Overview of Epilepsy Surgery

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INTRODUCTION

Drug therapy is still the primary management for epilepsy. However, surgery is a reasonable therapeutic option for patients suffering from recurrent epileptic attacks despite the best medical treatment.

Since Sir Victor Horsley (1886) first conducted a successful surgical resection of a cortical scar in a patient with recurrent Jacksonian seizures, epilepsy surgery has become an important therapeutic tool worldwide. Penfield and Jasper (1954) at the Montreal Neurological Institute (MNI) in Canada firmly established the frame of modern epilepsy surgery techniques. Bailey and Gibbs (1951) in Harvard Medical Center used electroencephalography (EEG) for anterior temporal lobectomy (ATL). Data from the MNI (Rasmussen, 1975) indicated that ATL achieved satisfactory control of seizures in approximately 70% of patients suffering from temporal lobe epilepsy (TLE). Recent development of more sophisticated EEG techniques and neuroimaging improved the surgical outcome further and the number of epileptic patients having surgery has increased significantly. For example, only 100 cases were operated annually before 1980 in the United States but the number increased to 1500 cases annually in 1991 (Engel J Jr.: Personal Communication). On the other hand, annual surgical cases are less than 10 in Korea suggesting that this therapeutic measure is much too underutilized. Although there have been previous clinical attempts at epilepsy surgery (chung et al, 1989), in the authors opinion, the epilepsy surgery program at Yonsei University Medical Center which was started only two years ago is the only well organized program available in Korea at present.

We certainly need more surgical programs at other major university hospitals to help patients suffering from recurrent epileptic attacks in spite of full medical support. In this aspect, a comprehensive review of epilepsy surgery is timely and appropriate for further encourage-

ment and considerations for this new field in Korea.

SURGICAL TECHNIQUES

Surgical techniques currently available are described in table 1. theoretical approaches of these techniques can be categorized as: (1) removal of the epileptogenic region responsible for the patient's habitual seizures. (2) interruption of the pathways of propagating ictal discharges. (3) decrease brain excitability by stimulating structures exerting a restraining influence. (4) prevention of neuronal synchronization.

The first approach is certainly the most effective and definitive treatment aiming at a cure for epileptic attacks, thus called either ablative, resective, or curative surgery. Among these ATL is the most commonly performed procedure because the majority of complex partial seizures originate from the temporal lobe. Approximately 70% of ablative surgery is ATL and the remaining 30% is the resection of extra temporal lobe foci (Engel, 1987; Rasmussen, 1975) Hemispherectomy (Adams, 1983; Rasmussen, 1983) has recently been revitalized and microsurgical amygdalohippocampectomy (Wieser and Yasargil, 1982) has attracted more attention recently. However, these procedures are still performed in more specialized epilepsy centers for selected cases. Therefore, ATL represents a majority of epilepsy surgery and the procedure will be the main focus of this review.

ATL is divided into standard and tailored resections according to the extent of cortical resection. In standard ATL, 4.5 cm along the sylvian fissure and 5 cm along the floor from the temporal pole is resected in the dominant side and the size increases to 5 cm and 6 cm respectively in the non-dominant side (Olivier, 1988) For both standard and the tailored ATL, inclusion of the medial temporal structures amygdala and the anterior 2 cm of the hippocampus in the resection is important because these medial temporal structures are the most commonly responsible lesions for temporal lobe seizures. In tailored lobectomy, resection is guided by either intraoperative electrocorticogram showing interictal epileptiform discharges or by presur-

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Table 1. Surgical Techniques and their theoretical approaches.

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1. resection of epileptic region.
 - a. anterior temporal lobectomy (ATL).
 - b. extratemporal corticectomy.
 - c. hemispherectomy: i) classical
ii) modified
 - d. amygdalohippocampectomy.
 2. interruption of epileptic propagation pathways.
 - a. corpus callosotomy: i) partial
ii) complete
 - b. stereotaxic ablation.
 3. decrease of brain excitability.
 - a. cerebellar stimulation.
 - b. vagus nerve stimulation.
 4. inhibition of epileptic neuronal synchronization
 - a. multiple subpial transection.
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gical EEG investigations using previously implanted subdural electrode strips or grids. The extent of resection is certainly modified by the location of structural lesions if they are detected by neuroimaging technique. It was recently reported that the completeness of lesionectomy was a crucial factor for the postsurgical outcome (Awad et al, 1991).

