

Surgical Morbidity of Invasive Monitoring in Epilepsy Surgery: An Experience from a Single Institution

Epilepsi Cerrahisi İnvaziv Monitarizasyonda Cerrahi Morbidite: Bir Merkezin Tecrübesi

ABSTRACT

AIM: This paper aimed to provide information related to surgical and neurological complications encountered following intracranial electrode placements in patients with medically intractable epilepsy.

MATERIAL and METHODS: Retrospective review of 70 patients with either subdural grid/strip or depth electrode implanted between 2004 and 2009 at the Epilepsy Unit in Cerrahpasa Medical Faculty.

RESULTS: A total of 276 electrode implantations were performed in 70 patients. There were no deaths related to implantation. The occurrence of infection and intracranial hematoma were found to be 1.4 and 1.4%, respectively. A total of 1 patient (1.4%) showed transient neurological complications. The rate of overall morbidity including neurological complications was found to be 4.2% (n = 3).

CONCLUSION: Based on our experience, intracranial electrode implantation is an effective and safe method with extremely low morbidity rate, especially in experienced hands.

KEYWORDS: Complications, Depth electrode, Epilepsy, Epilepsy surgery, Morbidity, Subdural grid, Subdural strip

ÖZ

AMAÇ: Bu yazı, ilaca dirençli epilepsi hastalarında uygulanan intrakraniyal elektrod yerleşmesine bağlı gelişen komplikasyonları sunmayı amaçlamıştır.

YÖNTEM ve GEREÇ: Cerrahpaşa Tıp Fakültesi Epilepsi Ünitesinde 2004 ile 2009 yılları arasında subdural grid/strip veya derinlik elektrot uygulanan 70 hasta retrospektif olarak gözden geçirilmiştir.

BULGULAR: Yetmiş hastaya toplam 276 elektrot takılmıştır. İmplantasyona bağlı ölüm olmamıştır. Enfeksiyon ve hematoma riski sırası ile %1,4 ve %1,4 olarak bulunmuştur. Toplam 1 hasta (% 1,4) geçici nörolojik komplikasyon göstermiştir. Nörolojik komplikasyonlar da dahil genel morbidite oranı %4,2 (n = 3) olarak tespit edilmiştir.

SONUÇ: Tecrübelerimize dayanarak diyebiliriz ki intrakraniyal elektrod uygulaması etkili ve güvenli bir metot olmakla beraber tecrübeli ellerde son derece düşük morbiditeye sahiptir.

ANAHTAR SÖZCÜKLER: Derinlik elektrod, Epilepsi, Epilepsi cerrahisi, Komplikasyon, Morbidite, Subdural grid, Subdural strip

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INTRODUCTION

The success rate of epilepsy surgery leading to seizure freedom or less frequency of seizure is clearly depending on the precise and/or accurate preoperative evaluation for defining epileptogenic zone (EZ). It has been clearly established that surgical resection of EZ as much as possible increases the likelihood of seizure free rate which in turn increases patients' quality of life (15, 23, 25). For the many years defining the EZ could be possible by using non-invasive preoperative studies before surgical intervention, however; in some challenging cases invasive studies, namely invasive video-electroencephalographic evaluations had to be performed to localize exact EZ and satisfactory seizure outcome without placing the patient in an intolerable condition because of catastrophic neurological deficit. Invasive monitorization is a surgical intervention in which intracranial placement of a subdural/epidural grid or strip (SDGS) or a depth electrode (DE) which greatly facilitates having abnormal electrical discharges directly coming from the cerebral cortex or from the deeper structures so that artifacts caused by surface EEG recordings are eliminated. Such invasive monitorization have been performed in advanced epilepsy centers around the world since the last 30 years and the current literature shows that it has become "gold standard" in cases where neither lateralization nor localization could be made regarding epileptogenic focus (14, 20, 33).

