Influence of Head Tissue Conductivity Uncertainties on EEG source localization

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Objective

Identify which tissue conductivity uncertainties have the strongest influence on electroencephalograpy (EEG) single dipole reconstructions and how these uncertainties affect the reconstruction results.

Introduction

The accurate localization of focal sources is desired in many clinical and scientific applications of EEG, for example, in epilepsy research. A basis for reliable source localizations is the use of detailed head models. Here, not only an exact geometric representation of the subject's head is of importance, but also the use of accurate conductivity values for the modeled compartments. In this study, we investigate how the tissue conductivity uncertainties of the different compartments affect the results of EEG source localization.

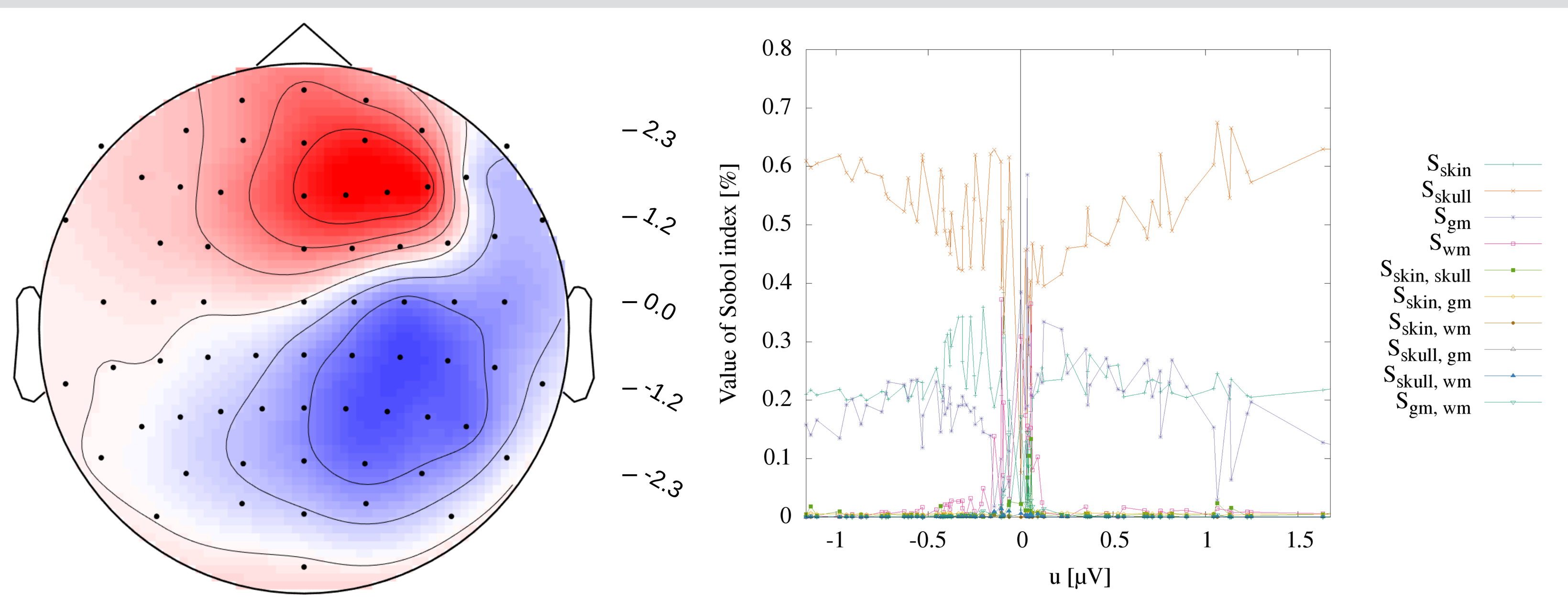

Figure 1: SEP topography at the peak (22.5 ms after stimulus, left) and Sobol indices for electrodes (sorted by voltage).

