CONDUCTIVITY ESTIMATION FOR EEG : WHAT IS RELEVANT ?

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ABSTRACT

The accuracy of EEG forward models partially depends on the head tissue conductivites. Some methods have then been proposed to estimate these conductivities. They are all based on the idea of imposing the electrical source in the head, and considering the conductivities as the only unknowns. Although the conductivity models are becoming more and more complex, it is not clear among the literature if it is really possible to estimate the conductivities of all the head tissues. We present here what are the limits of conductivity estimation for the common three-layer model (brain, skull, scalp), with and without skull anisotropy.

Index Terms— Electroencephalography (EEG), conductivity estimation

1. INTRODUCTION

Electroencephalography (EEG) is becoming a more and more common functional brain imaging modality. Thus, it is of interest to improve the resolution of the inverse EEG problem, which is spatially poorer than magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI). The main problem in EEG is its sensitivity to electrical properties of head tissues. In particular, the bad knowledge of skull conductivity can greatly affect the EEG source localization [1]. Further, the skull conductivity value varies highly among subjects. For the purpose of better source estimation, it is hence essential to be able to estimate *in vivo* conductivities of head tissues.

Two main approaches are used for conductivity estimation. Electrical Impedance Tomography (EIT) consists in a current injection on the scalp through selected EEG electrodes, and conductivity values are then inferred from potential measurements at the remaining electrodes [2, 3, 4]. A different method is to consider a natural source inside the brain. In this case, the electrical source can be controlled by using well-understood stimuli (like median nerve stimulation), combined with MEG for source localization [4, 5, 6].

In the articles about conductivity estimation, the dimension of the estimated conductivity varies widly : it can be just the skull conductivity [3], or all the conductivities of a four layer model [2, 5, 6]. The influence of the conductivities of the different head tissues on the forward and inverse problems has also been studied [7, 8], showing that some tissues have more effect than others. The question is then the following : is it possible to estimate the conductivities of all the tissues, and if not, what conductivities should be or can be estimated ?

In this paper, we consider the most common head model, composed of three layers for brain, skull and scalp. We study how the different conductivity values affect the electric potential, and what it means for conductivity estimation. We first assume isotropic tissues, and then we investigate the case of skull anisotropy, because it is of importance for EEG.

2. METHODS

2.1. Forward models

Spherical model

In a multilayer sphere model, an analytical expression of the surface potential generated by a dipole is available. We used the method described in [9], which can handle anisotropic conductivities. The geometry we worked on contains three spheres of radii 0.87, 0.92, 1. EEG measurements where simulated by choosing 60 electrode positions on the hemisphere corresponding to positive x axis.

Realistic model

For realistic models, we use the symmetric BEM formulation [10]. This method is more accurate than classical BEM, especially for superficial dipoles close to an interface (i.e. brain-skull). The geometry we used was built from the segmentation of a subject's MRI. We got three meshes for inner skull, outer skull and scalp. 60 electrode positions were taken from an EEG experiment on the same subject.

Conductivity values

As a reference, we used the following dimensionless conductivity values :

- 1 for brain
- 0.0125 for skull
- 1 for scalp

For an anisotropic skull, we chose 0.0125 in the radial direction and 0.125 in the tangential direction. All the simulations of EEG measurements were done with these reference conductivity values.

2.2. Conductivity estimation

We chose to study conductivity estimation using a source inside the brain modeled as a single dipole [4, 5, 6]. In this approach, one has EEG measurements corresponding to the evoked response of a focal source inside the brain. Several assumptions are then made : the source can be approximated by a single dipole, and prior knowledge on the source is available (position for instance). The goal is then to find the parameters of the forward model which give the best match between EEG measurements and simulated potential. For example, if the position of the dipole is known, the remaining parameters to estimate are the moment of the dipole and the conductivities.

We assume in the following that both position and orientation of the dipole are perfectly known, and that the amplitude of the source as well as the conductivities need to be estimated. This is equivalent to fix the amplitude of the dipole and estimate the conductivities just by considering the Relative Difference Measure (RDM) on the scalp between EEG measurements and simulated potential. Furthermore, because we are looking for dimensionless conductivities (not absolute values), one of the conductivities is fixed, and the conductivities of the other tissues are estimated relatively to it. This is done by fixing the value of brain conductivity to 1. To summarize, we assume a known dipole and the conductivites are estimated by minimizing the following quantity :

$$RDM(\sigma) = \left\| \frac{V_{meas}}{\|V_{meas}\|} - \frac{V_{sim}(\sigma)}{\|V_{sim}(\sigma)\|} \right\|$$

where V_{meas} is the measured potential and V_{sim} is the simulated potential with conductivity σ.

3. RESULTS

We performed simulations of EEG measurements for a given dipole by computing the potential at electrode positions with the reference conductivity values. No noise was added, which means that we have an ideal forward model which can perfectly match the EEG measurements. This was done in aim to focus on the errors coming from the conductivities.

3.1. Three layers, isotropic skull

In this section, we study the case of a three-layer model, describing brain, skull and scalp.

