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Language mapping using electrocorticography versus stereoelectroencephalography: A case series

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Abstract

Direct electrical stimulation (DES) is sometimes used in epilepsy surgery to identify areas that may result in language deficits if resected. Extraoperative language mapping is usually performed using electrocorticography (ECOG) – grids and strip electrodes; however, given the better safety profile of stereoelectroencephalogaphy (SEEG), it would be desirable to determine if mapping using SEEG is also effective. We report a case series of fifteen patients that underwent language mapping with either ECOG (5), SEEG (9), or both (1). Six patients in the SEEG group underwent resection or ablation with only mapping via SEEG. No patients in the SEEG group that underwent resective or ablative surgery experienced persistent language deficits. These results suggest that language mapping with SEEG may be considered as a clinically useful alternative to language mapping with ECOG.

Keywords

Language mapping; Direct electrical stimulation; Electrocorticography; Stereoelectroencephalogaphy; Case series

1. Introduction

Direct electrical stimulation (DES) is utilized during epilepsy surgery to map eloquent cortex in a process called language mapping; however, multiple techniques exist for language mapping, and practices vary considerably between institutions. Intraoperative

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Ethical statement
We confirm that we have read the Journal's position on issue involved in ethical publication and affirm that this report is consistent with those guidelines.

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language mapping has been demonstrated to limit persistent postoperative aphasia to a very low rate in the setting of glioma surgery [1], but it can be difficult and time consuming to perform. Extraoperative language mapping is also performed by applying current to intracranially implanted electrodes, either via electrocorticography (ECOG) – "grids and strips" – or via stereoelectroencephalography (SEEG). Given the greater or at least more contiguous cortical coverage present in most ECOG studies, the perception has been that ECOG offers superior performance than SEEG studies for language mapping. However, given the greater tolerability and safety of SEEG studies [2], it would be worthwhile to determine the effectiveness of language mapping utilizing SEEG.

Extensive case series of the performance of language mapping have been published for ECOG [3], but only single cases [4,5] or case series [6,7] have described the use of language mapping in the setting of SEEG. While these confirm that language deficits can be elicited by DES using SEEG, there exist no comparisons of ECOG and SEEG to determine the relative safety and yield of these modalities. Furthermore, one study that compared language mapping with SEEG to intraoperative DES showed discordance between the modalities [4]. Finally, no data exist to guide the method and location of SEEG electrode placement to maximize the yield during language mapping. In this case series, we examine 6 ECOG and 10 SEEG studies using DES for language mapping. Our hypothesis was that extraoperative language mapping using SEEG would be safe and better tolerated and would provide sufficient information for safe resection.

2. Methods

2.1. Consent and subjects

Consent was obtained from 15 consecutive adults (5 ECOG studies, 9 SEEG studies, and one who had SEEG followed by ECOG), who had language mapping during an intracranial study for the surgical management of drug-resistant epilepsy. The study was conducted according to the principles of the Declaration of Helsinki, and the consent documentation and procedure were approved by the Mount Sinai Hospital Institutional Review Board (IRB).

2.2. Language mapping procedure

Language testing was performed at the patient's bedside with an Ojemann cortical stimulator (Integra Neurosciences, Plainsboro, NJ). Pulse width was set at 0.5 ms, and the pulse frequency was set at 50 Hz. The current was initially set at 2 mA and gradually increased to a maximum of 10 mA (measured peak to baseline). During testing, video-EEG recording was continued using a Natus XLTEK128 or Quantum system (Natus Incorporated, Pleasanton, CA). Language testing was performed by the epileptologists or neuropsychologists for tasks including verbal fluency (counting, naming the months of the year, etc.), visual naming, auditory naming, and repetition. Speech arrest or paraphasic errors performed during stimulation were counted as "hits" if they could be reproduced by repeat stimulation. Correct performance of these tasks during stimulation labeled the electrode pair as "clear" suggesting that the tissue could be resected without resultant language deficit. After-discharges and seizures were noted during the language mapping. If a language disturbance was seen in the setting of a seizure, it was not considered a language "hit".