The second approach is aimed at abolishing or decreasing the severity of epileptic attacks by preventing the recruitment of other cerebral regions by the spreading of ictal discharges, thus called palliative surgery. Among those, stereotaxic ablation has largely disappeared because of the lack of lasting benefits but corpus callosotomy (C.C) has become more important since the modification of the technique by Wilson at Dartmouth (Wilson et al, 1975) C.C is especially effective for the control of drop attacks caused by tonic, atonic or other secondarily generalized seizures (Spencer et al, 1987). Interruption of corpus callosum effectively prevents the spread of ictal discharges from one hemisphere to the contralateral hemisphere, thus seizures remain localized to one hemisphere. The effect of C. C. is the best in patients with evidence of unilateral hemispheric dysfunction and the outcome is less favorable in patients with multifocal or bilateral hemispheric dysfunction (Spencer et al, 1987). Recently, C.C has been performed in two stages. Usually, Interruption of the anterior 2/3 of corpus callosum is followed by later complete division if the result is not satisfactory after first stage C.C.. Occasionally partial C.C is performed for poorly lateralized frontal lobe seizures (Purves et al, 1988) but this

kind of approach needs more experiment.

The theoretical basis of the third approach is that many subcortical structures project either inhibitory or excitatory influences to the cerebral cortex and alteration of their activities by electrical stimulation through implanted devices may affect the initiation or severity of epileptic attacks. However, the results of these techniques have been unsatisfactory (Wright et al, 1984). Recently, electrical stimulation of the vagus nerve (Rutecki, 1990) has been shown to be effective in animal models but its clinical use is still at the experimental stage. A new surgical technique called multiple subpial transection (MST) was introduced by Morrel et al (1989). The procedure is based upon experimental evidence indicating (1) that epileptogenic discharge requires substantial side to side or horizontal interaction of cortical neurons and (2) that the major functional properties of cortical tissue depend upon the vertical fiber connections of the columnar units. The technique consists of serial subpial transection of the epileptogenic region by using an "L" shaped instrument at the interval of 5mm to sever tangential intracortical fibers while preserving vertical fiber connections of both incoming and outgoing nerve pathways. This technique was devised for the epileptogenic region located on the indispensable cortex such as the speech area or motor cortex. The preliminary results have been encouraging but it still requires further clinical investigations.

RESULTS OF EPILEPSY SURGERY

The primary objective of epilepsy surgery is the improvement of seizure control but there are certainly risks associated with surgical as well as diagnostic investigative procedures. In addition, the effect of surgery on the patient's psychosocial function is another important aspect of surgical outcome.

Seizure control after surgery

There have been numerous publications available on the effect of surgery on seizure control, however, each epilepsy center uses a different classification of post surgical seizure control, which makes it difficult to compare the results from different centers. Recently, a new classification system of postsurgical outcome was proposed for worldwide use (Engel, 1987) but the data using the new classification are not yet available (table 2). The surgical outcome also seems different for each subset of patients. Patients investigated by depth EEG were associated with slightly better seizure control than the group investigated by non-invasive

Table 2. Classification of Surgical Outcome

Class I: seizure free; excludes early postoperative seizure
Class II: rare seizures; "almost seizure free"
Class III: worthwhile improvement
Class IV: no worthwhile improvement

modified from reference 17

EEG investigation (Olivier, 1988). Among patients investigated by depth EEG, patients showing focal ictal onset achieved a better outcome than the group showing regional ictal onset. On the other hand, the degree of lateralization of interictal discharges on scalp EEG seems to be an important prognostic factor (Chung et al, 1991). It is also understandable that better recognized epilepsy centers may be referred to for more intractable or difficult cases. These variables make it difficult to obtain precise figures on surgical outcome apart from a general statement. Data from the first Palm Desert Meeting on surgical treatment (Engel, 1987) indicated that ATL resulted in a seizure free outcome in 55.5%, seizure reduction greater than 75% in 27.7% and no worthwhile improvement in 16.8%. Therefore approximately 80% achieved satisfactory seizure outcome after ATL. However, many patients reportedly seizure free were still taking antiepileptic medications and were often having auras. In cases of extratemporal corticectomy, seizure free outcome was achieved in 43.2% and greater than 75% seizure reduction was 27.8%, thus the result was slightly less satisfactory than ATL.

