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Clinical Study

National trends and complication rates for invasive extraoperative electrocorticography in the USA

John D. Rolston *, David Ouyang, Dario J. Englot, Doris D. Wang, Edward F. Chang

Department of Neurological Surgery, University of California, San Francisco, 505 Parnassus Avenue, Box 0112, San Francisco, CA 94143-0112, USA

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ABSTRACT

Invasive electrocorticography (ECoG) is used in patients when it is difficult to localize epileptogenic foci for potential surgical resection. As MR neuroimaging has improved over the past decade, we hypothesized the utilization of ECoG diminishing over time. Using the USA Nationwide Inpatient Sample, we collected demographic and complication data on patients receiving ECoG over the years 1988–2008 and compared this to patients with medically refractory epilepsy during the same time period. A total of 695 cases using extraoperative ECoG were identified, corresponding to 3528 cases nationwide and accounting for 1.1% of patients with refractory epilepsy from 1988–2008. African Americans were less likely to receive ECoG than whites, as were patients with government insurance in comparison to those with private insurance. Large, urban, and academic hospitals were significantly more likely to perform ECoG than smaller, rural, and private practice institutions. The most frequent complication was cerebrospinal fluid leak (11.7%) and only one death was reported from the entire cohort, corresponding to an estimated six patients nationally. Invasive ECoG is a relatively safe procedure offered to a growing number of patients with refractory epilepsy each year. However, these data suggest the presence of demographic disparities in those patients receiving ECoG, possibly reflecting barriers due to race and socioeconomic status. Among patients with nonlocalized seizures, ECoG often represents their only hope for surgical treatment. We therefore must further examine the indications and efficacy of ECoG, and more work must be done to understand if and why ECoG is preferentially performed in select socioeconomic groups.

1. Introduction

Resective surgery is an effective treatment for medically refractory epilepsy [25]. Its efficacy however completely depends upon successful localization of the seizure onset zone (SOZ) [7]. Preoperative evaluation, consisting of MRI, scalp electroencephalography (EEG), and frequently positron emission tomography and magnetoencephalography, can help to define the SOZ, though sometimes provides discordant or non-localized findings.

In cases where the SOZ is unknown or unclear after multimodal preoperative evaluation, subdural grid, strip, and depth electrodes can be surgically placed in order to monitor the electrocorticogram (ECoG). These acutely or chronically implanted electrodes allow better acquisition of signals than scalp EEG, since the recorded data are not attenuated by the calvarium and have access to deep structures, like the amygdala and hippocampus. Implanting these electrodes chronically, sometimes for several weeks, allows the recording of multiple spontaneous or evoked seizures, providing what is felt to be more accurate information regarding the true onset zone for seizures. Typically, after successful localization of the SOZ, the electrodes are removed and the SOZ is resected.

Extraoperative ECoG has been in use since 1973, when first conducted by Paul H. Crandall [26]. Since then, many reports have documented its application [2,18,20,27]. However, it should be noted that most of the initial research conducted on extraoperative ECoG was conducted before the era of MRI. Moreover, there is no evidence from randomized-controlled trials that extraoperative ECoG is beneficial. Its use remains justified by expert opinion and the widespread feeling that, without ECoG, these patients would never receive potentially curative surgery.

Despite the widespread usage of ECoG, both intraoperatively and extraoperatively, its prevalence is unknown. The percentage of patients with refractory epilepsy undergoing ECoG has not been described to our knowledge. Furthermore, patient demographics have never been documented. The present article attempts to analyze the number of such operations being carried out across the USA, using the Nationwide Inpatient Sample (NIS), additionally

* Corresponding author. Tel.: +1 415 353 7500.
E-mail address: rolstonj@neurosurg.ucsf.edu (J.D. Rolston).

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focusing on characteristics of patients that predict whether or not they receive ECoG, as well as common complications for these patients.

2. Methods

Cases were identified using the NIS of the Healthcare Cost and Utilization Project. This sampling contains inpatient hospital stay data from over 1000 US hospitals in 44 states, representing a 20% stratified sample of US community hospitals.

The database was queried for admissions occurring during 1988–2008 with *International Classification of Diseases, Ninth Revision* (ICD-9) coding for both 02.93 (“Implantation, insertion, placement, or replacement of intracranial: brain pacemaker [neuropacemaker], depth electrodes, epidural pegs, electroencephalographic receiver, foramen ovale electrodes, intracranial electrostimulator, subdural grids, subdural strips”) and 345 (“Epilepsy and recurrent seizures”; all subheadings with the suffix “1” were included, to indicate refractory epilepsy). To differentiate intraoperative ECoG from extraoperative, chronic ECoG, we further narrowed our search. Only records with ICD-9 codes 01.22 (“removal of intracranial neurostimulator lead[s]”) and 01.23 (“reopening of craniotomy site”) were included. This prevented the counting of cases with acute intraoperative monitoring, where there was no second operation for removal of ECoG electrodes.

