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

Keywords

ECoG; Electrocorticography; Electroencephalography; Epilepsy; Epilepsy surgery; Seizures

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

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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 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 Native Americans both appear more likely to receive ECoG than whites (RR 1.46 and 1.10, respectively), though the data on ethnicity should be interpreted cautiously, since racial data is missing from a large number of patients (18.6% of ECoG patients and 31.4% of refractory epilepsy patients; Table 1). ECoG patients were also significantly less likely to use Medicaid/Medicare (RR 0.51, 95% CI 0.47–0.54) or self-payment (RR 0.32, 95% CI 0.23–0.44) than private insurance as their primary payer.

Hospital characteristics were also compared between refractory epilepsy patients undergoing and not undergoing ECoG recording. As might be anticipated, ECoG was far more likely to be conducted at urban teaching hospitals than rural, non-teaching hospitals (Table 1). Similarly, hospital size is related to ECoG, with large-sized hospitals more likely than small hospitals to perform the procedure (Table 1). Lastly, the location of the hospital also appears to be a factor: ECoG is more likely to be done in the northeast than midwest (RR 0.54, 95% CI 0.49–0.60), south (RR 0.58, 95% CI 0.54–0.63), or west (RR 0.70, 95% CI 0.64–0.77), despite the fact that the south has the largest number of admissions for refractory epilepsy.

Using binary logistic regression allowed us to control for confounding variables. With this analysis, many of the findings of univariate analysis were upheld. Race was again a significant predictor, with African Americans again less likely than whites to receive ECoG (odds ratio [OR] 0.78, $p = 0.002$) and Hispanics more likely (OR 1.46, $p < 0.001$). Again, patients with government insurance were less likely than patients with private insurance to receive ECoG (OR 0.62, $p < 0.001$), and patients from the communities with the highest median incomes were far more likely to receive ECoG (OR 1.97, $p < 0.001$). Urban hospitals were also more likely to offer ECoG than rural hospitals (OR 1.61, $p < 0.001$), as were teaching hospitals (OR 2.15, $p < 0.001$). Hospital region was again a significant predictor, with northeastern hospitals the most likely to provide ECoG (Table 2).

Lastly, we examined the frequency of complications associated with ECoG placement (Table 3). The most frequently reported complications were cerebrospinal fluid leaks (11.7%), anemia requiring transfusion (7.5%), infection (7.2%), and hematoma/hemorrhage (2.6%). Status epilepticus occurred in 0.4% of patients, though it is unclear from these data whether such events are related to ECoG placement, or related to the patient's baseline condition. Only one death was recorded in the ECoG cohort, corresponding to an estimated six deaths nationwide from 1989–2008 (0.2% of patients). The cause of death is not reported in the NIS dataset, so the true association between the ECoG procedure and the deaths is unknown.

4. Discussion

This is the first report, to our knowledge, of the prevalence of extraoperative ECoG use in epilepsy surgery, and the disparities in its utilization. The number of ECoG cases has steadily increased since the late 1980s, on pace with the increasing number of hospitalizations for refractory epilepsy nationwide. Interestingly, this differs from the only surgical treatment of epilepsy with supporting class I evidence, anterior temporal lobectomies, which have not kept pace with the rising number of refractory epilepsy hospitalizations [8,12,19]. The roots of this discrepancy are unknown, but ECoG is used for a variety of types and locations of epilepsy, and not limited to temporal lobe epilepsy. It is plausible that the number of non-temporal resections, and their associated ECoG mapping, is rising, while temporal lobectomies remain unchanged.

Examining the demographic data of ECoG patients suggested significant socioeconomic disparities: African Americans were significantly less likely to receive ECoG than whites, and patients with private insurance were more likely to receive ECoG than patients enrolled in Medicare or Medicaid (Table 1, 2). This trend has, unfortunately, been observed before in epilepsy surgery and in epilepsy care in general [1,4,5,8,15,21]. While the cause of these disparities is unknown, there are several possible mechanisms. First, the difference in insurance coverage between racial minorities might be one factor influencing these disparities, as white patients with epilepsy have previously been shown to be more likely to have private insurance than non-white patients [8]. Second, the relationship between different racial groups and the healthcare community is not always one of trust. There might be cultural or social reasons for patients to be less interested in surgical procedures than continued medical management [3,10,24]. Lastly, access to care, healthcare literacy, and physician attitudes might all play roles in creating this imbalance in care [5].

