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Multi-component intrinsic brain activities as a safe alternative to cortical stimulation for sensori-motor mapping in neurosurgery

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HIGHLIGHTS

- Wide-spectrum, intrinsic brain activities allow for non-stimulus functional brain mapping.
- Multi-component mapping yielded significantly higher accuracy than single-component mapping.
- Multi-component ECoG-based mapping may be a feasible alternative to cortical stimulation mapping.

ABSTRACT

Objective: To assess the feasibility of multi-component electrocorticography (ECoG)-based mapping using "wide-spectrum, intrinsic-brain activities" for identifying the primary sensori-motor area (S1-M1).
Methods: We evaluated 14 epilepsy patients with 1514 subdural electrodes implantation covering the perirolandic cortices at Kyoto University Hospital between 2011 and 2016. We performed multi-component, ECoG-based mapping (band-pass filter, 0.016–300/600 Hz) involving combined analyses of the single components: movement-related cortical potential (<0.5–1 Hz), event-related synchronization (76–200 Hz), and event-related de-synchronization (8–24 Hz) to identify the S1-M1. The feasibility of multi-component mapping was assessed through comparisons with single-component mapping and electrical cortical stimulation (ECS).
Results: Among 54 functional areas evaluation, ECoG-based maps showed significantly higher rate of localization concordances with ECS maps when the three single-component maps were consistent than when those were inconsistent with each other ($p < 0.001$ in motor, and $p = 0.02$ in sensory mappings). Multi-component mapping revealed high sensitivity (89–90%) and specificity (94–97%) as compared with ECS.
Conclusions: Wide-spectrum, multi-component ECoG-based mapping is feasible, having high sensitivity/specificity relative to ECS.
Significance: This safe (non-stimulus) mapping strategy, alternative to ECS, would allow clinicians to rule in/out the possibility of brain function prior to resection surgery.

1. Introduction

Functional brain mapping for the precise identification of the primary sensori-motor area (S1-M1) prior to epilepsy surgery is

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key for reducing the risk of postoperative functional deficits. This particular functional brain map was traditionally introduced by several methodologies, such as functional magnetic resonance imaging (fMRI) (Chakraborty and McEvoy, 2008), somatosensory evoked potentials (Dinner et al., 1986), and electrical cortical stimulation (ECS) (Ojemann et al., 1989; Awad et al., 1991; Branco et al., 2003). Because the resection margins were determined on the basis of the seizure foci and their adjacent eloquent cortices, cortical mapping should be made based on at least the spatial resolution of electrode placement in epilepsy surgery. ECS mapping by subdural electrodes is ideal in this regard and has the evidence that regions with reproducible positive responses to ECS are defined as functionally-positive areas (usually limited to 1–2 cm^2 in area and separated by non-functional sites) (Ebeling and Reulen, 1995). Thus, clinically ECS is regarded as the gold standard for preoperative functional mapping in patients with refractory focal epilepsy and with brain lesions. However, ECS carries the risk of stimulation-induced seizures, and after-discharges that impair the definition of functionally important zones, including the S1-M1 (Blume et al., 2004). These limitations are no longer present in functional mapping based on intrinsic-brain activities using electrocorticography (ECoG), which also provides an electrode-based spatial resolution.

ECoG components assessing different spectral activities range from very slow potentials (<0.5–1 Hz) such as movement-related cortical potentials (MRCP) (Neshige et al., 1988b; Ikeda et al., 1992) , to fast or high frequency activity such as event-related synchronization (ERS), and event-related de-synchronization (ERD) (Pfurtscheller, 2000; Pfurtscheller et al., 2003). Mapping based on each of these wide-spectrum components individually has revealed that intrinsic-brain activity plays supplementary roles in ECS mapping (Ikeda et al., 1992; Ikeda and Shibasaki, 1992; Leuthardt et al., 2007; Miller et al., 2007). It is essential to comprehensively reflect the various spectrum of frequencies of intrinsic-brain activities associated with neural processing; however, the accuracy and feasibility of mapping based on the combination of these three components (MRCP/ERS/ERD) has not been examined.

Brain mapping utilizing ECoG components is both sensitive and specific. MRCP represents three pre-movement, mainly slow components (early Bereitschaftspotential: BP, late BP, and motor potential: MP) related to M1, followed by a post-movement potential (reafferent potential: RAP) related to S1 (Kornhuber and Deecke, 1965; Shibasaki et al., 1980; Shibasaki and Hallett, 2006). Pre-movement slow components such as the BP reflects excitatory postsynaptic potentials in the apical dendrites of pyramidal neurons of the motor cortices before voluntary movement onset (Sasaki et al., 1981) and is reportedly useful for mapping functional zones before resection in epilepsy surgery (Ikeda and Shibasaki, 1992; Yazawa et al., 1997; Ikeda et al., 2002).

