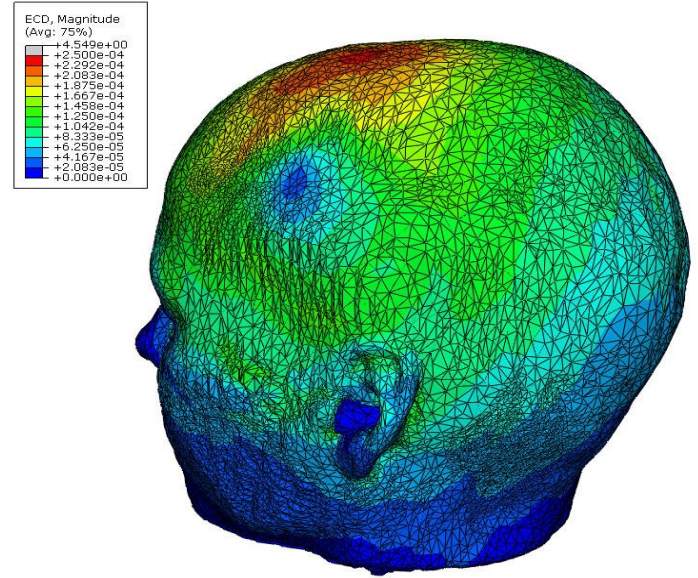


Figure 2: Distribution of electrical current density ($\mu\text{A}/\text{mm}^2$) on the surface of the head

the head in the neighborhood of the applied concentrated electric current. Figure 4 and Figure 5 show the distribution of electrical potential gradients on the surface of the

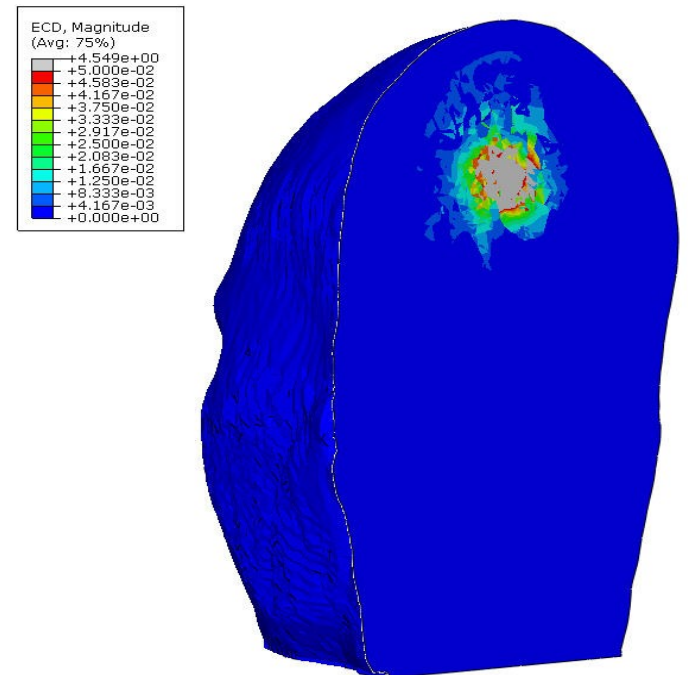


Figure 3: Distribution of electrical current density ($\mu\text{A}/\text{mm}^2$), cutaway view

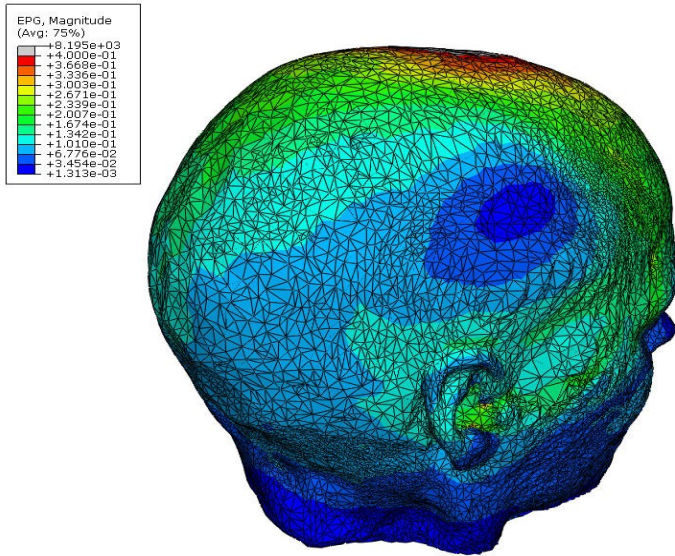


Figure 4: Distribution of electrical potential gradient ($\mu\text{V}/\text{mm}$) on the surface of the head

