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BRIEF COMMUNICATION

MEG and EEG Sensitivity in a Case of Medial Occipital Epilepsy

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Abstract Interictal or ictal events in partial epilepsies may project on scalp EEG contralaterally to the side of the epileptogenic lesion. Such paradoxical lateralization can be observed in case of para-sagittal generators, and is likely due to the spatial orientation of the generator, presenting an oblique projection towards the midline. We present here a case of medial occipital epilepsy investigated using EEG, MEG and stereoelectroencephalography (SEEG). MRI displayed a focal cortical dysplasia in the superior margin of the right calcarine fissure. SEEG demonstrated bilateral medial occipital interictal spikes, with an inversion of polarity at the level of the lesion and a contralateral propagation occurring in 10 ms. Interictal iterative EEG cartographies showed a large posterior field, with a maximum contralateral to the initial generator (EEG paradoxical lateralization). With the same number of channels, interictal iterative MEG cartographies were more precise and more complex than EEG ones, indicating an onset accurately lateralized. A few milliseconds later, MEG cartographies were quadripolar, thus indicating two homotopic active generators. These MEG and EEG cartographies have been reproduced using BESA dipole simulator. Relative merits of MEG and EEG are still debated. With 151 channels, MEG source localizations indicated the right medial occipital area, as demonstrated by SEEG. An investigation with a corresponding number of EEG channels was not performed. After a down sampling to 64 sensors, this precision was lost. MEG and EEG source localization results, both with 64 channels, were quite comparable, indicating both medial occipital areas. However, a careful analysis of MEG/EEG iterative cartographies, performed with the same number of channels in both modalities, demonstrated that, in this configuration, MEG sensitivity was superior to the EEG one, allowing separating two medial occipital sources, characterized in SEEG by a time delay of 10 ms.

Keywords MEG · EEG · SEEG · Epilepsy · Occipital lobe

Introduction

Paradoxical EEG lateralization is defined by the scalp projection of cortical activity contralateral to the source location. This phenomenon was described in parasagittal epileptogenic lesions (Catarino et al. 2012; Oishi et al. 2002; Tukel and Jasper 1952) and has been confirmed by intracranial recording in the context of presurgical assessment (Catarino et al. 2012; Lesser et al. 1987). This was also described in visual evoked potentials after half-field stimulation (Barett et al. 1976) and in somatosensory evoked potentials after stimulation of the posterior tibial nerve (Cruse et al. 1982; Lesser et al. 1987).

We report here an EEG paradoxical lateralization in a case of medial occipital epilepsy, investigated using high resolution EEG (HR-EEG), MEG and SEEG. At the sensor

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level and with the same number of channels, MEG sensitivity was superior to the EEG one, allowing separating two medial occipital sources and inferring their order of activations, which was confirmed by SEEG.

Materials and Methods

A 41-year-old right-handed woman presented partial seizures characterized initially by unresponsiveness or visual symptoms. Seizures were resistant to all drug treatment. Brain MRI was suggestive of a focal cortical dysplasia localized at the superior margin of the right calcarine fissure. EEG interictal spikes were contralateral, of maximal amplitude in left parieto-occipital channels. Ictal EEG demonstrated increased spiking on the same channels followed by a posterior bilateral discharge.

HR-EEG was performed with 64 channels and a realistic head model. The sampling rate was 1,000 Hz. Two source localization algorithms were used: equivalent current dipoles and MUSIC (Mosher et al. 1992). Detailed methodology has been previously described (Gavaret et al. 2009). Ten closely spaced spikes with high SNR were selected. In this study, a conductivity ratio (skull/scalp) of 1/20 was used. Source localizations were performed using an average of ten spikes.

MEG was recorded with a whole head, 151-channel biomagnetometer system (CTF Systems Inc., Port Coquitlam, Canada), down sampled secondarily to 64 channels. The sampling rate was 1,025 Hz. MEG study was approved by the institutional Review board of the French Institute of Health (FWA00005831). Two source localization algorithms were used: LCMV (Van Veen et al. 1997) and MUSIC. LCMV was performed using a concatenation of ten closely spaced spikes with high SNR; MUSIC, using an average of ten spikes.

Using BESA® dipole simulator, we fitted two equivalent current dipoles, localized in medial occipital areas and characterized by an oblique orientation towards the midline, in order to reproduce the experimental EEG and MEG data.

Results and Discussion

HR-EEG allowed recording of sub-continuous interictal-spikes. In these sub-continuous bursts, the range of interspike interval was irregular, comprised between 100 and 700 ms (mean duration of interspike interval: 264 ms). EEG spike duration was between 36 and 45 ms (EEG spike mean duration: 41 ms). During spikes, iterative amplitude maps, with 4 ms between each map, demonstrated a large posterior field, with left paramedian maximal amplitude (paradoxical lateralization with regard to the initial generator) (Fig. 1a). Source localizations indicated both medial occipital areas (MUSIC, Fig. 1a).