The numbers for hemispherectomy and corpus callosotomy were much smaller than ATL but seizure free outcome was 77.3% in hemispherectomy and 5% in C.C., greater than 75% seizure reduction was 18.2% and 71% respectively. These results seem to be reasonable considering that most surgical cases were chronic medically intractable on intensive medical management. In fact, most epilepsy surgery centers conduct a high quality medical management program. Recently, Dashieff (1989) raised an argument against the surgical outcome because no controlled prospective investigations have ever been done to compare surgery with medical treatment. In reply to the argument, Porter and Ojeman (1989) indicated that the published surgical outcome was far superior to known medical treatment, which made a prospective investigation inappropriate for ethical reasons. In fact, a retrospective study comparing surgery and medical treatment was recently published by Guldvog et al (1991). The study indicated that surgery was much

more effective for seizure control than medical treatment throughout the follow up period over more than 10 years. Instead, neurological deficits were more common in the surgical group which was statistically significant.

Recent figures of mortality and morbidity were less than 0.5% and 5% respectively in the ATL group, and more than half of the morbidity was only transient or clinically insignificant complications (Olivier, 1988; Van Buren, 1987). One of the interesting observations about surgical outcome was that the degree of seizure control in individual patients fluctuates over the period of follow up, thus some of the initially seizure free patients for the first one year may be reclassified into either rare recurrent seizures or less satisfactory seizure control groups over following years. On the other hand, some of the patients with initially recurrent seizures for the first year may eventually change into the seizure free group. Therefore, proportions of each groups of seizure outcome have been maintained throughout the follow-up period. It is generally agreed upon that the assessment of seizure outcome requires at least 2 years of follow up period after surgery (Engel, 1987).

Psychosocial Function after Surgery

Postsurgical changes of psychosocial function including cognition is the other important aspect of epilepsy surgery because the main objective of epilepsy surgery is to help the patients function better. Objective measurement of human psychosocial function is quite complex. Thorough neuropsychological testing batteries as well as laborious investigations of employment status, independent living scale, or other environmental factors may be required for adequate evaluations.

(1) Cognition

Measurement of intelligence quotient (IQ) by using the Wechsler Adult Intelligence test reflects the general cognitive function of the patient. Data from MNI (Olivier, 1988) and UCLA (Rausch and Crandall, 1982) suggested a mild to modest increase of full scale IQ after ATL but Rausch et al (1982) reported that improvement of IQ was statistically significant only in the patient group with complete seizure control after surgery. In other groups of seizure outcome, the change of IQ was not statistically significant. The effect of surgery on IQ seems to be also related with the side of ATL (Novelly et al, 1984) as well as the degree of seizure control (Rausch, 1987). It has been shown that verbal IQ was improved in only the right temporal lobectomy group but performance IQ improved both in the left and the right ATL group

(Novelly et al, 1984; Rausch and Crandall, 1982). Therefore the overall cognitive function seems to be better in the right ATL group compared to the left ATL. The differential effect on cognition according to the side of ATL seems more marked in the memory and in tests of learning. Ivnik et al (1988) reported that improvement of memory quotient was seen in 47% of the right ATL group but only 19% in the left ATL group. Memory quotient was significantly worse postoperatively only in 4% of the right ATL group but in 21% of the left ATL group. For auditory-visual learning tests, the same findings were observed indicating that the left ATL is more likely to impair memory and learning functions compared to the right ATL. This finding was further supported and extended by the data from the Cleveland Clinic (Chelune et al, 1991) which showed that a higher functioning patient preoperatively suffered more impairment of memory postoperatively after left ATL. The exact causes for the differential effect according to the side of ATL are not clear but it is likely that the left hemisphere is more important for memory. The hypothesis seems to be further supported by the data of selective amygdalohippocampectomy (AH). Wieser and Yarsagil (1982) reported that learning and verbal memory was not impaired in patients who had left AH but impaired in patients who received standard left ATL. These studies suggest that the size of left ATL should be minimized in patients especially with higher functioning level preoperatively. For these patients, selective AH is probably preferred although no hard data for the correlations between the size of left ATL and memory functions are available.

(2) Psychiatric or Behavioral Disturbances

It has been well known that minor psychiatric and behavioral disturbances were frequently seen in chronic epileptic patients. Falconer and Serafetinides (1963) reported that epilepsy surgery frequently improved these minor psychiatric disturbances, which was considered as a bonus to satisfactory seizure control. Jensen and Vaernet (1977) subsequently reported that the improvement of these minor psychiatric disturbances was most marked in patients who achieved the best seizure control but was less apparent in patients with recurrent seizures. Therefore, minor psychiatric or behavioral disturbances are not considered as contraindications of surgery. On the other hand, frank psychosis does not improve after surgery and the patient remains disabled despite successful seizure control after surgery. Guldvog et al (1991) reported more frequent development of psychosis in patients who had surgery compared to the patients managed medically, which has not been vigorously studied yet.