Although invasive recording is a safe and effective procedure, it is not free of morbidity given that it is a highly invasive diagnostic procedure to lateralize and/or localize epileptic tissues, which also carries additional risks beside epilepsy surgery itself. Complications from invasive diagnostic procedures should be known due to ethical considerations, and the surgeon should inform patients, their family members, and caregivers. Thus, quantification of the risks or complications is as important as seizure outcome to both surgeons and patients since each invasive intervention carries unique potential adverse effects, which must be considered when recommending surgery. Experience from different epilepsy centers with respect to complications from invasive recordings has lessened morbidity and even mortality rates and led it be a safe procedure (8, 22, 28). Hence we think

that sharing our experience in invasive monitoring as a tertiary epilepsy center in Turkey would help in pooling the data in the current literature in order to be more realistic that the epilepsy team must have a working hypothesis before going into such invasive diagnostic procedures. Our aim is not to compare the rate of complication between SDGSs and DEs, rather to give our results and discuss under the current literature.

MATERIAL and METHODS

Between April 2004 and December 2009, 70 patients have undergone invasive recording due to ambiguity between non-invasive diagnostic procedures and seizure semiology in relation to lateralization or localization of the epileptogenic focus, at the epilepsy center in Cerrahpasa Medical Faculty, Department of Neurosurgery. A list of all patients was obtained from the epilepsy surgery database. After each procedure (subdural grid/strip or depth electrode) a radiological imaging such as skull x-ray or computerized tomography (CT) or magnetic resonance imaging (MRI) was performed in order to verify the place of the electrodes inside the cranium so that surgical complications could be verified in all patients. Any neurological deficit secondary to invasive procedures in each patient was also noted while the patient was being recorded in the monitorization unit.

Selection Criteria

In this historical review of patient's charts, the only selection criteria for complications after invasive intracranial monitoring was for those patients whose first or subsequent intracranial placement of SDGS or DE studies were performed at our center.

Definition of complication

There is actually no universal definition of complication after epilepsy surgery but depending on a few previously published reports we defined a complication as unwanted, unexpected, and uncommon event after either a diagnostic or therapeutic procedure (1, 19). However, the authors who contributed to this study want to underline that the definition of a complication may be open for discussion because some postoperative disturbances have been considered as acceptable side effects and not as complications if they resolved completely within a few days. Thus, for example, minute

hemorrhages without any complication at the site of entry of a depth electrode which may be inevitable and should not be considered a surgical complication or brain edema after a placement of a larger subdural grid which may cause simple transient side effects such as dysnomia, mild hemiparesis, aphasia, and numbness in extremities, which generally resolve after anti-edema medication.

Invasive procedures

Invasive monitorization was initiated at our center in 2004 and there has been an evolution from the subdural grid/strip (SDGS) to depth electrodes since 2004. Between 2004 and 2006, SDGS was mainly used for lateralization or localization of the EZ. As the stereotactic frame became available in our operating theatre and commercially available depth electrodes in our country, we switched from SDGS to depth electrodes (DEs) during the last 1 to 2 years. The surgical technique either for SDGS or DEs has been explained in detail in the current literature (12, 30); however the technique with which the electrodes are inserted sometimes may show some differences from institution to institution so that there is no common standardization for the surgical placement of invasive apparatus. The detailed explanation of our surgical technique with respect to SDGS and DE placement is beyond the scope of this paper but general rules are worth mentioning. At our center placement of SDGS was carried out by either a burr hole or standard craniotomy under the general anesthesia. Before coming to the operating room, head positioning and skin incision should be planned to have enough exposure of the cerebral tissue of interest. Cerebral localization of SDGS can be performed under the guidance of MRI in the operating room. Particular attention should be paid to the site of interest otherwise the exact location of presumed epileptogenic tissue could be missed. Bone flap and dural opening also need careful attention since any injury to the cerebral cortex or cortical vessels will create a new epileptic focus in the future. Meticulous attention should be paid especially in dural opening that is generally stuck on the cerebral cortex in epilepsy patients. Once the brain is exposed, the grids should be placed under direct visualization in order to prevent vessel injury. Obtaining a digital image after the placement of the grid or strip should not be forgotten and it will guide

the team to define the epileptogenic focus while having seizure activity or during mapping. Patients usually spend a few hours after the implantation in the intensive care unit (ICU) and then are transferred to specialized unit for continuous video-EEG monitorization.