Methods

- Somatosensory evoked potentials (left hand median nerve stimulation) of a healthy human subject were measured (10-10 system, **Fig. 1**).
- A realistic five-compartment (skin, skull, cerebrospinal fluid/CSF, gray matter, white matter) head model was generated based on MRI data and the finite element method was used to compute forward solutions (**Fig. 2**).
- Based on generalized polynomial chaos (gPC) expansions, 10,000 samples for multi- and univariate distributions of conductivity values were drawn. A uniform distribution was assumed for each conductivity (**Tab. 1**).
- To investigate the influence on the inverse problem, goal function scans (GFS) were performed for each sample.

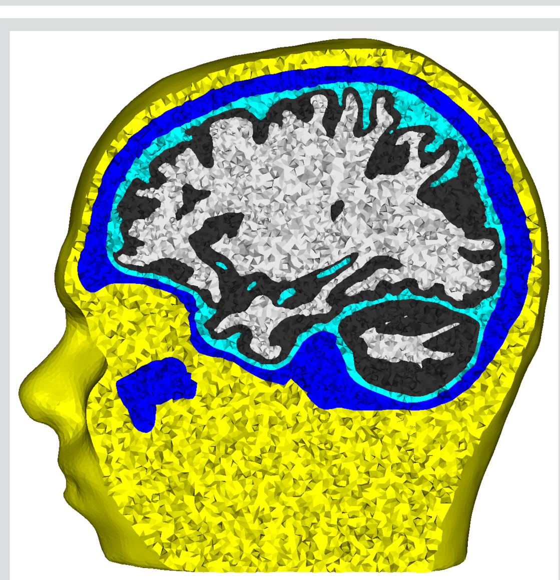

Figure 2: Five compartment FEM head model.

Tissue	Min.	Max.	Standard	Reference
Skin	280.0	870.0	430.0	Haueisen et al. (1997); Ramon et al. (2004)
Skull	1.6	33.0	10.0	Akhtari et al. (2002); Hoekema et al. (2003); Dannhauer et al. (2011)
CSF	1769.6	1810.4	1790.0	Baumann et al. (1997)
GM	220.0	670.0	330.0	Haueisen et al. (1997); Ramon et al. (2004)
WM	90.0	290.0	140.0	Haueisen et al. (1997); Ramon et al. (2004)

Table 1: Tissue conductivity intervals in mS/m.