MEG recorded sub-continuous interictal spikes. MEG spike duration was shorter than the EEG one, being comprised between 32 and 42 ms (MEG spike mean duration: 37 ms).

During spikes, iterative amplitude maps, with 3.2 ms between each map, were strikingly quadripolar, with an initial right-sided dipolar field followed by a contralateral homotopic dipolar field. At the sensor level, this dipolar and secondarily quadripolar cartography remained preserved after a down sampling to 64 channels (Fig. 1b). Source localizations with 151 channels indicated the right medial occipital area. After a down sampling to 64 channels, this precision was lost. MEG source localizations indicated both medial occipital areas (MUSIC, Fig. 1b).

Using BESA® dipole simulator, with two medial occipital equivalent current dipoles oriented towards the midline, the resulting MEG/EEG cartographies reproduced the experimental data. Indeed, iterative EEG amplitude maps demonstrated a large posterior field while iterative MEG amplitude maps had a quadripolar pattern, indicating the existence of two homotopic sources (Fig. 1c).

SEEG implantation was bilateral, predominant in the right temporo-parieto-occipital junction (Fig. 2). The right-sided electrode GC was the only one that recorded interictal spikes with inversion of polarity along its contacts (monopolar montage, scalp Fz reference). Moreover, at the peak of polarity inversion, the same spikes were characterized by a negative polarity in depth electrodes above GC and by a positive polarity in depth electrodes below GC. These data demonstrate that the electrode GC (medial leads at the level of the lesion) was the sole electrode that passed through the generator. In addition, we observed a time delay of 10 ms between right and left spikes.

Paradoxical lateralization can be explained by the spatial orientation of an equivalent dipole, with an orientation such that the activity is projected obliquely, leading to the highest amplitude being recorded on the opposite side (Catarino et al. 2012; Gloor 1985; Tomberg et al. 2005). We report here a case of occipital epilepsy, characterized by an EEG paradoxical lateralization.

We observed that iterative MEG amplitude maps were more precise and more complex than the EEG ones, indicating an adequate lateralized onset and spread towards contralateral homotopic area. These characteristics of MEG/EEG cartographies were preserved even after a downsampling of MEG data in order to have the same number of channels in MEG and EEG. This confirms that differences between EEG and MEG arise from different properties of field propagation, and not from a different number of sensors. This higher specificity of MEG over