The DEs are also inserted under general anesthesia and frame-based stereotactic technique is used in our center. It should be noted that surgical technique largely depends on the availability of devices in the epilepsy unit since some centers use navigation-based frameless technique for the electrode placement. At the morning of the day of surgery, the stereotaxy frame is placed under light sedation and the patient is transferred to the MRI unit. After performing MRI, targets are defined on the computer depending on the Talairach and Tournoux coordinates (21). Electrode placement is performed through the burr holes that enable us to visualize the cortex and the cortical vessels underneath. Additional attention should be paid in patients whose hemisphere is atrophic and fibrotic since insertion of DEs may be difficult so that it is easy to miss the target of interest.

Basic care such as meticulous control of infection with antiseptic techniques both during implantation and monitoring periods should be considered. Head dressing is performed with bacitracin soaked-sponges and antibiotics are administered as a rule until SDGS or DEs are removed at our center. Any anticoagulating or antiaggregating agents are stopped before the procedures. Cerebrospinal fluid leak generally stops spontaneously and the duration of monitoring ranges between 4 to 10 days. Steroids are also administered after the procedure but tapered off within one week. Either CT or MRI was taken after the implantation to demonstrate to what extent we have achieved the target(s) and to also see whether there was any acute surgical complication.

Data Recording

After a retrospective review of patient's charts, a database was created and some variables were grouped in order to make categorical comparisons. The following independent variables were included: age of patient, gender, site of implantation, number of lobes covered, number of electrode inserted, and duration of monitoring. The occurrence of complications regarding invasive monitoring was tabulated as follows: *surgical* including hematomas

(epidural, subdural, or intraparenchymal) and infections and *neurological*.

Statistical Analysis

All data collected from each patient were organized in a database (Excel, Microsoft Corp.). Numeric variables were provided as the mean ± SD. Correlation analysis was made using Pearson’s correlation tests. A probability value < 0.05 was considered statistically significant. All statistical calculations were performed using commercially available software (SPSS version 14.0 SPSS Inc.).

RESULTS

Surgical Complications

A total of 70 patients with complex partial (CP) seizures or secondary generalization underwent either SDGS or frame-based stereotactic placement of intracranial DE recordings. The mean age of the patients and mean age of onset of epilepsy were 23.4 ± 11.9 and 8.4 ± 9.1 years, respectively. Twenty-four patients had a history of a risk factor during infancy or childhood period including encephalitis (n = 7, meningitis (n = 4), head trauma (n = 5), febrile convulsion (n = 4), birth difficulties (n = 2) and both encephalitis and birth difficulties together (n = 2). In 10 patients a neurological deficit at the time of hospital admission was present and 2 patients; one with iron deficiency anemia and the other with diabetes mellitus and hypertension were using medications related to their illnesses. Table I provides clinical summary of patients evaluated in this study.

SDGSs were implanted in 41 and DEs in 21 patients during the study period. SDGSs had to be inserted together with DEs in 8 patients due to the extensive presumed epileptogenic zone. The majority of the patients needed multilobar insertion (n = 53; 76.4%) of either SDGSs or DEs that was followed by the frontal lobe. Regarding multilobar implantation, the fronto-temporal region was the most common site of implantation (n = 31; 58.4%), followed by the fronto-parieto-occipital region (n = 22; 41.4%). Of the 276 electrodes implanted, 142 (51.4%) were SDGSs only and 107 (41.7%) DEs only. Eight patients who had both modalities made up a total of 27 (9.7%) including 11 SDGSs and 16 DEs. The mean duration of the monitoring period was 4.3 ± 1.7. The reference for each patient was applied over the forehead (Table II).

