Influence of Volume Conductor Model Errors on EEG Dipole Source Localization in Neonates

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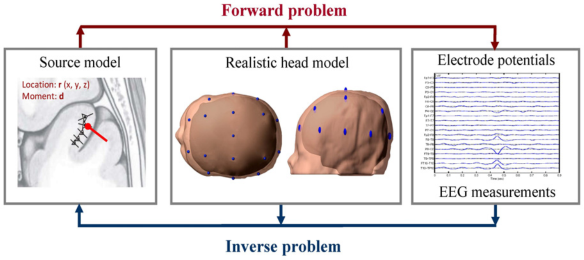
Introduction:

Magnetic resonance imaging (MRI) and electroencephalography (EEG) are the most important diagnostic tools in patients with neurological disorders. Integrating both techniques for 3D localization of active sources in the brain can help physicians to better understand their generation and propagation and do direct comparison with MRI lesions. Although EEG dipole source localization is widely used in adults to localize epileptic sources, it is challenging to apply it to neonates mainly because of the complex anatomy of the newborn brain and insufficient knowledge of tissue conductivities. To investigate the feasibility of neonatal EEG source localization, we developed an integrated method for dipole source localization in neonates based on a realistic head model. Here, we explain our method and examine the influence of three types of volume conductor model errors on dipole position errors. We explore the impact of: (1) omitting the anterior fontanel, (2) a wrong estimation of the neonatal skull conductivity and (3) the existence of the hole in the skull.

Methods:

Our fused method consists of three components: (1) MRI segmentation and 3-D realistic head modeling; (2) automatic seizure detection & localization; and (3) solving the forward and inverse problems for source localization (see Fig. 1a). Firstly, we segmented MRI scans to construct realistic head model with four compartments: scalp, skull, cerebrospinal fluid (CSF) and brain tissue [1,2,3]. For the skull reconstruction, we used the voxels between the brain and the scalp. The anterior fontanel is modeled as a part of the skull, where the skull layer is eroded at the top of the head to reach the maximum possible thickness (one voxel size). The segmented regions are used to generate a cubic grid with a cube side equal 0.7 mm. When different compartments of the brain are obtained, appropriate conductivities have to be attached to them. Since head conductivities, to our knowledge, have never been measured for neonates, in this work we estimated the conductivity values based on available studies for adults and small animals [4,5]. The conductivity of scalp, skull (with fontanel), CSF and brain tissue is chosen to be 0.43 S/m, 0.033 S/m, 1.79 S/m and 0.33 S/m, respectively. To test the influence of the anterior fontanel and the wrong estimation of the skull conductivity, we made four additional head models (see Fig. 1b). The second head model does not have the anterior fontanel, while the third model has a hole in the skull, which is modeled by assigning the scalp conductivity to the fontanel. In the fourth and fifth head models we changed the skull conductivity to 0.0067 S/m and 0.2 S/m respectively, which correspond to the minimal and maximal head conductance estimated in adults. In this work we used 17 electrodes placed on the head model following the international 10-20 system. Finally, the dipole localization problem in all experiments is solved using algorithms for neonatal seizure detection and localization [6] and the algorithm that deals with the forward and inverse problem [7].



(a)

regions	model 1	model 2	model 3	model 4	model 5
scalp	0.43	0.43	0.43	0.43	0.43
skull	0.033	0.033	0.033	0.0067	0.2
CSF	1.79	1.79	1.79	1.79	1.79
brain	0.33	0.33	0.33	0.33	0.33
fontanel	0.033	——	0.43	0.033	0.033

(b)

Fig.1. (a) An outline of the EEG source localization algorithm; (b) A table with the five head models and the assigned conductivities for each region.

Results:

The dipole localization errors (shifts), caused by using different volume conductor models, are calculated using 3-D Euclidean distance. In the first experiment we evaluated the influence of the second head model (no fontanel) on dipole location error and we found that the error is almost negligible (~0.7 mm). When modeling the hole on the place where the fontanel is located (third head model), we noticed that the dipole position errors are bigger in the vicinity of the hole (maximum error 4.2 mm) and the dipoles are fitted closer to the hole. However, the majority of the test dipoles had a dipole location error less than 1 mm. Next we tested the influence of the skull conductivity on dipole position errors. We found that the mean dipole shift between the head models with skull conductivities of 0.033 S/m and 0.2 S/m is ~2.5 mm (maximum error is 12 mm), while between the head models with the skull conductivities of 0.033 S/m and 0.0067 S/m is ~1.6 mm (maximum error is 10 mm). These values are lower than the values found in the similar studies with adults and we believe that one of the reasons might be the thinner skull in neonates. It is also noticed that dipole position errors occur for all tested dipoles in the entire brain volume and that the fitted dipoles are shifted radially from the original positions.

Conclusion:

In this work we have investigated the dipole position errors due to omitting the fontanel, having a hole in the skull and wrongly estimating the skull conductivities in newborn infants. Quantitative experimental results have shown that the dipole position errors are higher due to the wrong estimation of the skull conductivity than the ones found due to omitting the fontanel or having a hole in the skull. With further investigations and validation studies we believe that neonatal EEG source localization can be a useful diagnostic tool.

References

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