2.3. Electrode localization

Localization of electrodes was determined using preoperative MRIs and confirmed using postoperative computed tomographies (CTs). Coregistration of MRI and CT was performed using iELVIS [8], and the location of each electrode was selected on the postoperative CT. A parcellated image of the patien's cortical surface was generated using FreeSurfer from the T1 series of the preoperative MRI [9,10]. Cortical parcellation by FreeSurfer used the DKT40 Atlas [11]. The distance from the nearest gray matter structure was determined by starting at the voxel where the electrode was located. Then a spiral search pattern was used to find the closest gray matter voxel. The distance between the centers of these two voxels was counted as the electrode depth.

3. Results

Ten SEEG cases and 6 ECOG cases were mapped for language function. The patient demographics and clinical characteristics are listed in Table 1. The ECOG group had 4 men, 2 women; 4 right-handers, 2 left-handers; and half bilingual speakers. The SEEG group had 4 men, 6 women; 8 right-handers, 1 left-hander, and 1 ambidextrous; and 30% bilingual speakers. Thus, the ECOG group included more men and included more individuals with characteristics suggesting atypical language dominance such as left-handedness or bilingualism. That being the case, in the 10 individuals who underwent intracranial amobarbital procedures, only one (subject 4 in the ECOG group) had a right-sided dominant hemisphere.

Of the 1475 electrodes from the cases, 986 were tested – including 424 SEEG electrodes and 562 ECOG electrodes. The untested electrodes were not thought to be near areas of potential language function. Of the SEEG electrodes, 34 (12.8%) had language hits on the left and 0 had language hits on the right. Of the ECOG electrodes, 98 (39.4%) had language hits on the left and 0 had language hits on the right. The locations that triggered language hits in the left hemisphere of the SEEG and ECOG studies are depicted in Fig. 1. With respect to location in the brain, the maximum depth of an electrode that triggered language hits was 7.35 mm in comparison to a maximum of 16.3 mm for electrodes that did not trigger language hits.

With respect to outcomes, 5 of the patients from the ECOG group underwent resective surgery. Of these, 3 were seizure-free with a follow-up of 2 years or greater. One patient (subject 4) in the ECOG group was noted to have persistent language deficits after resection. Seven of the patients from the SEEG only group underwent resective (n = 4) or ablative (n = 3) surgeries. Five of these 7 patients were seizure-free with a follow-up of at least 1 year. One patient (subject 6) underwent ECOG after her SEEG to better delineate her seizure focus, and language mapping was repeated. This patient underwent left lateral temporal resection. She was free of language deficits but continued to have breakthrough seizures in the 6 months after surgery. The results of those two studies were concordant and are depicted in Supplementary Fig. 1. One patient (subject 15) underwent intraoperative language mapping in addition to mapping with the SEEG, and the results were concordant.

The remaining 6 patients underwent resective or ablative surgery after only mapping using SEEG. No patients from the SEEG group were noted to have language deficits after surgery as determined by their treating epileptologist and/or neuropsychologist.

Of the SEEG electrodes, 99 (25.6%) were also noted to trigger seizures on stimulation, and an additional 50 (13%) were noted to trigger afterdischarges. Of the 99 that triggered seizures, 37 (37.3%) were concordant with the patien’s seizure onset zone (SOZ) based on the intracranial EEG. Of the ECOG electrodes, 14 (3.4%) were also noted to cause seizures on stimulation, and an additional 62 (15.1%) were noted to trigger afterdischarges. Of the 14 that triggered seizures, none of them were concordant with the patien’s SOZ. There were no cases in the ECOG or SEEG group where seizures or afterdischarges prevented the completion of language mapping.

No significant adverse events occurred during any of the mapping studies. However, stimulation at 40 (9.7%) of the electrodes during the ECOG studies caused patient discomfort – either at the electrode site or as an unpleasant paresthesia. By contrast, only 24 (6.2%) of the electrodes during the SEEG studies caused discomfort.

4. Discussion

These results are the first case series to examine the performance, safety, and tolerability of ECOG and SEEG for extraoperative language mapping. A previous published case had compared language mapping with SEEG to intraoperative mapping and found them to be discordant [4], but the language deficits produced by stimulation during SEEG were not reproducible as in this series. Another recent case showed that language hits can be obtained by DES from SEEG but did not compare with other modalities [5]. A case series examined DES via SEEG of the parietal lobe, but no language deficits were reported [6]. Finally, an extensive case series reported the proportions of locations that had language deficits after DES via SEEG, but it did not report outcomes, and it did not report the relative location of the language hits including the depth of the electrodes [7].