We first show on figure 3.1 the influence of the different tissues on the RDM when the conductivity ratio varies with respect to the reference values. This was done for a fixed dipole, superficial and with radial orientation. Different depths and orientations give the same results. It appears that brain conductivity has a very weak influence on the RDM, whereas skull and scalp have almost the same influence, bigger than brain.

Then we consider conductivity estimation. A simulation of EEG measurement was performed for a superficial dipole with radial orientation. The brain conductivity is fixed to 1, and we try to estimate skull and scalp conductivities. We plotted on figure 3.1 the isolevels of the RDM with respect to skull and scalp conductivity ratios. We see that the RDM has a valley shape. Figure 3.1 shows the values of in the middle of the valley. Even if the RDM achieves a minimum, we see that along the bottom of the valley, its values remain very lower than 0.01. Considering all the additional errors that one has to face in real experiments (imprecision on the source, errors of the forward model), we think that the estimation of both skull and scalp conductivities is not possible. Moreover, even if one of the two conductivity is fixed to a wrong value, one can find a value for the other conductivity that gives a very low RDM (corresponding to the bottom of the valley, figures 3.1 and 3.1). Because the scalp conductivity is supposed to be rather well known and stable among subjects, our conclusion is that for such a 3-layer model, just the skull conductivity should be estimated.

3.2. Can skull anisotropy be neglected ?

The 3-layer isotropic head model is the most common in EEG. But the importance of skull anisotropy has been underlined in several articles [7, 8]. Is it yet possible to estimate an effective isotropic skull conductivity which can compensate for the errors of such a model ? We made simulations of EEG measurements using the spherical model with anisotropic skull. Then we estimated the isotropic skull conductivity which gives the best RDM. This was done for several dipoles, radial and tangential, with various depths, see figure 4. For the tangential dipole, the RDM remains under 0.02, even when the dipole is close to the skull, and the estimated skull conductivity is rather constant with respect to the dipole eccentricity. For the radial dipole, the RDM increases dramatically, up to 0.08 when the dipole gets close to the skull, and moreover the estimated conductivity varies a lot with respect to the dipole eccentricity. The case of the radial dipole shows that there is no isotropic skull conductivity value which gives a reasonably low RDM. Thus the skull anisotropy can not be neglected.

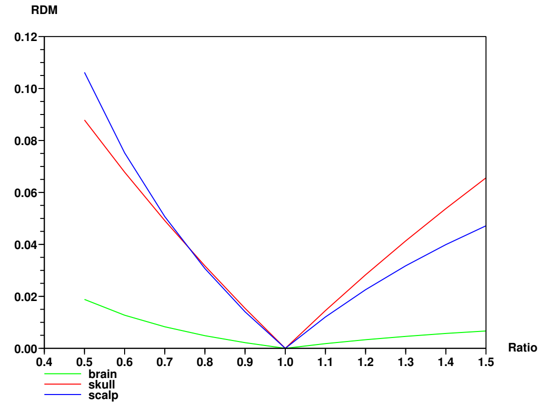

Fig. 1. Influence of the different conductivities on the RDM. The variation of the conductivity values is represented by the ratio with respect to the reference values.

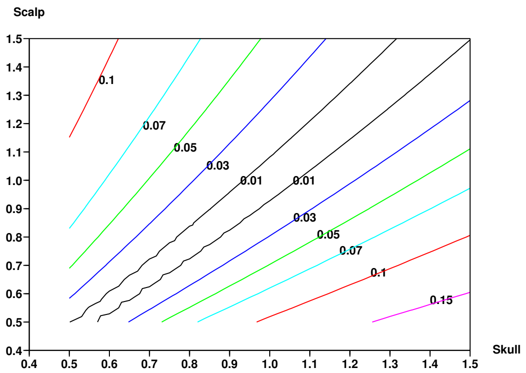

Fig. 2. Isolevels of the RDM with respect to skull and scalp conductivities.

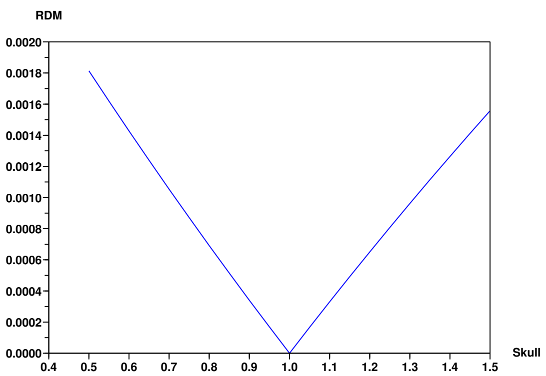

Fig. 3. Values of the RDM along the bottom of the valley from figure 3.1. For each skull conductivity value, we plotted the minimum of the RDM among scalp conductivities.

3.3. Three layers, anisotropic skull

We now study the case of a three-layer model, describing brain, skull and scalp ; with an anisotropic skull. There are four scalar conductivity values : brain, radial skull, tangential skull, scalp. As we did previously, we show the influence of the different conductivities on figure 3.3. This was done for a superficial and radial dipole, in aim to emphasize the anisotropic effect of the skull. The influence of brain conductivity is again weak, the tangential skull and the scalp have a rather strong influence, and the radial skull is clearly dominant.