(3) Psychosocial Function

Objective evaluation of the patient's psychosocial function is quite complicated and diverse methods have been used. Rausch and Crandall (1982) used social rating scales based on interviews to measure dependency and personal relationships. They found a significant improvement in rating scales in the measure of degree of dependency, work or school performance, and non-family relations in the group of patients who achieved complete seizure control after surgery. In patients with persisting seizures, no significant improvement was seen. Augustine et al (1984) investigated occupational adjustment by using an employment status rating in 32 epileptic patients at 2 years after surgery. The number of fully employed increased from 14 to 23, whereas the number of underemployed decreased from 8 to 0. However, the unemployed group changed little suggesting that the beneficial effect of epilepsy surgery is focused only on the patients who were underemployed. The degree of seizure control after surgery did not correlate with the improvement of employment status suggesting that recurrent seizures are not necessarily the major factor affecting employment. Other factors such as personality, motivation, cognitive functions etc., may also influence the degree of employment. Dodrill (1987) indicated that the patients reported a significant improvement in the majority of psychosocial categories of the Washington Epilepsy Personality Inventory (WEPI) but measurement of independent living outcome and employment status did not show significant improvement after surgery (Fraser, 1987). Therefore the influence of epilepsy surgery seems to be very limited for the practical social functioning of the patients. This field certainly requires further investigation and a more intensive and comprehensive rehabilitation program after surgery may be beneficial for their social adjustment after surgery.

SELECTION OF SURGICAL CANDIDATES

The selection process for surgical candidates involves essentially two steps; preselection by referring physicians and the actual presurgical evaluation process at the specialized epilepsy unit.

Preselection by Referring Physicians

This process indicates selecting epileptic patients who will be subsequently evaluated at the epilepsy unit to determine candidacy for epilepsy surgery. The presurgical evaluation process at the epilepsy unit is quite stressful, requiring intensive labor of highly trained

specialists, it is expensive, and is associated with small but definite risks. Therefore, it is quite important to screen patients who will be most likely to benefit by surgery prior to their actual presurgical evaluation undertaken not only for improving cost-effectiveness but also for the patient's own safety. Although it is not often easy to exactly determine whether the patient is an ideal candidate for surgery prior to the extensive evaluation at the epilepsy unit, the following guideline (table 3) may be helpful to select potential surgical candidates for subsequent evaluation. From the practical sense, it may also be recommended for general practitioners to refer their epileptic patients to the regional neurological centers or epilepsy centers if their seizures are not fully controlled for 6 months, where trained neurologists will decide either further drug therapy or referral to the epilepsy unit for surgical intervention.

Table 3. Selection Criteria for Focal Resective Surgery

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1. Seizures are medically intractable.
 2. type of seizures: partial seizures
primary cortex is not definitely involved.
 3. recurrent seizures are disturbing normal life style: frequency, severity of seizures, patient's work or life style.
 4. no progressive neurological diseases: tumor, degenerative neurological diseases.
 5. patient's premorbid condition is functional; absence of severe mental retardation ($IQ < 70$), frank psychosis.
 6. patient is motivated and cooperative.
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(1) The seizures must be medically intractable

Antiepileptic drug (AED) therapy must have been adequate in view of the latest standard over a period of years before medical therapy is considered as a failure. Adequate AED therapy indicates the use of a maximally tolerable dose of the AEDs which are most effective for the patient's seizure types either in the form of monotherapy or combination therapy. The minimal duration of uncontrolled recurrent seizures before considering surgery varies from two to five years between authors. Because remission of seizures is most often achieved within the first two years of adequate AED therapy (Elwes et al, 1984) two years seems to be the minimal criteria for seizure duration.

(2) Type of epileptic seizures

The diagnosis of exact seizure types is crucial for appropriate medical treatment as well as for surgical intervention. In most patients, this is easily determined by detailed clinical evaluation including a thorough

history taking and laboratory tests such as EEG and neuroimaging. If exact determination of the seizure type is not obtainable, a prolonged CCTV-EEG recording may be indicated for the correct diagnosis of seizures as well as seizure types.

For focal resective surgery, the patient's habitual seizures should be partial seizures and the primary cortex such as the motor cortex should not be involved at the onset of ictus. A palliative surgery such as corpus callosotomy can be performed in patients with generalized seizures mainly to decrease the severity of attacks to prevent physical injuries from falling attacks.