Table I: Clinical Characteristics of 70 Patients that had Undergone Invasive Monitorization

<u>Parameters</u>	<u>Number of cases</u>
Sex (M/F)	30/40
Mean age (yrs)	23.4 ± 11.9
Seizure onset (yrs)	8.4 ± 9.1
Risk factor (yes/no)	24/42
AED therapy	
One	11 (16.7%)
Two	37 (53%)
More than two	22 (30.3%)
Drugs other than AEDs	2 (3.0%)
Systemic diseases	2 (3.0%)
Neurological deficit at admission	10 (15.2%)
Intracranial monitorization	
Subdural grid / strip	41 (60.6%)
Depth electrode	21 (27.3%)
Both	8 (12.1%)
Total number of patients	70

AED: Antiepileptic drug.

Only 1 patient (1.4%) showed intracranial hematoma, which was epidural hematoma (EDH). This patient was thought to have dominant (left) hemispheric epilepsy so that a large coverage by SDGS and DE was applied. During monitorization in the video-EEG unit, a left fronto-temporal EDH developed that necessitated surgical evacuation that resulted in no sequelae. Neither intraparenchymal hematoma (IPH) nor subdural hematoma (SDH) was noted in our series.

The rate of infection was found to be 1.4% (1 patient). This patient developed meningitis that responded promptly to IV antibiotics without further complication.

Neurological Complications

One patient (1.4%) demonstrated a neurological complication following the implantation. Right hemiparesis close to hemiplegia was noted immediately after surgery. The CT demonstrated

that the strip was on the left central area that was being compressed by the strip. Immediate removal allowed the patient to recover completely and the follow-up was uneventful during the monitorization period (Table III).

It should be noted that there are always miscellaneous complications after every surgical procedure that are generally not directly related to surgical procedure itself. Thus in the present series such complications were not included in the statistical analysis because they are generally

Table II: Distribution of 276 Grid/Strip and Depth Electrodes Implanted in 70 Patients According to Each lobe*

	Subdural grid/strip (n = 41)	Depth electrode (n = 21)	Both (n = 8)	Total (n = 70)
Sex (M/F)	20/21	7/14	3/5	30/40
Mean age (years)	26.2 ± 10.4	20.3 ± 14.2	20.5 ± 9.0	-
Seizure onset (years)	7.7 ± 6.9	10.7 ± 13.9	8.6 ± 4.6	-
Distribution				
Frontal	7 (17.0%)	2 (9.5%)	0 (0%)	9 (12.8%)
Parietal	0 (0%)	0 (0%)	1 (12.5%)	1 (1.4%)
Occipital	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Temporal	2 (4.8%)	3 (14.2%)	2 (37.5%)	7 (10.0%)
Multilobar	32 (78.0%)	16 (76.1%)	5 (62.5%)	53 (76.4%)
Number of electrodes	142	107	27†	276
Mean monitoring (days)	4.4 ± 1.8	4.3 ± 1.8	3.3 ± 0.9	4.3 ± 1.7

* Percentages were calculated depending on patient numbers in each column.

† This group includes 11 grid/strip and 16 depth electrodes.

