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Comparison of high gamma electrocorticography and fMRI with electrocortical stimulation for localization of somatosensory and language cortex

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HIGHLIGHTS

- Stimulation of the thumb and auditory semantic decision task were used in intracranial ECoG and fMRI.
- The combination of hgECoG and fMRI increased the rate of patients with presurgical mapping results.
- The contribution of parallel localization tools can make presurgical mapping more flexible.

ABSTRACT

Objective: We investigated the contribution of electrocortical stimulation (ECS), induced high gamma electrocorticography (hgECoG) and functional magnetic resonance imaging (fMRI) for the localization of somatosensory and language cortex.
Methods: 23 Epileptic patients with subdural electrodes underwent a protocol of somatosensory stimulation and/or an auditory semantic decision task. 14 Patients did the same protocol with fMRI prior to implantation.
Results: ECS resulted in the identification of thumb somatosensory cortex in 12/16 patients. Taking ECS as a gold standard, hgECoG and fMRI identified 53.6/33% of true positive and 4/12% of false positive contacts, respectively. The hgECoG false positive sites were all found in the hand area of the post-central gyrus. ECS localized language-related sites in 7/12 patients with hgECoG and fMRI showing 50/64% of true positive and 8/23% of false positive contacts, respectively. All but one of the hgECoG/fMRI false positive contacts were located in plausible language areas. Four patients showed post-surgical impairments: the resection included the sites positively indicated by ECS, hgECoG and fMRI in 3 patients and a positive hgECoG site in one patient.
Conclusions: HgECoG and fMRI provide additional localization information in patients who cannot sufficiently collaborate during ECS.
Significance: HgECoG and fMRI make the cortical mapping procedure more flexible not only by identifying priority cortical sites for ECS or when ECS is not feasible, but also when ECS does not provide any result.

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1. Introduction

In patients with pharmacoresistant epilepsy, pre-surgical planning requires precise localization of both the epileptic zone and the eloquent cortical areas. In some patients, electrode implantation is necessary to achieve this goal. Electrocortical stimulation (ECS) of the individual contacts has been established as the gold-standard for individual cortical localization of critical brain regions. This includes not only those serving sensorimotor functions (Penfield and Boldrey, 1937; Seeck et al., 2010) but also those involved in cognitive functions such as language (Penfield and Roberts, 1959; Ojemann et al., 1989). However, ECS is not suitable for all patients given that it necessitates many hours of testing. It has also been shown to be less sensitive in pediatric patients (Ojemann et al., 2003; Schevon et al., 2007; de Ribaupierre et al., 2012; Wray et al., 2012). To overcome the limitations of ECS, non-invasive and invasive functional mapping approaches based mainly on functional magnetic resonance imaging (fMRI) and subdural electrocorticographic recordings (ECoG) have been developed (Crone et al., 2006; Swanson et al., 2007).

fMRI mapping is nowadays part of the presurgical evaluation in most centres and its validation with respect to ECS has shown fairly robust results, both for sensory-motor and language functions (FitzGerald et al., 1997; Carpentier et al., 2001; Rutten et al., 2002; Towle et al., 2003; Korvenoja et al., 2006; Kunii et al., 2011; Genetti et al., 2013). The spatio-anatomical organization of the somatosensory cortex is well confined to the central region and less prone to individual changes than the organization of complex functions such as language processing, which may imply several areas of associative cortex (Price, 2010). Especially in awake craniotomies for surgery of pathologies in the dominant hemisphere, fMRI is frequently used as a complementary tool for surgical planning, whilst concrete surgical decisions are based on ECS (FitzGerald et al., 1997; Carpentier et al., 2001; Rutten et al., 2002).

Presurgical mapping based on ECoG has led to encouraging results in a number of studies (Crone et al., 2006). In contrast to ECS, ECoG does not have the drawback of afterdischarges triggered by the stimulation, which may lead to ambiguous results, and is much less time-consuming since data can be obtained from all electrode sites at once. The central sulcus can be identified by ECoG power increase in the higher gamma frequencies (>100 Hz) starting around 20 ms after median nerve electrical stimulation (Fukuda et al., 2008, 2010). Several studies have also evaluated the yield of high gamma ECoG (hgECoG) for mapping of language cortex (Crone et al., 2001a,b; Sinai et al., 2005; Brown et al., 2008; Towle et al., 2008; Ruescher et al., 2013). Overall, it appears that hgECoG mapping during a naming task confirmed language-related ECS sites with relatively low sensitivity but high specificity in patients undergoing ECS (Sinai et al., 2005) – even in the pediatric group (Brown et al., 2008; Cho-Hisamoto et al., 2012).