We report 6 patients who underwent resective or ablative surgery using only DES via SEEG for language mapping, 4 of which were in the dominant hemisphere. None of these patients had language deficits after surgery. This suggests that mapping with SEEG may be just as effective as language mapping with ECOG. In 2 other patients who underwent SEEG language mapping, intraoperative language mapping or comparison with ECOG mapping produced concordant results. Furthermore, this study emphasizes the necessity of reproducible deficits in the setting of language mapping, as a case series where deficits were not reproducible produced discordant results between SEEG and inoperative mapping [4].

With respect to the technical aspects of the procedure, the locations from these mapped electrodes suggest that SEEG electrodes to be used for mapping should be positioned no more than 7 mm from the cortical surface.

In addition, we confirm that eliciting seizures by DES is highly concordant with the patien’s SOZ in the setting of SEEG. This did not appear to be the case during mapping with ECOG in our study. This result conforms to prior work that has shown the concordance between the

SOZ and seizures elicited during SEEG [7,12]. Note that the concordance between seizures and afterdischarges elicted by DES and the SOZ specifically refers to bipolar stimulation. Comparison of bipolar and monopolar stimulation showed that monopolar stimulation is less likely to trigger afterdischarges [13]. Stimulation during this study was exclusively bipolar. The SEEG language mapping procedure also appears to be slightly better tolerated than the ECOG language mapping procedure with fewer adverse events in the SEEG group than in the ECOG group.

This study, however, is not without limitations and should be interpreted with caution. First, the absolute yield of language mapping for the two procedures cannot be calculated because the patients were not randomized to the type of implant procedure and did not all undergo both procedures; also, electrode coverage differed between patients although all were deemed to require language mapping. Second, the procedure used was dictated by clinical need, and patients that were perceived to require more in-depth language mapping were more likely to undergo ECOG.

5. Conclusion

Studies have shown that the difference in complication risk between ECOG and SEEG is significant. The neurologic infection risk for ECOG is 2.3% and the hemorrhage risk is 4% [14] compared with 0.8% infection risk and 1% hemorrhage risk for SEEG [2]. Yet, the perception exists in the epilepsy community that ECOG may be required in cases of language mapping. We present a case series that shows that language mapping with SEEG appears to be safe, slightly better tolerated, and provides similar information to mapping with ECOG, but future studies are required to confirm these findings in a large matched population through a randomized controlled trial or a comparative effectiveness study.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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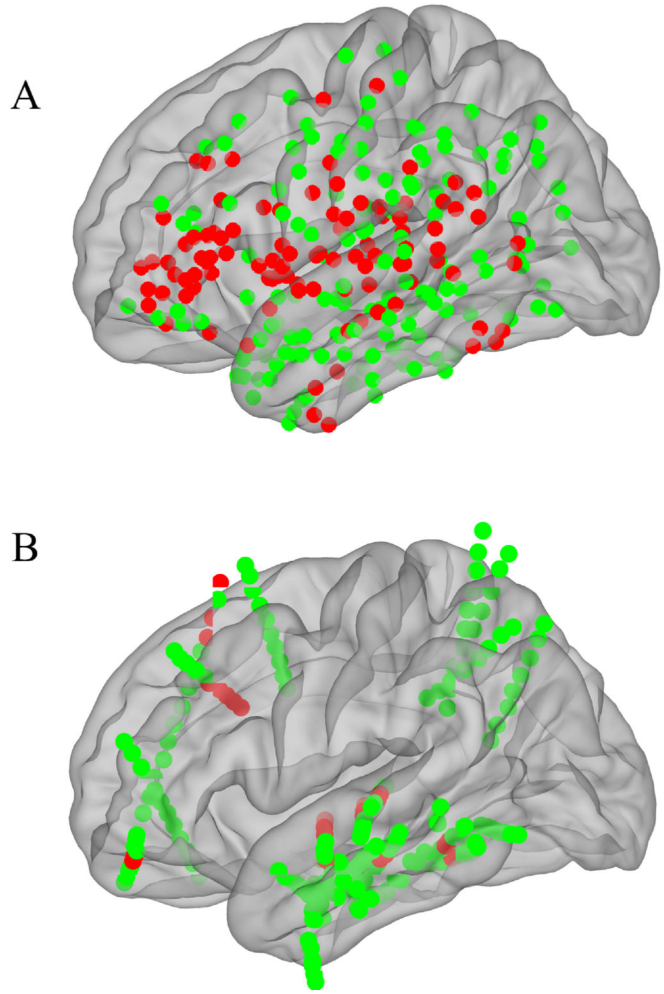

Fig. 1.