In comparison with the early BP, the late BP and MP revealed strongly localized characteristics at M1, indicating a spatio-specific contribution to voluntary, movement preparation and execution (Kornhuber and Deecke, 1965; Shibasaki et al., 1980; Shibasaki and Hallett, 2006). ERD represents the localized amplitude decrease of ECoG frequency bands (alpha and beta bands) in S1-M1 prior to self-movements, and can be produced by increased excitability in the thalamocortical circuit. By contrast, gamma ERS represents an increase in higher frequency bands and is indicative of a deactivated local cortical area with decreased excitability (Pfurtscheller et al., 2003). While ERD helps us to define functional localization with a larger extent of distribution, the ERS (>80 Hz) often has a more focused spatiotemporal pattern that may be associated with local neuronal processing (Crone et al., 1998; Ohara et al., 2000a; Manning et al., 2009; Miller et al., 2009).

Given the specificity and sensitivity of these individual ECoG components (BPs, MP, and RAP in MRCP, alpha to beta bands of ERD, and high-gamma band of ERS), we hypothesized that mapping based on a combination of these components, “wide-spectrum, ECoG-based mapping”, would evaluate cortical function in even greater detail than that by using each component alone. Higher levels of specificity and sensitivity will contribute to more reliable clinical decisions about the resection margins (specifically, to “rule in or out” a given area of interest according to its suspected function). Furthermore, it is challenging to investigate the concordance between ECoG- and ECS-based maps according to consistencies among maps based on MRCP/ERS/ERD. To this end, the present study aimed to compare wide-spectrum, multi-component, ECoG-based mapping (“multi-component mapping”) with single-component ECoG-based mapping (“single-component mapping”) and ECS. There have been previous reports where intrinsic-brain activities could delineate the motor area, but (1) they employed only a single-component (fast- or low-frequency activities) and (2) the precise both sensitivity and specificity were not provided as precise as done in our study (Su and Ojemann, 2013). This is the first clinical data analysis where wide-spectrum, intrinsic activities were employed and compared to ECS with more than 1000 electrodes.

2. Methods

2.1. Patients

We recruited patients with focal epilepsy who underwent subdural electrode implantation for presurgical evaluation at Kyoto University Hospital between January 2010 and July 2016. Inclusion criteria were (i) implantation of subdural electrodes covering the perirolandic cortices and (ii) completion of ECoG-based mapping for at least three motor tasks. Fourteen patients (five females and nine males; mean age of 34.2 years, ranging 16–61 years) were enrolled in this study (Table 1). Subdural electrodes were implanted in the frontal and parietal lobes of seven patients, frontal, parietal, and temporal lobes of six patients, and the frontal, parietal, and occipital lobes of one patient (in five of 14 patients, electrodes were implanted ipsilateral to the patient’s hand-dominance). A total of 53 motor task sessions (three to five tasks

Table 1
Clinical characteristics of patients and motor tasks.

	Patients (n = 14)
Age, years (mean ± SD)	34.2 ± 12.0
Epilepsy onset age, years (mean ± SD)	15.1 ± 8.0
Gender, male, n [%]	9 [64]
Epilepsy classification, n [%]	
Frontal lobe epilepsy	8 [57]
Parietal lobe epilepsy	3 [21]
Temporal lobe epilepsy	3 [21]
Electrode locations, n [%]	
Frontal and parietal	7 [50]
Frontal, parietal, and temporal	6 [43]
Frontal, parietal, and occipital	1 [7]
Subdural electrodes, n (mean ± SD)	
Total implanted electrodes	108.1 ± 30.0
Electrodes corresponding to motor area[a]	15.5 ± 6.0
Electrodes corresponding to sensory area[b]	11.3 ± 4.6
Motor tasks, n [%]	
Face	12 [86]
Proximal upper extremity	12 [86]
Distal upper extremity	14 [100]
Proximal lower extremity	2 [14]
Distal lower extremity	13 [93]

[a] Electrode located on the pre-central gyrus, precentral sulcus, or central sulcus.
[b] Electrode located on the post-central gyrus, post-central sulcus, or central sulcus. SD = standard deviation.