Pre-central and post-central gyri were included in the frontal and parietal lobes respectively

Table III: Morbidity in 70 Patients with 276 Subdural Grid/Strip or Depth Electrode Implantation*

	Subdural grid/strip (n = 41)	Depth electrode (n = 21)	Both (n = 8)	Total (n = 70)
Surgical	1 (2.4%)	0 (0.0%)	1 (12.8%)	2 (2.8%)
Hematoma†	0 (0.0%)	0 (0.0%)	1 (12.8%)	1 (1.4%)
•Epidural hematoma	0 (0.0%)	0 (0.0%)	1 (12.8%)	1 (1.4%)
Infection	1 (2.4%)	0 (0.0%)	0 (0.0%)	1 (1.4%)
•Meningitis	1 (2.4%)	0 (0.0%)	0 (0.0%)	1 (1.4%)
Neurological	1 (2.4%)	0 (0.0%)	0 (0.0%)	1 (1.4%)
•Hemiparesis	1 (2.4%)	0 (0.0%)	0 (0.0%)	1 (1.4%)
Total number	2	0	1	3
Valid percent (morbidity)	4.8%	0.0%	12.5%	4.2%
Mortality	-	-	-	0 (0%)

* Percentages were calculated depending on patient numbers in each column.

† Microhemorrhages at the entry site of depth electrodes are not included.

inevitable or acceptable during implantation. Micro or small hemorrhages at the entry sites of the depth electrodes demonstrated on the post-implantation CT or MRI in the present series were therefore not included as they are recognized as inevitable or acceptable changes unless they reach a size adequate to cause a neurological deficit or to require surgical intervention. There was only one patient who had severe atrophic right hemisphere on which depth electrodes had caused cerebral contusion at the entry site. Furthermore, the majority of the patients showed transient headache and this was thought to be due to small amount of cerebrospinal fluid (CSF) leak during implantation or mild cerebral edema, especially after large grid implantation.

The overall surgical morbidity rate including neurological complications was 4.2% (n = 3) in the current series.

Statistical Results

There was no statistical difference in the complication (including hematoma, infection and other) risk between gender (χ^2 ; 0.18) and history of a risk factor (χ^2 ; 0.74). When considering the lobes separately, we could not perform statistical analysis due to the fact that the majority of the patients had multilobar implantation. Although it seems that SDGSs caused more complications than DEs in this series with a limited number of patients, statistical analysis did not demonstrate a difference regarding complication rates between those patients with SDGSs and those who had DEs implantation (χ^2 ; 0.94). The number of lobes covered (Pearson's correlation; 0.07) was not associated with increase rate of morbidity but showed a tendency to be significant. Furthermore, age (Pearson's correlation; 0.46) and duration of monitoring (Pearson's correlation; 0.62) in our series did not have an effect on the complication rate. No mortality has been encountered in this entire series of patients.

DISCUSSION

The success rate of epilepsy surgery undoubtedly depends on the exact definition of EZ which is generally much more extensive than seen on preoperative imaging. The advancing technology used in the diagnosis and treatment of temporal and extratemporal lobe epilepsies has led to a high rate of favorable seizure outcome (15, 23, 25) and increased quality of life for the patients (24, 26, 34).

Non-invasive diagnostic studies fail to define EZ in almost 10 to 15% of patients with epilepsy, necessitating invasive intracranial EEG monitorization (subdural grids/strips or depth electrodes) (13, 27). During the last 10 to 15 years, intracranial placement of electrodes in especially non-lesional epilepsy has become popular and frequent and it has been reported that those patients who have been evaluated with intracranial monitorization have a more favorable seizure outcome compared those who had no invasive monitorization (5, 18). Thus, intracranial monitorization is now considered as a "gold standard" diagnostic tool in selected patients.

Although it has been reported that invasive diagnostic modalities and epilepsy surgery itself have a very low morbidity rate (1, 19, 22), some complications such as intracranial hemorrhage can put the patient in such a catastrophic condition that it may overshadow the successful results of the surgery. Thus, quantification of the risks and benefits is equally important to both the patients and the surgeons. They must be considered and discussed with the patient before applying any invasive diagnostic and therapeutic interventions. Despite extensive literature discussing diagnostic and surgical approaches and outcomes following either temporal or extratemporal lobe epilepsies, the complications of invasive diagnostic procedures and therapeutic interventions are poorly documented. The majority of studies concerning complications after intracranial recording techniques mostly include subdural or epidural strips or grids (30, 32) and only a few studies including a satisfactory number of cases have reported mortality and morbidity following DE insertions for epilepsy (5, 18, 22). More importantly, most of the literature regarding the complication rates of invasive monitorization is in reviewed books that generally discuss the complications from multiple centers and/or multiple surgeons (7, 12, 17). Although the heterogeneity of these studies may cause bias in the rate of complications, they provide helpful statistics for both the evaluation of clinical practice and for counseling patients before surgery.

