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Review

Proceedings of the Fifth International Workshop on Advances in Electrocorticography

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ABSTRACT

The Fifth International Workshop on Advances in Electrocorticography convened in San Diego, CA, on November 7–8, 2013. Advancements in methodology, implementation, and commercialization across both research and in the interval year since the last workshop were the focus of the gathering. Electrocorticography (ECoG) is now firmly established as a preferred signal source for advanced research in functional, cognitive, and neuroprosthetic domains. Published output in ECoG fields has increased tenfold in the past decade. These proceedings attempt to summarize the state of the art.

1. Introduction

A. Ritaccio

The Fifth International Workshop on Advances in Electrocorticography (ECoG) took place on November 7–8, 2013, in San Diego, California. Advances in ECoG research and applications demand at least a yearly reckoning to keep pace with pertinent developments. This workshop has provided a venue for such a review since our inaugural meeting in 2008. This fifth workshop manifested the promise of ECoG-based recording by elucidating the evolution of stable clinical and research applications in the clinical, behavioral, and experimental neurosciences. Once again, strong emphasis was given to the role and contribution of the patient with epilepsy as the window into human ECoG. Advances in methodology, implementation, and commercialization of passive functional mapping using ECoG were updated. Electrocorticography-driven neurobehavioral insights into frontal lobe functions, such as language prediction, were presented. A contemporary review of consensus and controversy in the recording and utility of pathologic high-frequency oscillations put a decade's worth of observations into a practical perspective. The inevitable and valuable incorporation of ECoG tools in multimodal functional localization was summarized. Transformative changes in design and manufacture of high-density customized ECoG electrode arrays were described to an audience of clinicians and

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researchers who were expectant of improved stability and spatial resolution.

Neurostimulation and neuromodulation of brain functions have caught the attention of the media and the general public. The number of centers engaged in human ECoG-based research has proliferated tenfold in the past decade, as has publication volume (Fig. 1). United States government funding projects directed at ECoG-based researchers regularly constitute headline news [1]. At the same time, criticisms of underrepresented limitations and exaggerated claims within many neuroscientific disciplines, including ECoG, have also proliferated [2]. The earnest goal of these workshops and their accompanying proceedings is to provide a lucid, content-rich summary of the field to date, free from hyperbole.

2. Clinical

2.1. Clinical primer

L.J. Hirsch

Intracranial electroencephalogram (EEG) recordings are indicated for the surgical treatment of drug-resistant epilepsy when other tests used to identify the seizure focus are discordant or inconclusive, when there is no magnetic resonance imaging (MRI) abnormality (except select medial temporal cases), when the seizure onset zone abuts eloquent cortex (including many lesional cases), and when there is dual pathology (e.g., hippocampal sclerosis plus a lesion). Although some cortical mapping and identification of the irritative ("spiking") zone can be done via brief intraoperative ECoG, implanted electrodes are usually required in order to identify the seizure onset zone. Complete removal of the seizure onset zone is associated with a greater chance of seizure freedom, even after accounting for lesion resection [3].

There is no good evidence that intraoperative ECoG can help guide neocortical resection during temporal lobectomy in patients with mesial temporal sclerosis; one study suggested that it may be beneficial in guiding the posterior extent of hippocampal resection[4]. Intraoperative ECoG may be adequate to guide resection in select cases with focal cortical dysplasia if continuous spiking is seen, as occurs in about two-thirds of cases [4]. There is no proven use for activation techniques, determination of afterdischarge thresholds, or elicitation of habitual auras/seizures in surgical planning, and there is some evidence that all of these can be misleading.

Complications of implanted intracranial electrodes occur in about 9% of patients and are mostly transient, with permanent deficits in <2% and rare mortality [5]. Risks are higher with greater numbers of implanted electrodes, larger subdural grids, and peri-Rolandic location.