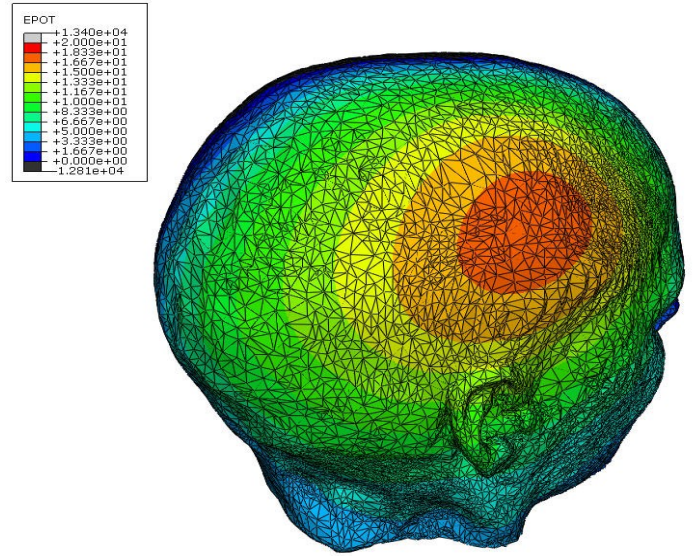


Figure 6: Distribution of electrical potential (μV) on the surface of the head

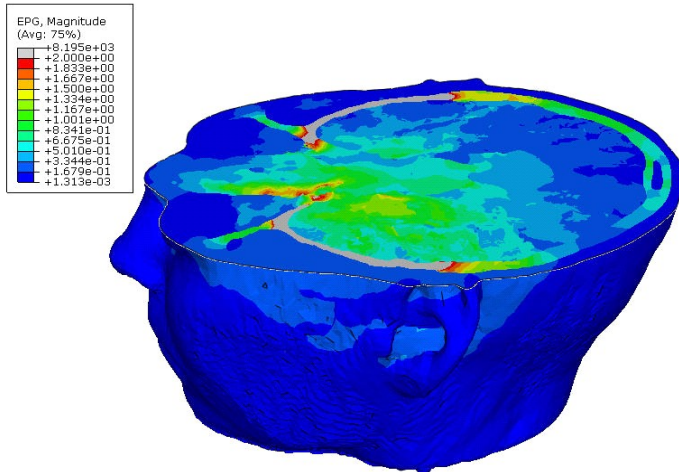


Figure 5: Distribution of electrical potential gradient ($\mu\text{V}/\text{mm}$), cutaway view

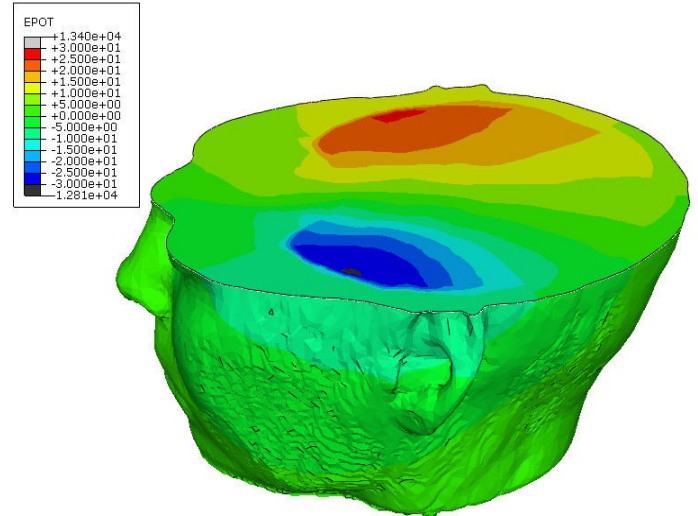


Figure 7: Distribution of electrical potential (μV), cutaway view

head and in the interior of the head. Figure 6 and Figure 7 show the distribution of electrical potentials on the surface of the head and within the head. These results are compared to the intracranial and scalp EEG measurements obtained from patients implanted with depth electrodes using in vivo experiments in [4]. The forward solution can then be used to estimate inversely the locations of electrical sources from known EEG measurements.

Conclusions

Currently, EEG is used as a diagnostic tool to determine the location of the source of electrical disturbances inside the brain. However, this localization is not very accurate

at present. Numerical simulations of electrical conduction in the brain can help correlate the EEG signals to the electrical sources and increase the understanding of the influence of increased complexity on the forward solution. An improved forward solution can in turn determine the location of sources accurately from measured EEG values by solving the inverse problem. Accurate localization of the electrical disturbances will help neurosurgeons fine tune their surgical procedures, making such procedures more accurate and minimally invasive. The coupled thermal-electrical analysis procedure in Abaqus can be used to simulate intracranial electrical conduction and is well poised to play a big role in this crucial medical advancement.

Acknowledgements

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Abaqus References

For additional information on the Abaqus capabilities referred to in this brief, please see the following Abaqus 6.11 documentation references:

- Abaqus Analysis User's Manual
 - "Coupled thermal-electrical analysis," Section 6.7.3.

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