Surgical Complications

According to previously published series focusing only on the complications following invasive monitorization, it is clear that the most

common complication is infection whilst the most feared complication was found to be intracranial hemorrhage and the mortality rate has been reported to be 1% or less (5, 9, 22, 20, 29). The risks of hemorrhage in stereotactic placement of DE range from 0.6 to 2.1% (5, 18) in previous and more recent series (22, 30). One of the largest series reported so far is by Talairach, et al. (20) who showed 3 (0.5%) intracerebral hemorrhages in 560 patients following DE insertions. In another series of 163 patients, the reported risk of intracerebral hemorrhages was 2.5% and 2 patients (1.4%) died; one from posterior cerebral artery injury and another after laceration of a parasagittal bridging vein (6). In Munari's series, intracerebral hematomas were found in 4 (1.4%) among 277 patients, one of which required evacuation (11). Van Buren (28) collected data from a number of different epilepsy centers and reported 2.7% intracerebral hemorrhage risk in 879 DE implantations. Another larger series including 2,000 DE implantations for the monitoring of seizure from different centers found one case of hematoma that required evacuation (2). A literature review by Pilcher et al. (16) found a 2.5% rate of hemorrhage in 1,582 patients evaluated with DE. A recent study including 6,415 DE insertions showed 0.8% intracranial hemorrhage (22). Regarding SDGS, it has been documented that the risk of intracerebral hemorrhage is higher than those of DEs and it mostly depends on the extent of surface contact and the total volume of implanted material had been suggested to be positively associated with complications (9, 29). In a multicentre study 14.3% of those implanted with subdural grids had complications as compared to 3.8% implanted with strips (19). Behren et al. (1) showed that 25 of their 189 monitored patients had subdural grid implantation and six (24%) of those with subdural grid had either subdural hemorrhages or transient neurological deficit. In contrast, only four (2.2%) cases of hemorrhage was reported among patients implanted with strip electrodes. Similar findings were also reported by Burneo et al. (3) who demonstrated that 3% of patients implanted with subdural strips had complications as compared to 13% of those implanted with grid arrays. Wong et al. (29) recently reported that only 4 (5.5%) patients had intracranial hemorrhages in 72 patients evaluated with SDGS. Almost all authors of the studies mentioned above agree that the risk of intracerebral hemorrhages is low.

In our series, we had only 1 intracerebral hemorrhage that was EDH approximating 1.4% following a total of 276 SDGS and DE insertions in 70 patients and no mortality was found. This patient was implanted both SDGS and DEs which necessitated the removal. The rate of hemorrhage seems to be a little bit lower than those of the previously published series from different centers and literature reviews reported so far. This difference may be explained by the fact that previous series mostly included cases from different centers and even from different surgeons who use different techniques. In order to decrease or avoid hemorrhagic complications in DE insertion, some authors suggested burr holes rather than twist drill holes to allow visualization of surface vessels and some rarely implant more than two DE per patient. Our data does not agree with the idea that more than 2 electrodes per patient could increase the risks of hematoma. Some data showed that twist drill holes are also extremely safe and using double-dose gadolinium MRI co-registered with neuronavigation provides excellent view of cortical vessels that leads to safe pial penetration (5, 22). For SDGS implantation, it is reasonable to explain that grid arrays covering a wide surface may be more rigid and may cause greater surface tension over the cortical surface leading to cerebral edema which could interfere with both arterial and venous circulation. Our experience agrees with Cahan and Crandall (4) who noted that valproic acid or aspirin should be avoided prior to invasive diagnostic technique.