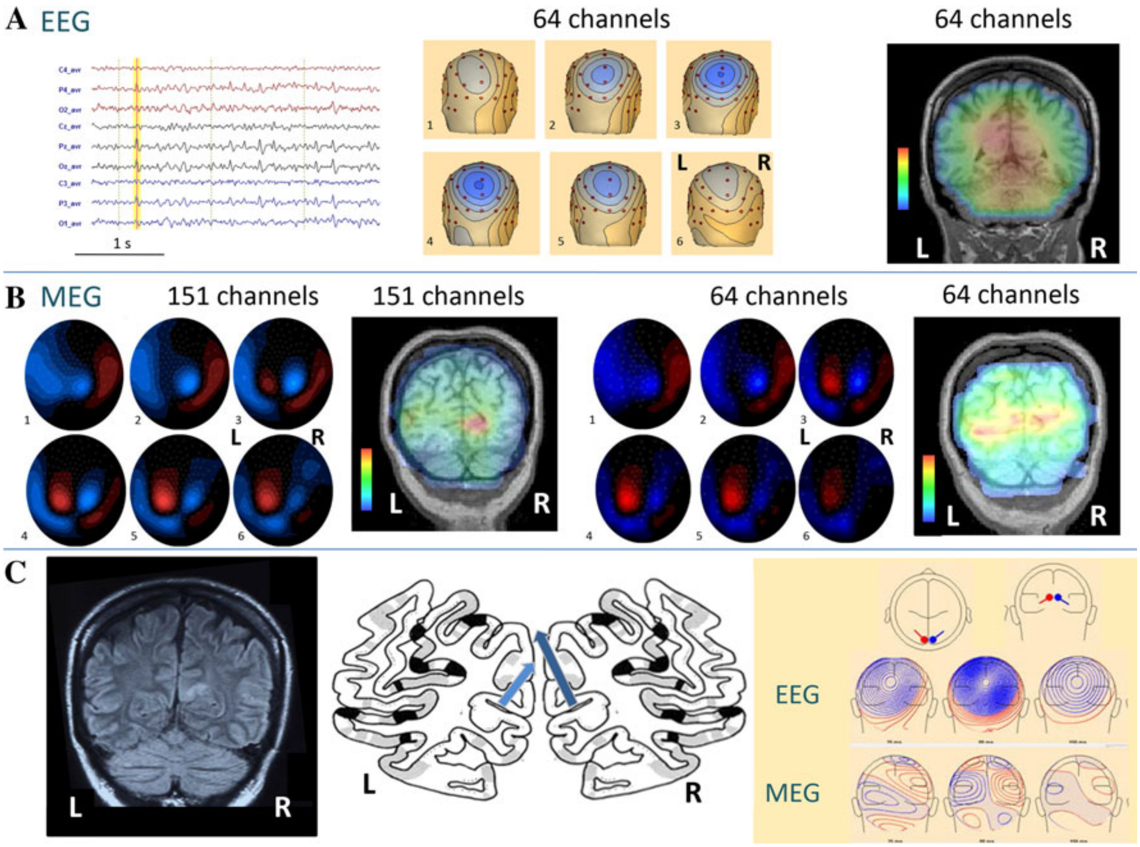

Fig. 1 **a** *EEG* Interictal spikes were sub-continuous (monopolar montage, average reference). During interictal spikes, 4 ms between each, iterative EEG amplitude cartographies (cartographies *1–6*) were simpler than MEG ones, being monopolar, with a maxima contralateral to the initial generator (EEG paradoxical lateralization). EEG source localization using MUSIC indicated both medial posterior areas. **b** *MEG* MEG data with 151 channels (*left part*) and with 64 channels (*right part*). Iterative MEG amplitude maps, 3.2 ms between each, were quite unchanged after a downsampling to 64 channels, indicating an onset (cartographies *1*, *2*) accurately lateralized, in regard to intracerebral data. A few milliseconds later (cartographies *3*, *4*), MEG cartographies were quadripolar, thus indicating two homotopic active generators. With 151 channels, MEG source localization using MUSIC indicated the right medial occipital area. With 64 channels, MEG source localizations were comparable to the EEG ones, indicating both medial posterior brain areas. **c** MRI was suggestive of a FCD localized at the superior margin of the right calcarine fissure (FLAIR hypersignal). Medial homotopic posterior equivalent dipoles, orientated towards the midline. Using BESA® dipole simulator, EEG and MEG amplitude cartographies similar to experimental data were modelled by two dipoles, localized in medial posterior areas and orientated towards the midline

EEG for separating synchronous bilateral sources has been observed for auditory evoked field (Cheyne et al. 2007). Two factors are important in the differences between MEG and EEG. First, the magnetic field is orthogonal to the electrical field. Second, MEG fields are less influenced by the low conductivity of the skull, which produces a "blurring" effect in EEG fields. The blurring effect has important consequences for bilateral sources presenting a high level of synchrony. With two equivalent dipoles pointing towards the midline, the resulting field is roughly monopolar in EEG, with an amplitude cartography presenting one maximum only. In contrast, MEG amplitude cartographies allowed separation of the sources at sensor level.

With 151 channels, MEG source localizations indicated the right medial occipital area, as demonstrated by SEEG. After a down sampling to 64 sensors, this precision was lost. Indeed, with MUSIC and LCMV, MEG and EEG source localization results, both with 64 channels, were quite comparable, indicating both medial occipital areas. These results, based on the fact that the source lateralization was lost with downsampling, demonstrated that high density recordings improve the yield of brain imaging based on MEG, as previously demonstrated with EEG (Lantz et al. 2003).

Finally, with the same number of channels in both modalities, MEG demonstrated a superior sensitivity to the EEG, at the sensor level, revealed by a careful analysis of iterative MEG/EEG amplitude cartographies during spikes. In EEG/MEG source imaging, in order to highlight and to better characterize the differences between these two modalities; it thus appears of importance not only to select