Complementary language mapping by hgECoG is of particular interest because ECS has shown false positive or negative results. ECS language mapping based only on visual naming has not always been able to prevent language deficits (Davies et al., 2005; Hamberger et al., 2005). In addition, there are case reports on resection of areas that evoked speech arrest by ECS without any post-operative language deficits (Seeck et al., 2006). Furthermore, the resection of certain sites that had been labeled as 'negative' by ECS but 'positive' by hgECoG, resulted in post-operative language deficits suggesting a potential higher sensitivity of hgECoG (Kojima et al., 2012; Cervenka et al., 2013).

In the present study, we sought to compare on an individual level the contribution of (pre-implantation) fMRI and hgECoG to localize primary sensory and language cortex, using ECS for comparison in a consecutive series of twenty-three epilepsy surgical candidates.

2. Methods

2.1. Patients

Twenty-three consecutive patients (8 females, 15 males; aged 4–48 years; mean ± SD 24 ± 13 years) who underwent surgical implantation of subdural grid electrodes were included (Table 1). All patients had medically intractable epilepsy of either temporal

Table 1
Patient data. F: female; M: male; L: left; R: right; S: somatosensory; L: language; FLI: frontal lateralization index; TPLI: temporoparietal lateralization index. The number of subdural electrodes is indicated in the grid location column.

	Age/sex	Handedness	fMRI FLI	fMRI TPLI	Lesion	Grid location	Condition
1	19/M	R	–	–	Hippocampus sclerosis, dysplasia	4×5 Left temporo-parietal	S
2	13/F	R	–	–	Tuberous sclerosis	6×8 Left fronto-temporo-parietal	S
3	11/M	L	NA	R (−38)	Dysplasia, gliosis	8×8 Left fronto-temporo-parietal	S/L
4	47/F	R	–	–	Negative	8×8 Right fronto-temporo-parietal	S
5	26/F	R	L (66)	L (100)	Negative	4×8 Left temporo-parietal	L
6	17/M	R	–	–	Hippocampus sclerosis, ischemic lesion	8×8 Right fronto-temporo-parietal	S
7	4/F	R	–	–	Tuberous sclerosis, dysplasia	8×8 Right fronto-temporo-parietal	S
8	36/M	R	–	–	Hippocampus sclerosis, ischemic lesions	4×8 Right fronto-parietal	S
9	26/F	R	L (80)	L (87)	Gliosis	8×8 Left temporo-parieto-occipital	S/L
10	35/M	R	–	–	Negative	6×8 Left temporo-parietal	S
11	12/F	R	–	–	Dysplasia	4×8 Left fronto-parietal	S
12	12/M	R	–	–	Negative	4×8 Left fronto-temporo-parietal	L
13	11/M	R	–	–	Dysplasia	8×8 Right fronto-temporo-parietal	S
14	41/M	R	L (100)	L (100)	Post-traumatic lesion	2×8/2×4/2×4 Left frontal, 4×8 left temporo-parietal	L
15	13/M	R	–	–	Tuberous sclerosis	8×8 Left fronto-temporo-parietal	S/L
16	27/M	R	L (68)	L (100)	Negative	4×6 Left temporo-parietal	L
17	11/F	R	L (100)	L (100)	Negative	8×8 Left fronto-temporo-parietal	S/L
18	9/M	R	–	–	Post-infection lesion	5×8 Left temporo-parietal	S/L
19	39/F	R	–	–	Hippocampal sclerosis, periventricular nodular heterotopia	5×8 Left fronto-parietal	S
20	35/M	R	–	–	Negative	8×8 Left temporo-parietal	S/L
21	22/M	R	–	–	Gliosis	7×8 Left temporo-parieto-occipital	S
22	18/M	L	R (−100)	R (−53)	Negative	4×8 Left fronto-parietal, 4×8 left temporo-parietal	L
23	48/M	Amb	R (−56)	R (−100)	Post cavernoma resection	1×8 Left frontal, 1×4/1×6/1×8 left temporal	L