Demographic data also revealed that males with refractory epilepsy were more likely than females to undergo ECoG. The causes of this are unknown, though many case series of surgery for extratemporal lobe epilepsy have shown male predominance in patients [6,9,16]. Additional factors might include physician attitude and patient preference.

Hospital characteristics revealed most ECoG cases occurring at urban teaching hospitals, which might have been anticipated, and is compatible with other trends in epilepsy surgery [8]. Similarly, hospital size also predicted ECoG, with larger hospitals more likely to provide the procedure. Geographically, the northeast was more likely than the midwest, south or west to offer ECoG. This is at odds with temporal lobectomy, which is least common in the northeast, as compared to the other regions [9].

The most frequent complication of extraoperative ECoG monitoring was cerebrospinal fluid leakage, which occurred in 11.7% of patients. Many cases series have been published over the past several years that document complications, but interestingly none mention cerebrospinal fluid leaks, prompting criticism in some cases [23]. The most reliably reported complication was intracranial hematomas requiring surgical intervention. These were reported in 3.0% to 9.8% of patients, far higher than our observed rate of 2.6% [14,17,22,23].

Due to the nature of the NIS database, our results are necessarily limited [13]. The NIS relies on accurate coding of patient characteristics, diagnoses, procedures, and complications. Some characteristics are frequently not entered (especially race), making any observed demographic trends suggestive, rather than conclusive. This is particularly problematic if there are biases toward data entry (for example, preferentially under or over-reporting race on select ethnic groups). Furthermore, data on complications are likely to underestimate their prevalence, as subsidiary ICD coding (where complications are generally reported) tends to be less complete than that of primary diagnoses [13]. Lastly, ICD coding is not always specific. For example, the code used for studies of anterior temporal lobectomy, 01.53, is a general code for lobectomy of any lobe, not just the temporal lobe [13]. To guard against this degeneracy of the ICD system, we have used multiple inclusion and exclusion codes to ensure we include our population of interest, though this likely excludes many legitimate patients whose files lack thorough coding. Despite these limitations, inherent to all NIS studies, the above results reflect our best estimate of nationwide trends, and, to our knowledge, the first and only attempt at such an estimate. Some characteristics of these trends are troubling, and all deserve further research so that we may describe the true prevalence of disparities and complications for our patients undergoing this invasive, but common, procedure.

5. Conclusions

The use of ECoG for epilepsy has kept pace with the burgeoning number of refractory epilepsy cases in the USA. However, demographic information from the NIS points to significant racial and insurance-based disparities concerning refractory epilepsy patients who receive ECoG. Overall, these data show the relative safety and prevalence of ECoG for epilepsy surgery, though underscore the socioeconomic disparities involved in higher tertiary levels of epilepsy care.

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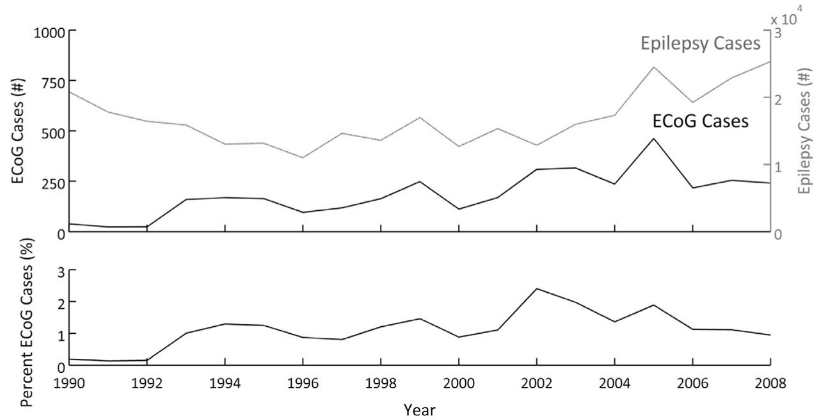

Fig. 1.

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.

