In Vivo Estimation of the Scalp and Skull Conductivity

Taweechai Ouypornkochagorn, Nick Polydorides and Hugh McCann

University of Edinburgh, Edinburgh, UK, t.ouypornkochagorn@sms.ed.ac.uk

Abstract: The scalp and skull conductivities (σ_{sc}, σ_{sk} respectively) are determined from Electrical Impedance Tomography (EIT) data using the Gauss-Newton method (GN). Our best estimates of σ_{sc} and σ_{sk} are 0.58 S/m and 0.008 S/m respectively. It is necessary to use the true head geometry.

1 Introduction

Although many authors have reported in vivo values for σ_{sc} and σ_{sk}, most of them refer only to particular regions of the head. For example, it is reported in [1] that σ_{sc} in a selected region is 0.43 S/m, and in [2-4] that σ_{sk} in various regions is in the range 0.0078-0.0801 S/m. In EIT, where the whole head is modelled, it is typical to set all regions of each tissue to a single conductivity value. Here we determine σ_{sc} and σ_{sk} by comparing experimental EIT data with such a model. Our approach is to fit a geometrically accurate head model having two unknowns, σ_{sc} and σ_{sk}, to a set of real measurements by performing a few iterations of the Gauss-Newton method to regress the measurement into the model. The GN formula to evaluate σ is shown in (1) where σ is [σ_{sc};σ_{sk}], J is the 2-parameter Jacobian, V_{meas} is the measurement vector, and V_i is the model prediction for σ_i, and i is the iteration index.

$$\sigma_{i+1} = \sigma_i + \left(J^T J\right)^{-1} J^T \left(V_{meas} - V_i\right) \qquad (1)$$

2 Methods

Three measurement trials on a single human subject were carried out on three different dates. EIT measurements were recorded at 100 frames per second with 32 electrodes. Three head models (called Model1, 2, and 3) having 338k, 396k, and 53k elements respectively were used. Model 1, the geometrically accurate head model for the subject, was available from MRI scans. In this model, both isotropic and anisotropic (σ_{radial}: $\sigma_{tangential}$ ratio of 1:10) skull conductivities were implemented for comparison. The sensitivity of the method to various effects was tested and found to be small: by simulation, the dependence of the results on electrode shape and position, and on contact impedance, was found to be small, of order 1%; experimentally, the results obtained from multiple installations on the same subject on different days also varied by about 1%.

By carrying out a large number of simulations with a wide variety of conductivity values for CSF, grey matter and white matter, and studying the resulting correlation with scalp and skull conductivity results, we conclude that there is no significant dependence of our results upon the accuracy of the CSF, grey matter and white matter conductivity values.

Equation (1) was employed to evaluate σ with 15 iterations (both σ are finally converged). The estimated σ_{sc} and σ_{sk} are 0.58 S/m and 0.008 S/m, respectively, for both the isotropic and anisotropic versions of Model1 (see table). Compared to the reported values [1], σ_{sc} is significantly larger, while σ_{sk} is at the low end of the range of previously reported values [2-4]. It should be noted that the σ values determined here are effectively from the whole head, in contrast to the small selected regions used in [1-4]. The surface plot of the error term in our iteration procedure is shown in Fig.1, showing a distinct trough in the region of the preferred values. The dependence on σ_{sc} is weak in the range 0.4-0.8 S/m, while being much more strongly dependent on σ_{sk} in the region 0.008-0.010 S/m.

Table: The evaluated σ (S/m)[1] and prediction relative error[1]

	Model1 (reference)		Model2	Model3
	Isotropic	Anisotropic	Isotropic	Isotropic
σ_{scalp}	0.58±.026	0.58±.026	0.23±.007	0.45±.019
σ_{skull}	.008±.0005	.008±.0005	.017±.0011	.006±.0007
Err.	0.28±.008	0.28±.008	0.32±.005	0.33±.012

[1] The value represents in the format of mean±standard deviation

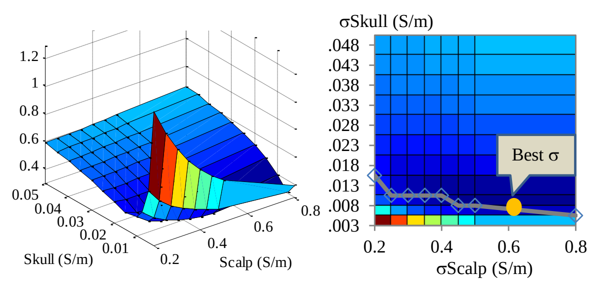

Figure 1: The relative error from the variation of σ_{sc} and σ_{sk}

The evaluated σ values from Model2 and 3, non-subject specific models, are different to Model1 and the errors are higher. The estimation from Model3 is closer to that from Model1, probably since their geometry is quite similar (despite the relatively poor mesh refinement of Model3). Model2 is geometrically different to both of the other models; even when it was scaled to the same size as Model1, the estimated σ_{sc} and σ_{sk} values are 0.29 and 0.0137 S/m, close to the results in the table.

3 Conclusions

We find that the determination of the scalp and skull conductivities by using EIT are strongly dependent on the true head geometry, necessitating the use of subject-specific anatomical scans, by MRI and CT. The results obtained using such a subject-specific model are consistent with values in the literature [5,6].

References

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