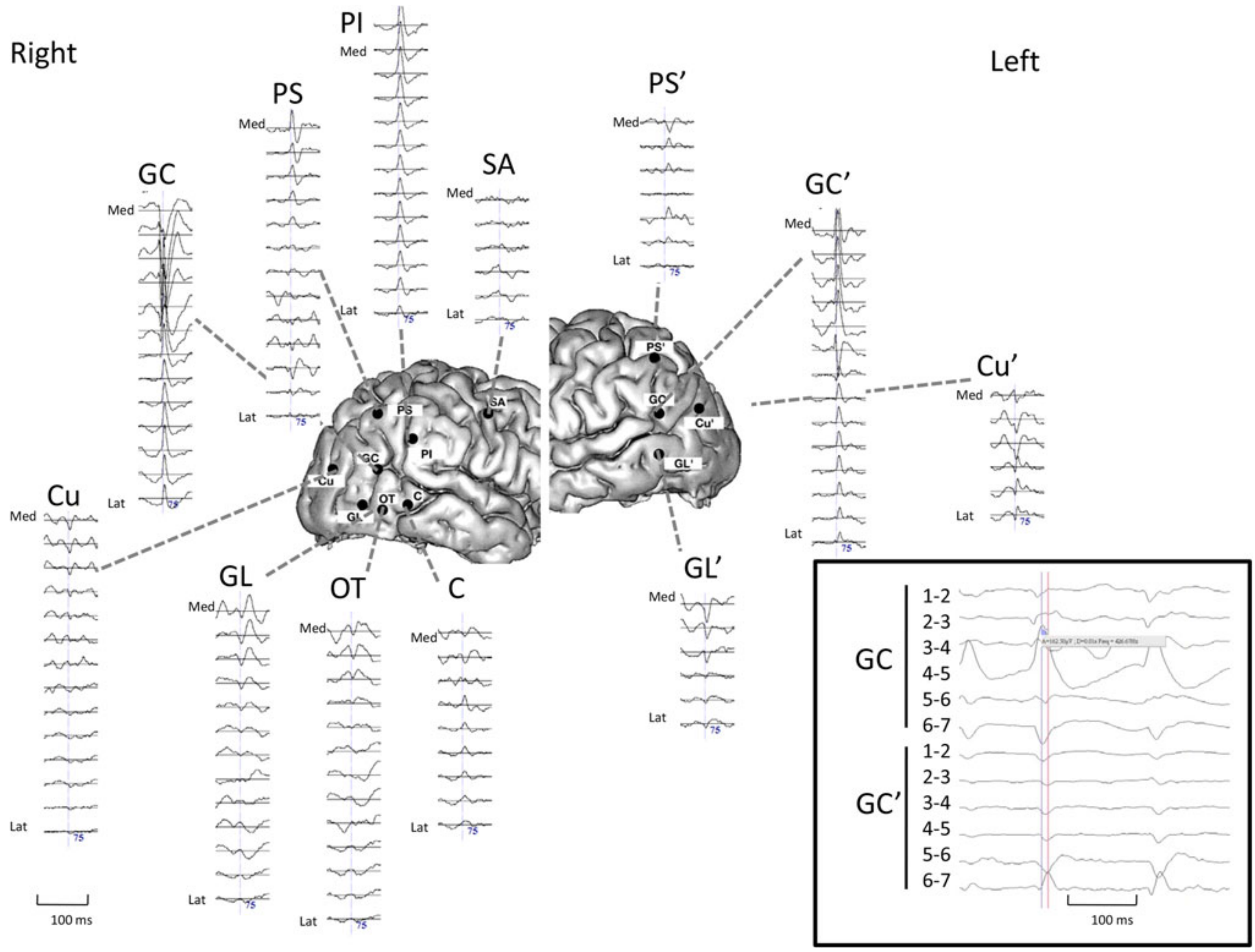

Fig. 2 Interictal spikes recorded at the level of each depth electrode (monopolar montage, scalp Fz reference). SEEG schema superimposed upon patient's 3D MRI. Interictal spikes co-implicated both medial posterior brain areas but the *right-sided* electrode GC was the only one that recorded interictal spikes with inversion of polarity along its contacts. Moreover, at the peak of polarity inversion, spikes were characterized by a negative polarity in depth electrodes above GC (PS, PI, PS′, GC′) and a positive polarity in depth electrodes below GC (Cu, GL, OT, C, GL′, Cu′). These data demonstrate that the electrode GC was the sole electrode that passed through the generator. Moreover, a time delay of 10 ms was observed between *right* and *left* depth electrodes GC and GC′

interictal spikes and to perform source localizations with distinct algorithms, but to carefully analyze iterative amplitude cartographies.

Relative merits of MEG and EEG are still debated (Barkley 2004; Baumgartner 2004; Goldenholz et al. 2009; Iwasaki et al. 2005; Malmivuo 2012). Regional differences in signal to noise ratios of cortical sources in MEG and EEG are observed (Goldenholz et al. 2009). Moreover, MEG and EEG have distinct sensitivities according to the orientation of cortical generators (Manshanden et al. 2002). Some studies demonstrate a better sensitivity of MEG compared to EEG but it is demonstrated with more MEG than EEG channels (De Tiège et al. 2012; Iwasaki et al. 2005; Ossenblok et al. 2007). Our observation illustrates that, in regard to medial occipital areas and with the same number of channels, MEG sensitivity was superior at the sensor level to the EEG ones, allowing separation of two medial occipital sources, characterized in SEEG by a time delay of 10 ms.

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