Spatial localisation of EEG dipoles in MRI using the 10-20 International System anatomical references

J. Pascau[a,b] , M. Desco[a], P. Rojo[c] , A. Santos[b], J Lopez[a], M. A. Pozo[d]

[a] Hospital G. U. “Gregorio Marañón”, C/ Dr. Esquerdo 46, 28007 Madrid, Spain.

[b] ETSI Telecomunicación, Universidad Politécnica de Madrid, 28040 Madrid, Spain.

[c] Hospital de la Princesa, C/ Diego de León 62, 28006 Madrid, Spain.

[d] Unidad de Cartografía Cerebral, Instituto Pluridisciplinar de la UCM. 28040 Madrid, Spain.

desco@mce.hggm.es

Abstract. *This paper presents a method to locate EEG dipoles (recorded using the 10-20 International System of Electrode Placement) on the patient’s MRI. The 10-20 anatomical landmarks are identified on the MRI with the help of a surface rendering and the dipole position provided by the BESA software is transferred into MRI coordinates. As a difference with other methods, no external markers are necessary. The results on eight treatment refractory epileptic patients show that this approach improves the information provided by the BESA program, locating the dipole on its anatomical source.*

Keywords: Electroencephalography, EEG, Magnetic Resonance Imaging, MRI, Epilepsy.

Introduction

EEG source analysis is generally performed using dipole models and specific programs that calculate their localisation. This information is usually represented by drawing the dipole on ideal spherical head projections, thus providing a rough estimation of the anatomical position of the source. Clinical diagnosis could be improved by transferring this position to the patient’s 3D MRI.

The most common method for finding the dipole on the MRI is to place markers on the patient’s skin. These markers can be located on the electrodes positions (Towle, 1993, Yoo, 1997) or on the anatomical landmarks that define the 10-20 reference system (Merlet, 1996, Dieckmann, 1998, Lagerlund, 1993). The identification of these points on the MRI allows to calculate the coordinate transformation necessary to represent the dipole in its anatomical position. In many cases this procedure is not applicable (MRI acquired previously or no facilities to use markers) and the dipole localisation becomes impossible. A method not requiring external markers would be very interesting in these cases.

Our approach to project the EEG dipole source onto the patients MRI is based on the identification of anatomical landmarks on 3D tri-planar views and surface rendering, thus avoiding the need of external markers. This method has been tested on several patients and provides a way to link the EEG dipole locations to their underlying anatomy. As these patients are candidates to surgical treatment, the contribution of this process may be a significant support to other imaging techniques that do not always provide definitive results.

Patients and Methods

The study group includes eight treatment refractory epileptic patients. In this work we have studied their MRI (T1 and T2 weighted sequences) and EEG for dipole localisation. After this analysis five of them underwent surgical treatment.

EEG acquisition and source localisation

EEG electrode positioning followed the 10-20 International System of Electrode Placement. EEG activity was recorded with a 62-channel Neuroscan equipment (Neuroscan Labs, Sterling, USA), using a common average reference. EEG activity was recorded for 15 to 20 min and digitally filtered with LFF 2Hz and HFF 20 Hz in resting conditions with the eyes closed.

The recorded epileptiform discharges were identified by visual inspection of EEG in search of interictal spikes or sharp waves. EEG epochs of 1024 ms centred on the negative peak of the discharge were collected and averaged (range 36 to 180 epochs).

Brain Electric Source Analysis software (BESA v.2.2 from MEGIS Software GmbH, Munich, Germany) was used for dipole source modelling. This program uses a simple four-shell spherical head model, with the shells representing the brain, cerebrospinal fluid (CSF), skull and scalp (Scherg, 1991, 1992). The thickness and conductivities of the layers required by the model were: 70 mm for the cortical surface radius, 72 mm for CSF, 7 mm for skull thickness and 6 mm for scalp, being 85 mm of outer layer sphere radius. Conductivities were 0.33, 1.0, 0.0042 and 0.33 mhos/m for brain, CSF, skull and scalp respectively.

Spatio-temporal multiple dipole modelling was performed according to following strategy:

A. The 1st dipole was fitted for the whole epochs of 1024 ms.

B. The 2nd dipole was constrained to the epoch of the spike itself (51-108 ms).

A residual variance of <10% was considered an appropriate fit.

With these model parameters, BESA software calculates an equivalent dipole at the appropriate location within the electrical head model described above. This process is guided by the operator, who formulates hypothesis about the number of sources and their location. The solution found by the program consists of one or several dipoles with their origin, orientation and moment expressed in the 10-20 coordinate system. These sources are drawn on the spherical head model, giving a rough estimation of their anatomical position (Fig. 1).