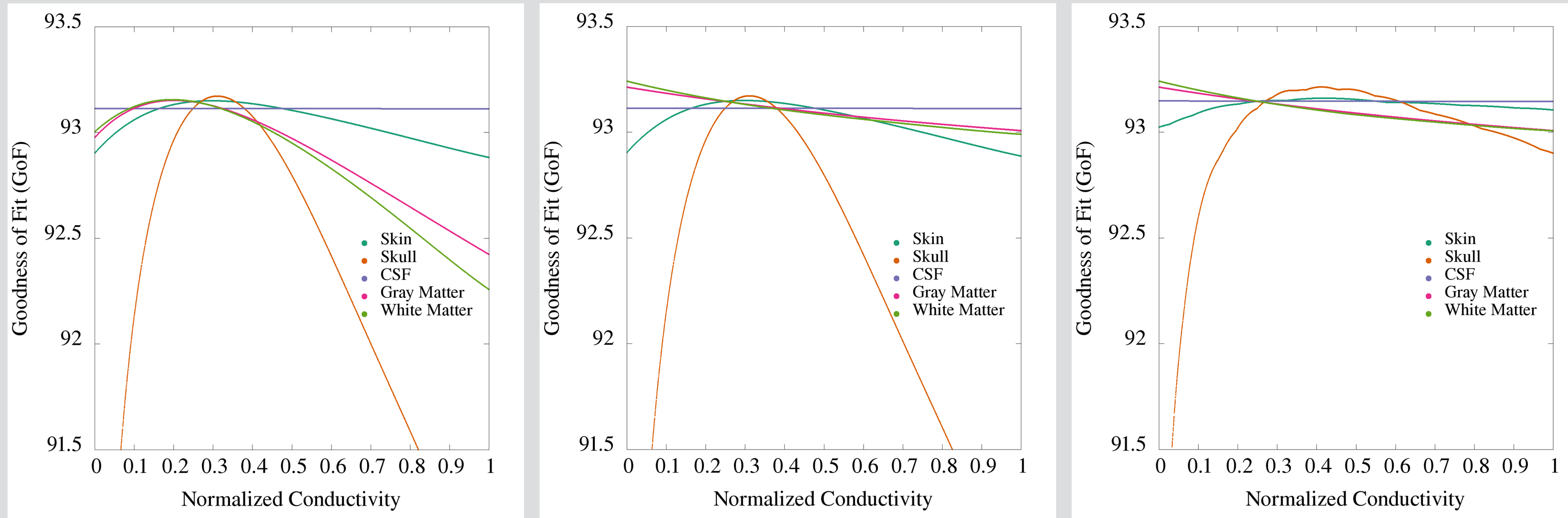

Figure 3: GoF for fixed dipole orientation and position (left), rotating dipole fit (middle), and moving dipole fit (right). Conductivities are normalized to the interval from 0 to 1 for visualization reasons.

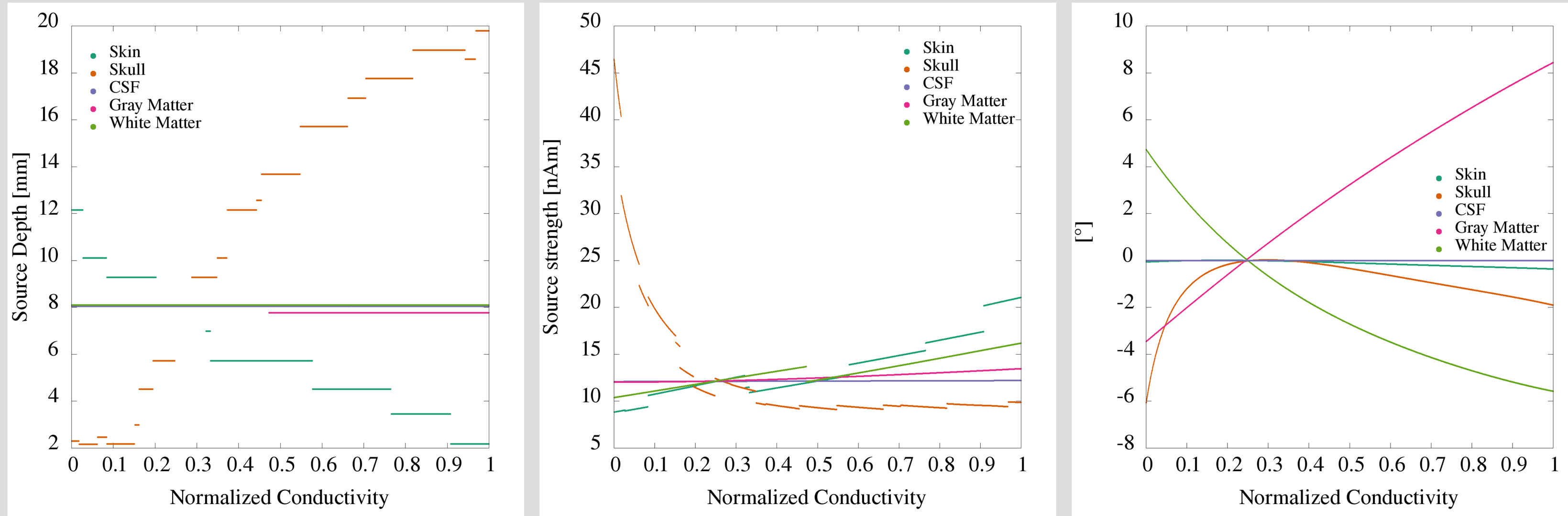

Figure 4: Source depth (left) and source strength (middle) for moving dipole fit and change of source orientation in radial direction (right) for rotating dipole fit as function of the tissue conductivity for univariate distributions.