Table 1

Comparison of demographic data of electrocorticography patients and patients with refractory epilepsy

	ECoG patients, n (%)	Epilepsy patients, n (%)	Relative risk (95% CI)
Age (mean ± SD)	25.9 ± 14.5	30.6 ± 21.8	$p < 0.0001$
Sex			
Female	1660 (47.0)	160929 (49.7)	1 [Reference]
Male	1868 (53.0)	160498 (49.6)	1.13 (1.06–1.20)†
Unknown	0 (0)	2430 (0.8)	
Race			
White	2127 (60.3)	165106 (51.0)	1 [Reference]
Hispanic	467 (13.2)	24724 (7.6)	1.46 (1.32–1.61)†
African American	203 (5.7)	27411 (8.5)	0.58 (0.51–0.67)†
Asian or Pacific Islander	50 (1.4)	3400 (1.0)	1.14 (0.87–1.51)
Native American	22 (0.6)	1557 (0.5)	1.10 (0.72–1.67)
Unknown	657 (18.6)	101624 (31.4)	0.51 (0.46–0.55)†
Primary payer			
Private	2106 (59.7)	138506 (42.8)	1 [Reference]
Medicare/Medicaid	1236 (35.0)	161486 (49.9)	0.51 (0.47–0.54)†
Self-pay	38 (1.1)	7902 (2.4)	0.32 (0.23–0.44)†
No charge	5 (0.1)	606 (0.2)	0.55 (0.23–1.31)
Unknown	144 (4.1)	15358 (4.7)	0.62 (0.52–0.73)†
Hospital location			
Urban	3409 (96.6)	294195 (90.8)	1 [Reference]
Rural	118 (3.4)	29675 (9.2)	0.35 (0.29–0.42)†
Hospital teaching status			
Teaching	3134 (88.9)	229472 (70.9)	1 [Reference]
Non-teaching	393 (11.1)	94362 (29.1)	0.31 (0.28–0.34)†
Hospital region			
Northeast	1276 (36.2)	81938 (25.3)	1 [Reference]
Midwest	589 (16.7)	70263 (21.7)	0.54 (0.49–0.60)†
South	992 (28.1)	109861 (33.9)	0.58 (0.54–0.63)†
West	670 (19.0)	61795 (19.1)	0.70 (0.64–0.77)†
Hospital bed size			
Small	472 (13.4)	43126 (13.3)	1 [Reference]
Medium	491 (13.9)	72862 (22.5)	0.62 (0.55–0.70)†
Large	2565 (72.7)	207846 (64.2)	1.13 (1.02–1.24)†

†Indicates statistical significance of $p < 0.001$.

CI = confidence interval, ECoG = electrocorticography, SD = standard deviation.

Table 2

Predictors of electrocorticography utilization from multivariate analysis

Characteristic	OR (95% CI)
Age	0.996 (0.994–0.998)[†]
Sex	
Male	1 [Reference]
Female	0.93 (0.86, 1.00)
Race	
White	1 [reference]
African American	0.78 (0.67–0.91)[‡]
Hispanic	1.46 (1.29–1.65)[†]
Asian or Pacific Islander	1.20 (0.90–1.60)
Native American	0.63 (0.39–1.03)
Payment	
Private insurer	1 [Reference]
Medicare/Medicaid	0.62 (0.56–0.67)[†]
Self-pay	0.36 (0.24–0.53)[†]
No charge	0.58 (0.24–1.45)
Median income	
Bottom quartile	1 [Reference]
2nd quartile	1.47 (1.27–1.70)[†]
3rd quartile	1.64 (1.42–1.88)[†]
Highest quartile	1.97 (1.73–2.26)[†]
Hospital location	
Rural	1 [Reference]
Urban	1.61 (1.28–2.02)[†]
Hospital teaching status	
Non-teaching	1 [Reference]
Academic	2.15 (1.90–2.44)[†]
Hospital bed size	
Small	1 [Reference]
Medium	0.59 (0.51–0.69)[†]
Large	0.99 (0.87–1.11)
Hospital region	
Northeast	1 [Reference]
Midwest	0.67 (0.60–0.76)[†]
South	0.82 (0.74–0.91)[†]
West	0.79 (0.70–0.89)[†]

[†]Indicates statistical significance of $p < 0.001$.

‡Indicates statistical significance of $p = 0.002$.

CI = confidence interval, OR = odds ratio.

Table 3

Complications of electrocorticography

Complication	Estimated number of cases (%)
CSF leak	414 (11.7)
Blood transfusion	264 (7.5)
Postoperative infection	254 (7.2)
Hemorrhage/Hematoma	92 (2.6)
Ventriculostomy/Hydrocephalus	52 (1.5)
Stroke/Neurological complication	68 (1.9)
Cardiac arrest/Dysrhythmia	60 (1.7)
Respiratory failure	54 (1.5)
Status epilepticus	15 (0.4)
Pulmonary embolus	16 (0.4)
Death	6 (0.2)

CSF = cerebrospinal fluid.