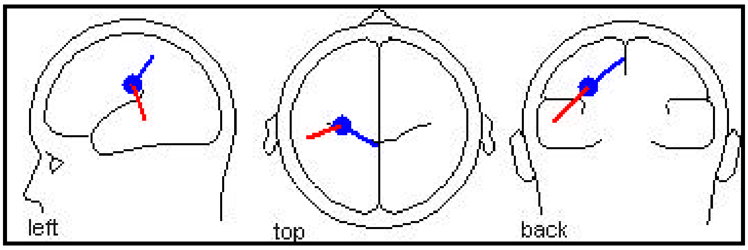

Figure 1: Standard graphical output of BESA software for source location (four-shell head model)

Dipole projection on MRI coordinate system

The coordinate axis were calculated in the MRI using the four anatomical landmarks that the 10-20 International System defines (Lagerlund et al., 1993). A specific application was developed to find the positions of these points in the MRI. A skin surface rendering combined with a triplanar 3D viewer allowed the user to manually identify the nasion (N), inion (I) and both pre-auricular points (PreL and PreR) (Fig. 2).

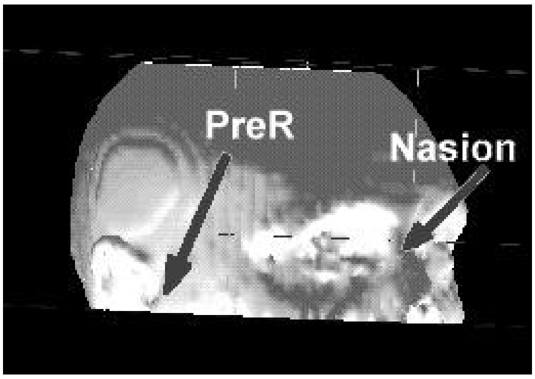

Figure 2: Two landmarks identified on the MRI surface rendering.

Once the four landmarks are set, the dipole coordinate system can be determined. First, the three unitary vectors are calculated: v^{NI} from inion to nasion, v^{LR} from the right pre-auricular point to the left one, and v^{CZ} from the middle point of the segment nasion-inion being perpendicular to the other two. During EEG acquisition, and according to the 10-20 coordinate system, the electrodes were positioned dividing both N-I and PreL-PreR half circumferences in 10 parts. For that reason, at 18 degrees (180/10) steps starting from N, I, PreL and PreR we locate the electrodes Frontal Pole (FP), Occipital Pole (OP), T7 and T8. Theoretically, the centre of the electrodes sphere should be the crossing point of the lines PF-OP and T7-T8. If these lines do not intersect, the sphere centre is set at the point with minimum distance to both lines (Fig. 3). The sphere centre should be near the bottom of the third ventricle, and about 5 mm. anterior to the posterior commissure (Towle et al. 1993). In all the cases, this issue was specifically confirmed by the operator before proceeding.

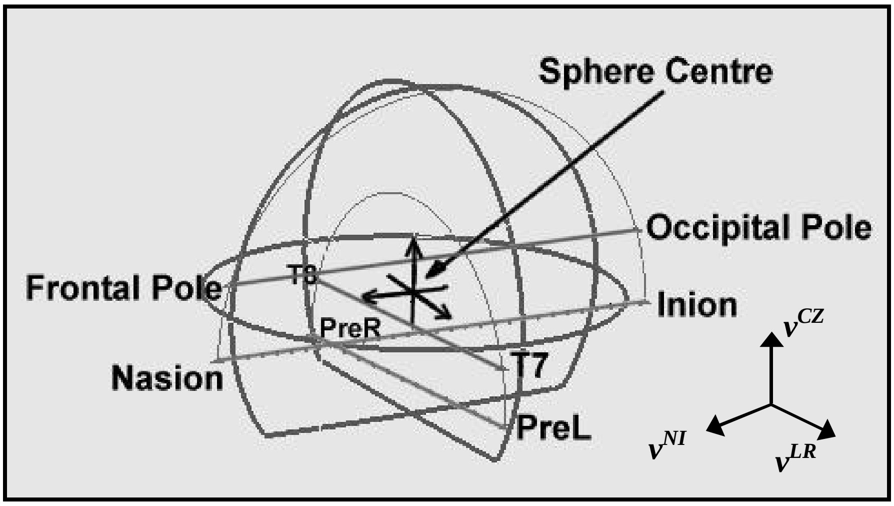

Figure 3: The dipole coordinate system calculated from the four 10-20 anatomical references, (nasion, inion and the pre-auricular points), showing the unit vectors and the sphere centre.