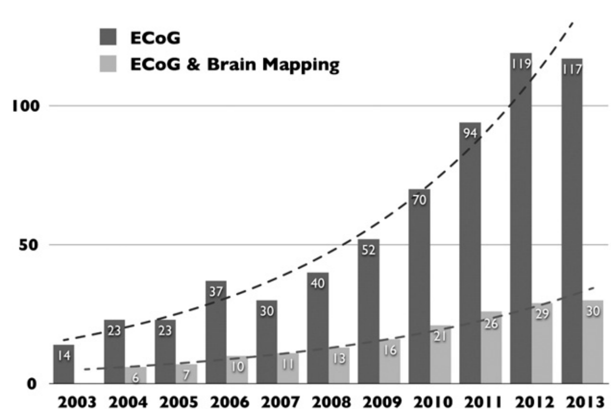

Fig. 1. Results of simple searches in PubMed for the terms "electrocorticography" and, separately, "electrocorticography and brain mapping." Results demonstrate a roughly tenfold increase in publication output and investigators.

The relative utility of subdural strips/grids, depth electrodes, stereo-EEG, and combinations of these is unknown. Recent gamma activation mapping techniques may speed up functional mapping, either intraoperatively or extraoperatively [6].

Mesial temporal-onset seizures on depth electrode recordings often begin with rhythmic spiking at <2 Hz or low-voltage 10- to 16-Hz activity. Unfortunately, spread to the hippocampus can look identical. Well-localized neocortical onsets often start with low-amplitude fast activity, typically >16 Hz, often >30 Hz. Many seizure onsets are difficult to localize to a discrete area and may involve wider epileptogenic networks, such as the limbic network, the occipital–lateral temporal network, and the parietal–frontal network [7].

High-frequency oscillations (HFOs; ripples: 80–250 Hz and fast ripples: 250–600 Hz) may help localize epileptogenic tissue [8,9]. Fast ripples seem to be more specific than ripples for seizure onset zones, especially when associated with interictal spikes [10]. High-frequency oscillations may be more localizing than traditional interictal epileptiform discharges [8,9]. Identification of HFOs requires high sampling rates (preferably ≥2000 Hz) and different filter and "paper speed" settings or automated detection. One small recent study suggested that single-pulse stimulation-induced fast ripples were suggestive of the epileptogenic zone [11].

Devices are now available for recording chronic ambulatory intracranial EEG. Such devices may allow seizure prediction and warning, which would improve patient safety and quality of life, as well as allow responsive treatment for seizure prevention (e.g., via stimulation—now FDA-approved, cooling, or medications). Electrocorticographic signal analysis is also useful for brain–computer interfaces.

Section 2.1 was presented at the Fourth International Workshop on Advances in Electrocorticography [12] and is reprinted with permission.

2.2. What is testing the brain telling us?

R.P. Lesser

Electrical stimulation was described as a treatment for disease at the time of the Roman Empire and as a treatment for epilepsy in 13th-century Persia. In the 18th century, Benjamin Franklin studied electrical stimulation using Leyden jars, and his studies included at least one person with a history of seizures. Wilder Penfield and collaborators used stimulation to define functional brain areas. Based on their work and that of others, standard homunculi are often drawn suggesting a set location for all body representations along the sensorimotor strip. Although sensorimotor locations, in general, conform to those shown on homunculi, there are frequent deviations from the set patterns implied by these illustrations. There can be multiple widespread sites for specific body parts; these sites can overlap, and their locations can vary over time.

One goal of seizure treatment is complete control of seizures or, at least, of seizures interfering with consciousness. Because seizures continue in one-quarter to one-third of patients despite anticonvulsant medication, epileptologists often consider performing epilepsy surgery. However, standard surgical techniques may not be applicable because of difficulties in localization or potential consequences of operating in eloquent cortex. This, in turn, has led to interest in additional treatments such as stimulation. The vagus nerve stimulator and, more recently, deep brain stimulation (in Europe) and the responsive neurostimulation device (in the USA) have been approved as treatments for intractable epilepsy. Although they are used in patients whose seizures cannot be controlled by standard surgical techniques, their efficacy has been modest. Why is that?

Penfield and Jasper, when defining functional areas, found that stimulation could produce afterdischarges (ADs). These are usually an unwanted side effect of brain stimulation, but since they are, in effect, induced electrical seizure patterns, studying them may help us to understand how seizures occur and how to terminate them. Just as there are variations in the functional responses to stimulation, there are