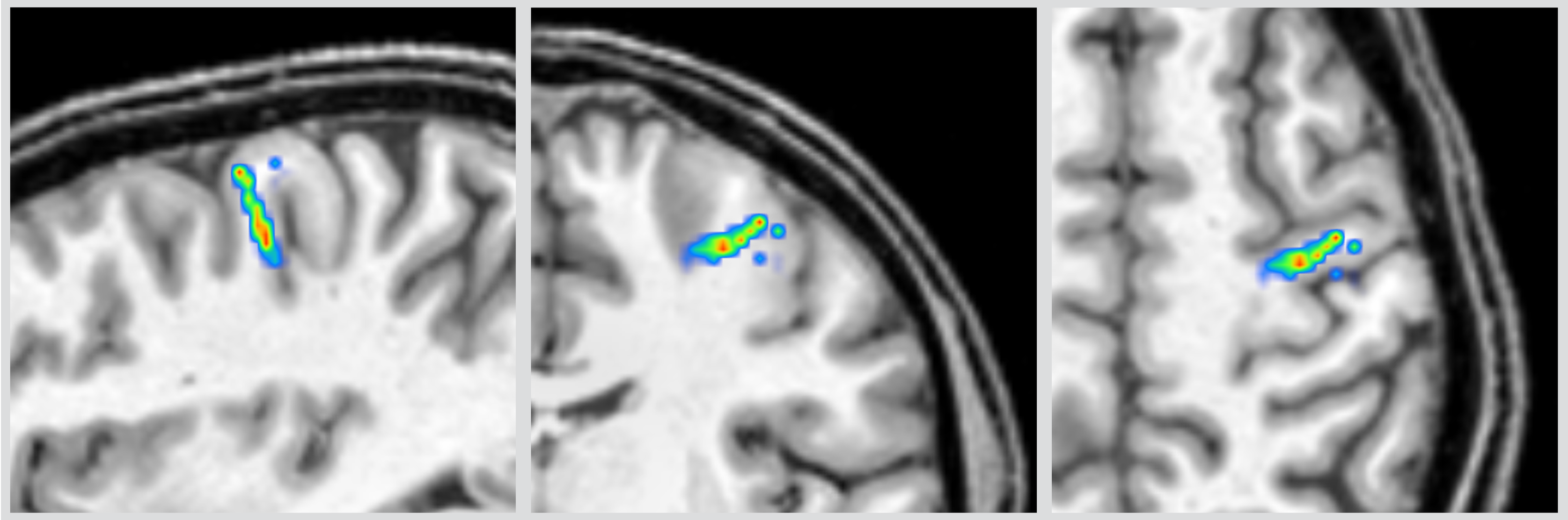

Figure 5: Distribution of source localizations for multivariate distribution. Slices (sagittal left, coronal middle, axial right) taken through the center of gravity of source locations.