The dipole data provided by BESA (Cartesian coordinates x, y and z, orientation angles q and f, and dipole moment m) are transferred into the MRI using the coordinate system defined by the unitary vectors and the sphere centre. The outer sphere has a radius of 85 mm in the BESA four-shell head model. This simple model is then adjusted to the patient's actual head dimensions. Dipole coordinates are scaled to the x, y and z radius measured from the centre of the sphere in the MRI. The method is summarised in equation 1, and figure 4 shows an example of the result.

$$\begin{bmatrix} D'_x \\ D'_y \\ D'_z \\ 1 \end{bmatrix} = \begin{bmatrix} v_x^{NI} & v_y^{NI} & v_z^{NI} & C_x \\ v_x^{LR} & v_y^{LR} & v_z^{LR} & C_y \\ v_x^{CZ} & v_y^{CZ} & v_z^{CZ} & C_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} D_x \\ D_y \\ D_z \\ 1 \end{bmatrix}$$

$$\begin{gathered} D \equiv \textit{Dipole coordinates in 10-20 system} \\ D' \equiv \textit{Dipole coordinates in MRI system} \\ v^{NI}, v^{LR}, v^{CZ} \equiv \textit{Unitary vectors from 10-20 system} \\ C \equiv \textit{Sphere centre (10-20 system origin)} \\ s_x = \frac{r_x}{85}, s_y = \frac{r_y}{85}, s_z = \frac{r_z}{85} \quad \textit{Scale factors} \\ r_x, r_y, r_z \equiv \textit{Head radii measured from } C \end{gathered} \qquad \text{(Eq. 1)}$$

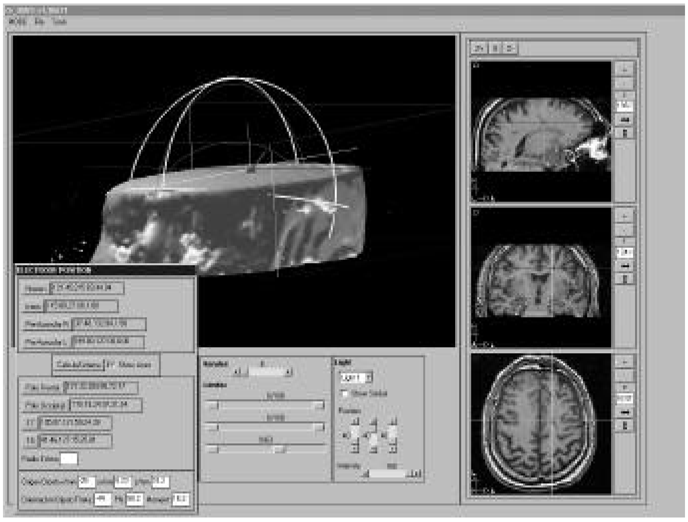

Figure 4: Dipole projection onto the patient's MRI and the sphere used in the electrical head model.

Results and Discussion

The dipole location in relation with the underlying anatomy was studied in 8 patients. For every patient the dipole was projected onto the MRI and the target anatomical structure compared with the patient diagnosis using other techniques (PET, SPECT and neuro-psychological evaluation).

Five patients underwent surgical treatment. In four of them resection included the area where dipole was located and post-operative evaluation showed positive results. In one patient the surgical treatment did not make use of the dipole results, since the obtained position did not match the other diagnostic techniques. Nevertheless, the patient was operated and the follow-up did not show significant improvement.