Let us now fix brain conductivity to 1 and consider the estimation of the other conductivities. We can not plot the RDM with respect to radial skull, tangential skull and scalp in the same time. We then fix one conductivity to the reference value, and plot the RDM with respect to the other values, see figure 6. We face again valley shapes of the RDM, with values under 0.02 in the bottom, which means that the estimation of just two conductivties would be hard with additionnal errors. If just one conductivity is estimated, it should be the radial skull because of its strong influence. For various tangential skull and scalp conductivity values, we estimated the radial skull conductivity which gives the best RDM, this is shown on figure 3.3. For wrong values in a quite wide range around the reference tangential skull and scalp values, we can find a radial skull conductivity which gives an RDM under 0.02. In real experiments, other factors are leading to additionnal errors (noise, registration of the EEG helmet, numerical accuracy), and a RDM under 0.05 is oddly achieved, even for focal sources. Our conclusion is that the conductivity model is sufficiently improved just by estimating the radial skull conductivity.

4. CONCLUSION

We presented results about conductivity estimation of the head tissues in EEG. Our study was done with dimensionless conductivies, in an ideal case where the forward model can match exactly the measurements, and a dipolar source is perfectly known. So we give upper bounds about what is possible in conductivity estimation. In the well-known three-layer isotropic conductivity model (brain, skull, scalp), only the skull conductivity needs to be estimated. It is sufficient to improve the accuracy of the conductivity model, and anyway it is not possible to estimate two conductivities. We showed that the skull anisotropy can lead to important errors if it is not taken into account in the forward model. In a three-layer model with an anisotropic skull, it seems again hard to estimate more than one conductivity. The best choice is to estimate just the radial skull conductivity, because it has the strongest influence on the surface potential. We showed that the estimation of just the radial skull conductivity is sufficient to reduce the error of the forward model to a relevant level. From our experience,

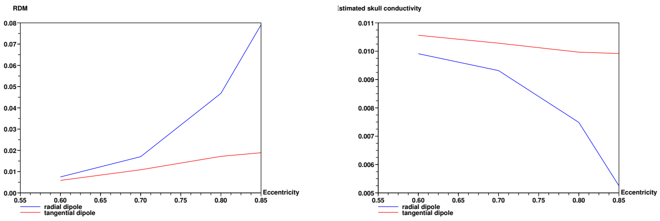

Fig. 4. The RDM (left) given by the estimated isotropic skull conductivity (right) with respect to the dipole eccentricity.

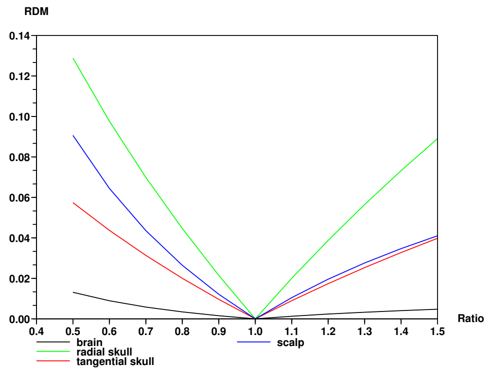

Fig. 5. Influence of the different conductivities on the RDM.

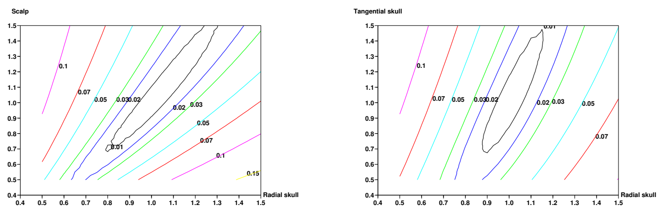

Fig. 6. The shape of the RDM in two conductivity plans : radial skull and scalp (left), radial skull and tangential skull (right).

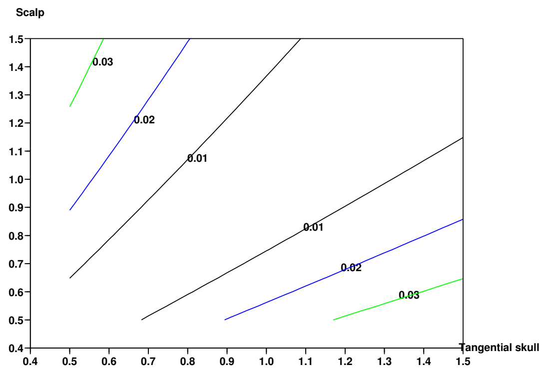

Fig. 7. For different tangential skull and scalp conductivities, we took the radial skull conductivity which gives the best RDM. This RDM is plotted with respect to tangential skull and scalp conductivities.

the EIT method would not give better results, except allowing the estimation of absolute conductivity values thanks to the knowledge of the strength of the injected current.

5. REFERENCES

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