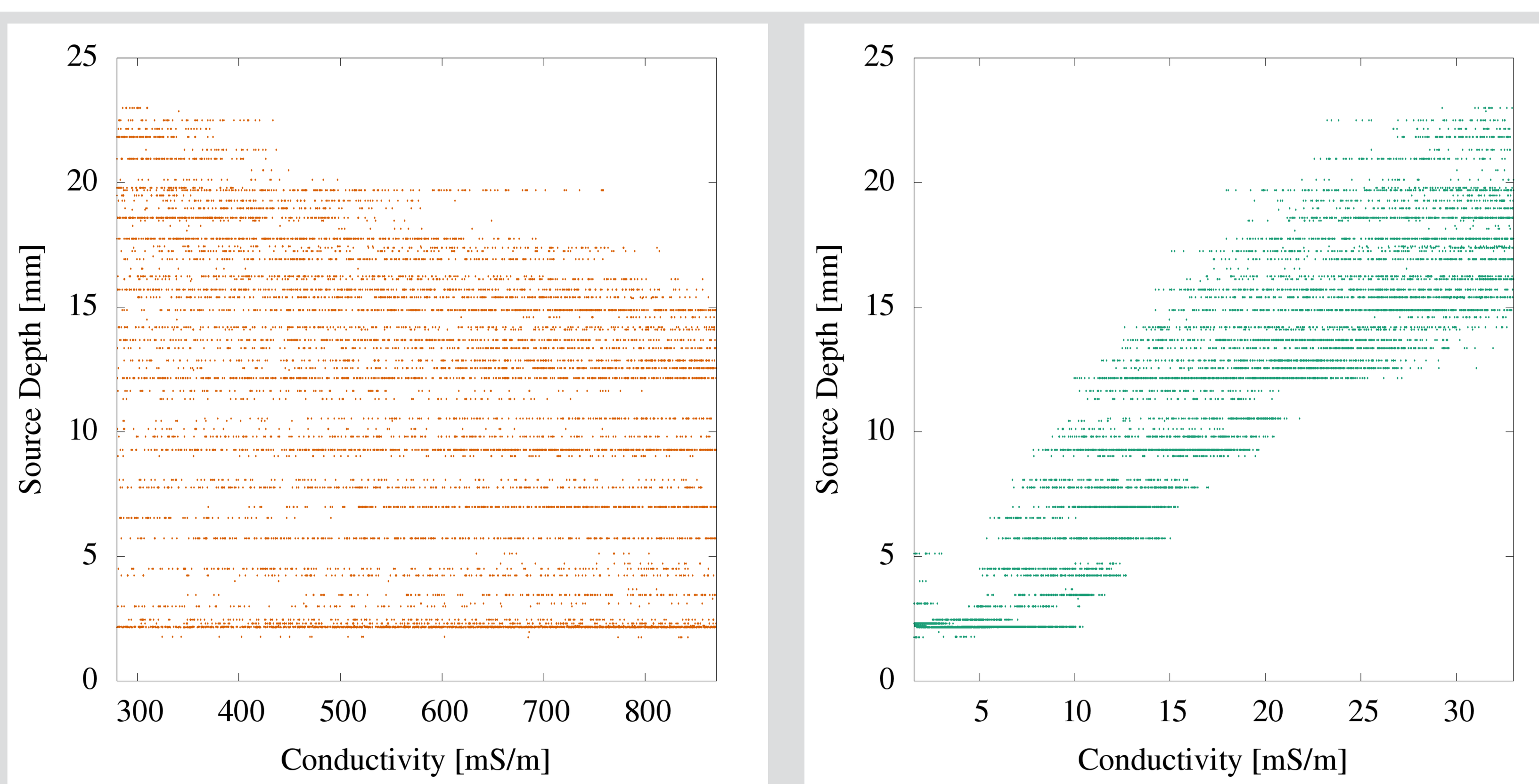

Figure 6: Source depth as function of the skin (left) and skull (right) conductivity for multivariate distribution.