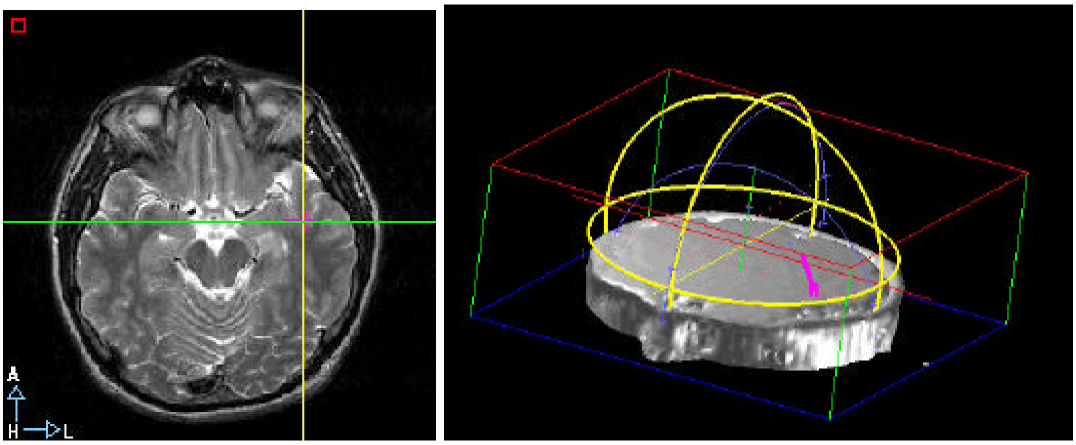

Figure 5: Dipole location results on a patient's MRI. The dipole appears in a Left Temporal area, matching the results obtained with other techniques.

Two patients are now waiting for surgery, and the dipole results have helped in this decision. In one more patient the dipole does not match the other techniques, and surgery has not been indicated up to now.

These results demonstrate that this technique is useful for checking the anatomical origin of the EEG source location, improving the rough dipole positioning provided by BESA. The manual identification of the four 10-20 system anatomical references seems to be accurate enough to locate the dipole on the MRI, according to clinical criteria.

A limitation of our work is that no objective assessment of the method accuracy can be obtained, since there is no 'gold standard technique' to compare with. On the other hand, the BESA approximations are reported to yield errors in the range of 2 cm. For this reason, only clinical evaluation of the results are provided.

The goal of depicting the dipole position together with the MRI anatomical data is clinically very interesting. That is the reason why different approaches have been proposed. Most authors suggest the use of external markers, located in a few reference points (Merlet, 1996, Dieckmann, 1998, Lagerlund, 1993) or placed on every electrode (Towle, 1993, Yoo, 1997). There is also a commercial package available – CURRY® from Neuroscan Labs – , that using the electrode position information, obtained from external markers, solves the EEG inverse problem in a realistic head model (Neuroscan, 2000). Although this package seems to be the best solution for EEG source localisation, it requires to provide the location of every electrode on the MRI .

As a difference with other methods based on external markers, our approach can be used either in prospective or retrospective way. This overcomes the problem of obtaining the MRI image with the external markers, and allows for the use of any MRI of the patient, acquired without any specific purpose, before or after the EEG.

As a conclusion, the results show that projection of EEG dipole data onto the MRI may play a key role in the indication of surgery for the treatment of refractory epileptic patients, provided it is simple and easy to perform.

Acknowledgements

This work was supported in part by projects TIC99-1085-C002 and CAM 8.5/23/99 and 08.1/049/98.

References

1. Diekmann, V., Becker, W., Jürgens, R., Grözinger, B., Kleiser, B., Richter, H. P., Wollinsky, K. H. (1998). “Localisation of epileptic foci with electric, magnetic and combined electronic models” *Electroencephalogr Clin Neurophysiol* 106: 297-313.
2. Lagerlund, T. D., F. W. Sharbrough, et al. (1993). “Determination of 10-20 system electrode locations using magnetic resonance image scanning with markers.” *Electroencephalogr Clin Neurophysiol* 86(1): 7-14.
3. Merlet, I., L. Garcia-Larrea, et al. (1999). “Simplified projection of EEG dipole sources onto human brain anatomy.” *Neurophysiol Clin* 29(1): 39-52.
4. Merlet, I., L. Garcia-Larrea, et al. (1996). “Source propagation of interictal spikes in temporal lobe epilepsy. Correlations between spike dipole modelling and [18F]fluorodeoxyglucose PET data.” *Brain* 119(Pt 2): 377-92.
5. Neuroscan Labs, (2000). Curry software web page. “Curry. Multimodal neuroimaging”, http://208.240.89.62/neuroscan/curry4.htm.
6. Scherg, M. and T. W. Picton (1991). “Separation and identification of event-related potential components by brain electric source analysis.” *Electroencephalogr Clin Neurophysiol Suppl* 42: 24-37.
7. Scherg, M. (1992). “Functional imaging and localization of electromagnetic brain activity.” *Brain Topogr* 5(2): 103-11.
8. Towle, V. L., J. Bolanos, et al. (1993). “The spatial location of EEG electrodes: locating the best-fitting sphere relative to cortical anatomy.” *Electroencephalogr Clin Neurophysiol* 86(1): 1-6.
9. Yoo, S. S., C. R. Guttmann, et al. (1997). “3D localization of surface 10-20 EEG electrodes on high resolution anatomical MR images.” *Electroencephalogr Clin Neurophysiol* 102(4): 335-9.