Infectious complications after implantation have been reported to be the most frequent complication, ranging from 1 to 5% for DEs (1, 18, 22) and 2 to 16% for SDGS insertions (7, 9, 29). Meningitis has been the most commonly reported central nervous system (CNS) infection and less commonly, brain abscess, most of which responded well to antibiotic therapy. The high risk of intracranial infections in SDGS implantation has been attributed to the large craniotomy and high rate of CSF fistula (9, 29). Some authors have suggested using antibiotics during the monitorization process in order to prevent or decrease infection (1, 7, 10). However, there has been ongoing debate whether antibiotics are necessary or not in both DEs and SDGS implantation. It has been demonstrated in larger studies that there is no additional benefit of the continuous use of IV

antibiotic during the recording period in either DE or SDGS (31). Furthermore, some use low doses of oral antibiotic during the recording period but they suggest that it may not be necessary (18). In order to reduce the possibility of infection, some authors have suggested that the duration of recording should be less than 2 weeks and the electrodes should be tunneled far away from the point of pial entrance to prevent CSF leak (3, 16).

Only one patient presented with infection, making up 1.4% of the cases in our series. In agreement with the current literature, meningitis (1.4%) was the most common infection noted. We should note that one cannot speculate that low risk of infection is mainly due to antibiotic use based on our results as removing the electrodes in the operating room in a sterile condition instead of at the bedside (18) also helps to decrease infection rate. We think that meticulous control of infection with antiseptic techniques both during implantation and the monitoring period is the key to success in lowering the infection rate although we did not have a chance to compare patients in whom IV antibiotics were used with those who did not have antibiotic use during the monitorization period. Similar to the findings of previous large series (5, 11, 20, 22, 33, 28) the administration of corticosteroids improved symptoms of headache, nausea, and emesis but did not increase the rate of infectious complications. No wound infections developed in the patients treated with corticosteroid therapy. The effect of corticosteroids on the risk of complication was not analyzed due to the small number of patients included in our series.

The complications that we called "miscellaneous" were found in some cases and include a variety of complications such as transient headache, fever etc.

Neurological Complications

Neurological complications were seen in a total of 1 patient, which made up 1.4% in our series. Like many others (3, 10, 22, 31), we found no cases of permanent neurological deficit or death related to invasive electrode placement or removal. Right hemiparesis was observed in 1 case that had complete recovery after immediate removal of the strip compressing the left central area.

Overall morbidity including surgical and neurological complications was found in a total of 3 patients in the current series (4.2%) and neither permanent complications nor death occurred similar to previously published larger clinical series (5, 11, 20, 22, 28, 33).

Limitations

The authors who contributed to this study want to acknowledge the limitations. The main limitation of the current study is its retrospective nature as the diagnosis was obtained from the information registered in the charts that could have introduced some collection bias. Secondly, it would be very useful if we could provide information regarding unexpected postoperative cognitive deficits or psychiatric complications that may have a significant effect on the patient's quality of life.

CONCLUSION

Based on our experience, invasive monitorization is a useful and safe electrophysiological technique providing extensive help for defining the epileptic focus with low morbidity. The number or density of electrodes per lobe seems to be associated with high risk of complications. Further development in non-invasive imaging techniques may someday obviate the need for invasive electrode placement and its attendant complications. For the time being, invasive electrode implantation is still the "gold standard" in identifying seizure foci and eloquent areas of the brain in patients with refractory epilepsy. It is clear that advances in operative techniques, anesthesia, and intensive care during the last several decades have greatly decreased the risk of serious complications and that experienced hands in epilepsy surgery is the key to success.

Disclaimer

The authors do not report any conflict of interest concerning the materials and methods used in this study or the findings specified in this paper.

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