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SHORT COMMUNICATION

Clinical evidence for the utility of movement compensation algorithm in magnetoencephalography: Successful localization during focal seizure

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Summary A movement compensation (MC) algorithm may help to evaluate seizure focus in magnetoencephalography despite patient movement. We report a boy whose ictal MEG focus was localized to the same sublobar region before and after head turning when MC was applied, but which was erroneously localized to a different area without MC. This study provides the first clinical evidence for utility of MC in magnetoencephalography for localizing focal seizures.

Introduction

Magnetoencephalography (MEG) is a noninvasive technique most commonly used to record epileptic spikes and to determine their location from magnetic fields picked up extracranially (Salayev et al., 2006). Source localization based on magnetic fields has better spatial resolution than that based on electroencephalography (EEG), because the transmission of magnetic fields from the intracranial sources to the extracranial sensors is not affected by the conductivity of the intervening tissue layers (i.e. scalp, fat tissue and cerebrospinal fluid; Barkley and Baumgartner, 2003).

Although they occur relatively rarely during MEG recordings, MEG investigation of seizures may better reveal the seizure onset zone than EEG. One of the biggest concerns during such recordings is movement-related artifact that frequently occurs at seizure onset; these artifacts can significantly decrease the quality of MEG recording (Yoshinaga et al., 2004). Because of the paucity of ictal MEG recordings, and the technical difficulty encountered, there have

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been relatively few previous investigations reporting ictal MEG findings (Shiraishi et al., 2001; Eliashiv et al., 2002; Yoshinaga et al., 2004).

Recently, an algorithm for movement compensation (MC) that uses continuous head position monitoring (Medvedovsky et al., 2007) has been proposed. Coupled with a temporally extended signal space separation (MC—tSSS) method, it is especially useful in suppression of artifacts originating close to the sensors. Medvedovsky et al. demonstrated its utility for somatosensory evoked responses by deliberately changing head position in healthy subjects. Their report suggested that the algorithm might be useful in patients with epilepsy to evaluate the exact focus of seizures despite patient movement. When contemplating the direct application of this algorithm during seizure localization, there are several concerns: since Medvedovsky's study was based on evoked responses, the data are averaged and can be obtained repeatedly under controlled circumstances, obviously not the case in the setting of epileptic seizures. In addition, this algorithm has not been validated in a clinical environment for seizure localization. Here we report a case in which we were able to perform MEG single equivalent dipole analysis to localize seizure onset zone, due to successful artifact removal and movement compensation at the initial phase of a seizure.

Case presentation

A 16 year-old boy was sent to the MEG laboratory after multiday video-EEG monitoring failed to record any seizures or interictal spikes. His epilepsy began 16 h after birth, following a diffuse perinatal ischemic event. From the age of 3, his seizures evolved into episodes of unresponsiveness associated with staring. From 6 to 9 years old he was maintained seizure-free on phenytoin, and thereafter was seizure-free on no antiepileptic drugs (AEDs), until age 14 when he had a generalized tonic clonic seizure out of sleep. He was restarted on phenytoin and rendered seizure-free. Recent repeated scalp EEGs were normal, and his MRI showed chronic encephalomalacia changes in both frontal lobes, likely due to ischemia at birth.

MEG and EEG signals were recorded simultaneously for 40 min, including both awake and sleep conditions, at a sampling rate of 1000 Hz and acquisition-band-pass filtered between 0.5 and 70 Hz. Technical details were described elsewhere (Salayev et al., 2006). Simultaneous video with frame-by-frame synchronization to the MEG/EEG data was also collected in order to monitor clinical changes. The head position monitoring capability, provided by the MEG manufacturer, derives from low-amplitude continuous sinusoidal currents (at 293, 307, 314, 321, and 328 Hz) that are injected into four HPI coils which are firmly attached to the subject's head, and that have exact positions determined prior to MEG recording. The position and orientation of the coils — and therefore the head — with respect to the sensor array was computed 100 times per second, based on a 200 ms window, slid in 10 ms steps. For the continuous localization procedure, each coil was approximated as a magnetic dipole with 6 parameters (position and dipole moment vectors in the sensor coordinate system), with its position determined using a least-squares fit (Wehner et al., 2008).

The records were processed from the raw data off-line in two batches: (1) with tSSS processing without MC, and (2) with tSSS and MC processing. For review, the data were further band-pass filtered from 6 to 50 Hz in order to emphasize the spikey component. To see the effect of MC, spike dipole analysis was performed over exactly the same time period from the two files described above. For equivalent current dipole analysis, 56 locations (112 gradiometer sensors) covering the area of maximal signal, namely the left to mid fronto-centro-temporal region, were selected. Although no interictal spikes were recorded, the patient had one seizure during which the electrical/magnetic manifestation started 41 s before clinical onset. The ictal activity was manifest on the EEG as a run of spikes originating from mid to left fronto-central area, and with MEG dipoles localized to the left mid frontal gyrus (Fig. 1). In these early spikes, dipole locations from both files (i.e. processed with tSSS algorithm with/without MC) were estimated on the same left mid frontal gyrus (Fig. 1b). The clinical seizure started with smooth head turning to the right at a rate of about 2° per second, consistent with a seizure onset from the left mid frontal gyrus (Salanova et al., 1995). During the onset of the clinical seizure, MEG signals were not distorted (Fig. 2a) until generalization occurred, approximately 6 s after head turning began. Spike dipoles from the file processed with MC—tSSS were consistently estimated, at a sublobar level (according to the classification of Knowlton et al., 2006) on the left mid frontal gyrus (Fig. 2b top), concordant to the location of the spike dipoles from before clinical seizure onset. However, dipoles from the file without MC—tSSS were shifted onto the left superior frontal gyrus, a completely different and incorrect sublobar area (Fig. 2b bottom).

The head position monitoring signal revealed that the patient's head rotated approximately 14.2° to the right from his baseline position, as shown in Fig. 2c. Fig. 2b shows the dipole analysis after this rotation, at the time outlined by the box in Fig. 2a. Based on the radius of the patient's head of 91.3 cm, we calculated the shift along an arc of approximately, 2.3 cm. The change in position, along with the statistical parameters with/without MC of dipole estimation (such as goodness of fit, confidence volume and dipole moment) are shown in Table 1. Despite the dramatic decreased movement of the seizure focus within the head when corrected by MC, no significant differences in the dipole quality statistics were observed. Since the patient's seizures were rare and relatively well controlled with AEDs, medical treatment was continued instead of recommending surgery. Although this course meant that there was no definitive seizure onset zone (SOZ) localization by resective surgery, the stability of the SOZ is what was employed in this study to validate MC.

Discussion

This study provides the first clinical evidence for the utility of movement compensation in MEG for detection of the seizure focus by showing the concordant dipole location before and after substantial head turning that occurred within a clinical seizure. The most critical time during