Locations of language hits for SEEG and grid and strip studies. (A) The compiled results from language mapping from the 6 grid and strip studies. The locations of any language deficit produced by stimulation are indicated by red dots whereas the locations with no deficit are indicated by green dots. (B) The compiled results from language mapping from the 10 SEEG studies. The locations of any language deficit produced by stimulation are indicated by red dots whereas the locations with no deficit are indicated by green dots.

Table 1

Case	Age (at Implant)	Epilepsy Onset Age	Handed	Language	Cause?	Implant Side	Type	Wada L Lang	Wada R Lang	SOZ	Surgery?	Hits	Clear	Follow Up Duration	Outcome
1	44 F	41	R	Eng/Span	Nonlesional	L	G/S	17	0	L posterior temporal	Lost to Follow Up	40	68		
2	27 M	19	R	Eng	R subdural emypema	BL	G/S			R anterior frontal	R frontal disconnection	0	70	2.5 y	Engel I
3	51 M	21	R	Eng	Nonlesional	R	G/S	14	2	Broad R lateral temporal	R lateral temporal resection	0	92	2 y	Engel I
4	30 M	21	L	Eng	L temporal AVM and TBI	L	G/S	0	8	L basal temporal	L anterior temporal resection	37	98	2.5 y	Engel II
5	34 M	32	L	Eng/Kor	Resected L temporal meningioma	L	G/S	13	0	L anterior temporal	L anterior temporal resection	17	44	2 y	Engel I
6	47 F	44	R	Thai/Eng	Nonlesional	L L	G/S SEEG	19	1	L lateral temporal and Heschl's gyrus	L lateral temporal resection	4 4	92 38	< 6 m	Engel II
7	25 F	24	L	Span	L temporal heterotopia	L	SEEG	16	3	L hippocampus	L hippocampal laser ablation	8	16	1.5 y	Engel I
8	32 F	0.5	R	Eng	R sided MTS	R	SEEG	20	1	R hippocampus	R hippocampal laser ablation	0	34	2 y	Engel III
9	34 F	19	R	Span	L parietal cortical dysplasia	BL	SEEG			L parietal	L parietal resection	0	48	1.5 y	Engel I
10	43 M	3	R	Eng/Fre	Nonlesional	BL	SEEG	8	0	Bilateral mesial temporal	Bilateral mesial temporal RNS	0	32		
11	49 M	20	R	Span	Meningitis	BL	SEEG			Broad L frontal	L frontal resection	10	56	2 y	Engel I
12	36 F	22	R	Eng	L temporal AVM	L	SEEG	18	8	L lateral temporal	L lesionectomy	0	40	1 y	Engel I
13	26 F	15	R	Eng/Span	R temporal atrophy	BL	SEEG			No detected		4	36		
14	30 M	24	Amb	Eng	Nonlesional	R	SEEG	20	0	R hippocampus	R hippocampal laser ablation	0	42	6 m	Engel II
15	19 M	14	R	Eng	L temporal ganglioglioma	L	SEEG			L lateral temporal	L lesionectomy	8	48	1 y	Engel I

Demographic information for the included patients including handedness, predominant spoken language(s), cause of epilepsy, implant side, type of implant, the results of intracarotid amobarbital testing(Wada), seizure onset zone (SOZ), and outcome data. Abbreviations are as follows: R – right, L – left, Amb – ambidextrous, BL – bilateral,MTS – mesial temporal sclerosis, AVM – arteriovenous malformation, TBI – traumatic brain injury, G/S – grids and strips or ECOG, SEEG – stereoelectroencepholagraphy, RNS – responsive neurostimulation, Eng – English, Span – Spanish, Fre – French, Kor – Korean.