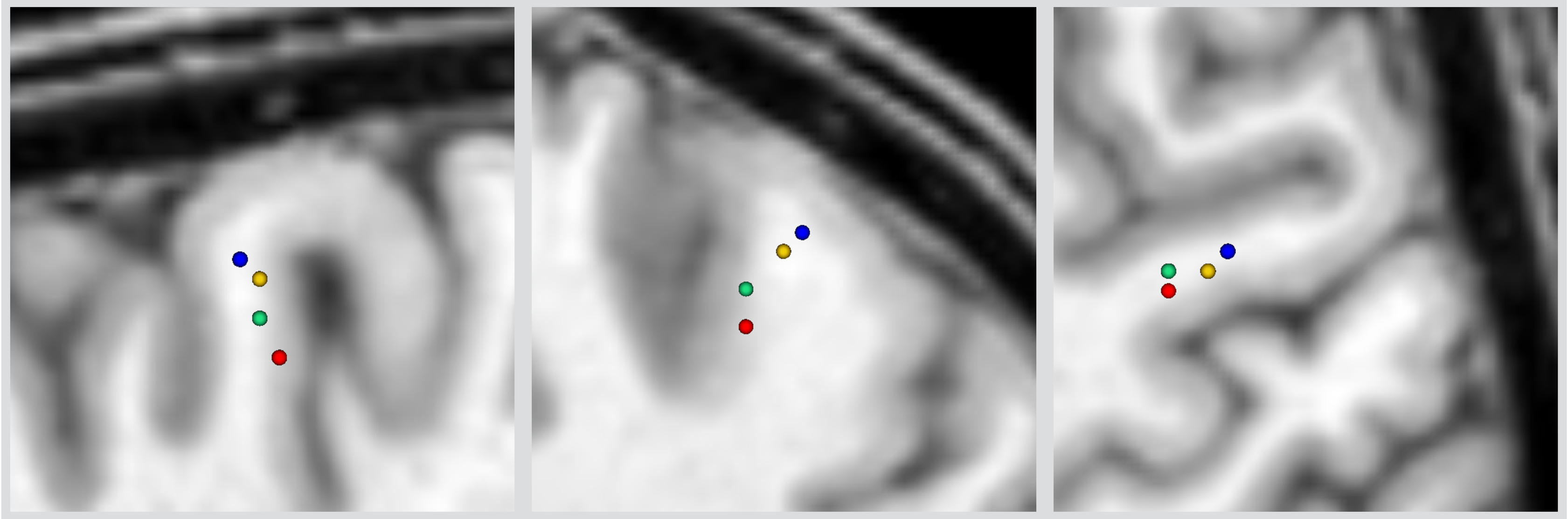

Figure 7: Source locations with optimal GoF for multi- and univariate distributions (blue - skin, green - skull, yellow - CSF, gray matter, white matter, red - multivariate) on MRI (sagittal left, coronal middle, axial right).

Distribution	GoF	SD(GoF)	σ_{skin}	σ_{skull}	σ_{csf}	σ_{gm}	σ_{wm}
uni skin	93.16	0.03	**526.9**	10.0	1790.0	330.0	140.0
uni skull	93.21	0.49	430.0	**14.5**	1790.0	330.0	140.0
uni csf	93.15	0.00	430.0	10.0	**1769.6**	330.0	140.0
uni gm	93.21	0.06	430.0	10.0	1790.0	**220.0**	140.0
uni wm	93.24	0.07	430.0	10.0	1790.0	330.0	**90.0**
Multi	93.70	0.64	**869.7**	**27.7**	1790.0	**339.3**	**93.4**

Table 2: Optimal GoF achieved for uni- and multivariate distribution and corresponding conductivities.

Results

- Skull and skin conductivity have the strongest influence on the EEG forward solution and the single dipole localization, resulting in changes in source localization of up to 2 cm and 1 cm, respectively.
- Gray and white matter conductivity uncertainties barely affect the dipole localization, but lead to variations in reconstructed dipole orientation of more than 10°.
- The small uncertainties of the CSF conductivity do not affect the result of the dipole reconstruction. However, not modeling a CSF compartment nevertheless has a strong effect on EEG forward solutions.
- The conductivity uncertainties barely affect the goodness of fit (GoF), as conductivity variations are compensated by changes of source localization (skin, skull) or source orientation (gray matter, white matter).

Conclusion

- Conductivity uncertainties have a strong influence on the results of dipole reconstructions.
- The strongest influence is found for the skull conductivity, which should therefore be the first choice when performing conductivity calibration.
- It has to be determined if it is more beneficial to additionally calibrate the skin conductivity or the white matter conductivity when possible.
- The CSF conductivity is very exactly determined and a CSF compartment should therefore be modeled whenever possible.

References

Vorwerk, J., Aydin, Ü., Wolters, C.H., & Butson, C. R.. Influence of head tissue conductivity uncertainties on EEG dipole reconstruction. Submitted.

Conflicts of Interest

CRB has served as a consultant for NeuroPace, Advanced Bionics, Boston Scientific, IntelectMedical, Abbott (St. Jude Medical), and Functional Neuromodulation. CRB is also a shareholder of Intelect Medical and is an inventor of several patents related to neuromodulation therapy. All other authors have nothing to declare.

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