To further protect from miscoding, we specified that cases must also have ICD-9 codes 89.14 or 89.19 (EEG and video-EEG recording) and must exclude 86.94–98 (insertion or replacement of pulse generators), which would be used for vagus nerve stimulator placement or deep brain stimulator placement. This also helped guard against the rare patient receiving deep brain stimulator implants for Parkinson’s disease, who might also have epilepsy [11], and also guard against the rare patient receiving neurostimulation for epilepsy (which was in limited clinical trials during the time these data were collected).

Because the NIS data is a subsample of all hospital admissions, it is necessary to weight each record to extrapolate national trends. These weights are provided in the NIS database, and produced by stratifying hospitals based on geographic region, urban/rural location, teaching status, bed size, and ownership, then calculating the ratio of NIS-recorded discharges in that stratum to the total number of discharges in that stratum (obtained from American Hospital Association data). Unless otherwise specified, all data are reported as weighted nationwide estimates. All costs are reported in US dollars. All analyses use the weighted data unless otherwise specified. Statistical analysis was performed using the Statistical Package for the Social Sciences version 21.0.0 (SPSS, Chicago, IL, USA).

3. Results

ECoG cases from 1990 to 2008 were extracted from the NIS database, a 20% subsample of nationwide hospital admissions. A total of 695 cases met our search criteria, corresponding to an estimated 3528 ECoG cases nationally (using NIS weighting information; see Methods). Overall, the number of ECoG cases significantly increased over time at an estimated rate of 14.9 patients per year (95% confidence interval [CI] 8.4–21.4, $F = 23.4$, $p < 0.0001$; Fig. 1). This is true even if the first 3 years, 1990–1992, which had significantly lower numbers of reported cases, were excluded (rate = 12.0 patients per year, 95% CI 3.0–20.9, $F = 8.15$, $p = 0.13$).

Basic demographics revealed that most patients who underwent ECoG evaluation were male, white, and had private insurance (Table 1). Males comprised 53.0% of patients and whites 60.3%. Hispanics were the second most numerous ethnicity, accounting for 13.2% of patients, while African Americans comprised 5.7%. Private insurers covered 59.7% of patients, and government-run Medicare and Medicaid insured 35.0%. The median charge was $93,822, but ranged widely from $13,090 to $938,869, with a standard deviation (SD) of $91,429. Patient age ranged from 0 to 73 years, with a mean of 25.9 ± SD 14.5 years. The average reported length of stay was 15.6 days (range 2–113 days, SD 9.2 days).

We also wished to compare how these trends related to overall admissions for refractory epilepsy. From 1989–2008, 62,717 patients with refractory epilepsy met our inclusion criteria, corresponding to 323,857 patients nationwide. As was the case for ECoG, the number of hospitalizations for refractory epilepsy also increased significantly from 1989 to 2008, growing at an estimated rate of 521 patients per year ($F = 9.5$, $p = 0.006$), consistent with prior studies [8]. The percentage of patients with refractory epilepsy undergoing ECoG yearly ranged from 0.1 to 2.4% (mean 1.1 ± SD 0.6%), and this percentage showed a gradual significant increase over time ($F = 5.7$, $p = 0.03$; Fig. 1).

Importantly, we found that the demographic characteristics of ECoG patients differed significantly from those of the refractory epilepsy population at large. Specifically, ECoG patients were significantly younger than the general epilepsy population (25.9 *versus* 30.6 years; $p < 0.0001$), were more likely to be male (relative risk [RR] 1.13, 95% CI 1.06–1.20), and less likely to be African American (0.58, 95% CI 0.51–0.67). Interestingly, Hispanics and

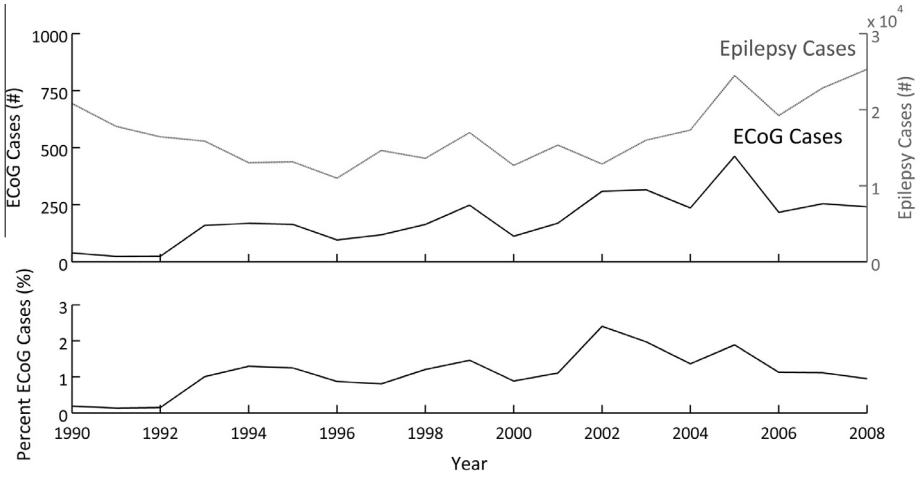

Fig. 1. The number of electrocorticography (ECoG) patients and epilepsy patients in the USA over time. (Top) The number of ECoG patients is plotted (black line) along with the total number of epilepsy patients (gray). (Bottom) ECoG patients as a percentage of epilepsy patients plotted over time.