(3) Recurrent seizures interfere with maintaining normal life

The degree of epileptic seizures affecting the patient's daily life is a complicated and quite subjective matter. Some patients who have only one or two seizures a year may complain of severe disability from the attacks but other patients don't feel any disturbances in their daily activities despite more frequent attacks mainly because of the very mild clinical manifestations of the seizures. In general, seizures recurring at a frequency of more than one episode a month may be regarded as serious enough to disturb the patient's daily activities. However, for a patient who is a surgeon, a lawyer, or a professional driver even one epileptic attack with loss of consciousness a year may not be tolerable. Therefore, physicians must consider various aspects of the seizures such as severity, frequency, presence of aura as well as the patient's work and life style.

(4) Progressive neurological disease

When the patient's seizures result from underlying progressive neurological diseases such as a tumor, the surgery is planned to treat the underlying illnesses not for the seizure per se. For other progressive neurological illnesses such as neurodegenerative illnesses, epilepsy surgery does not halt the progression of underlying illness.

(5) Premorbid condition

Epilepsy surgery is expensive and it is aimed at improving the patient's functional status by preventing recurrent seizures. Thus, for a patient who is severely disabled already, successful seizure control by surgery may not improve his status enough to be functional. Also, severe mental retardation usually indicates diffuse or multifocal cerebral dysfunction and their surgical outcome after resective surgery is less satisfactory. Most

epilepsy centers do not perform resective surgery when the patient's IQ is less than 70. However, there is a recent trend of performing palliative surgery; corpus callosotomy, in patients who are more profoundly retarded basically to prevent physical injury from ictal falling or to help manage the patient, which is readily justifiable. Patients with frank psychosis do not improve their function after successful seizure control because psychosis persists after surgery. However, minor psychiatric or behavioral disturbances may improve after successful seizure control. Perictal psychosis, which is a transient phenomenon related to the occurrence of epileptic attacks is not a contraindication for surgery.

(6) Patient's motivation and cooperation

Presurgical evaluation is quite stressful and requires the patient's full cooperation. Poorly motivated and uncooperative patients may not go through the evaluation process and expose themselves to unnecessary risks.

Presurgical evaluation at the epilepsy unit

Patients fulfilling the above preselection criteria undergo the actual presurgical evaluation process at an epilepsy unit.

The aim of presurgical evaluation for focal resective surgery is the exact localization of the epileptogenic region responsible for the patient's habitual seizures and testing for clinical safety of the focal resection of the epileptogenic region. When the determined epileptogenic region is at the dispensible cortex, focal resective surgery can be undertaken. If the exact localization of the epileptogenic region was not determined or the region was in the indispensable cortical area, the surgery is deferred.

The discussion in this section will be mainly focused on ATL which is the most commonly performed focal resective surgical procedure.

Each epilepsy center uses its own protocols consisting of batteries of various tests for accurate localization of the epileptogenic region. The protocols may vary for different centers because each center has different philosophies, facilities and uses different surgical techniques. However, there was a recent proposal from the first Palm Desert meeting in 1986 for more standardization of protocols to compare the results from different centers worldwide and to improve the ultimate surgical outcome. It should be admitted that no one protocol is the best for all the purposes but that each has its own advantages for different groups of the epileptic population. In general, more comprehensive

protocols consist of EEG investigations, neuroimaging and other laboratory tests looking for different aspects of focal cerebral dysfunction (Table 4).

EEG is certainly the primary laboratory tool investigating the abnormal epileptogenic excitability of the cortex but extensive neural connections between different areas of the cortex and different geometry of cortical structures may mislead the interpretation. Therefore, EEG investigation alone has always possibilities of false localization and use of other independent laboratory tests for focal cerebral functional deficits may be complementary. The congruence of results from EEG study,

Table 4. Protocol for Presurgical Evaluation

(A) Phase I	
1. tests for abnormal epileptogenic excitability	
a) video-EEG telemetry	video-taped ictal behavior
	interictal epileptiform discharges ictal EEG onset.
b) ictal imaging: SPECT or PET	
2. tests for focal functional deficits	
a) neuropsychological test	
b) thiopental activation test	
c) intracarotid amytal (Wada) test	
3. neuroimaging	
a) structural imaging	
i) CT	
ii) MRI	
b) functional imaging	
i) PET	
ii) SPECT: interictal	ictal
(B) Phase II	
1. tests for abnormal epileptogenic excitability	
a) video-EEG telemetry using invasive electrodes	interictal epileptiform discharges
	ictal EEG onset
2. tests for focal functional deficits	
a) thiopental activation test	
b) Evoked potentials (P ₃₀₀)	
c) after discharge threshold to electrical stimulation.	
3. functional mapping	
a) electrical stimulation through subdural electrode grid	
(C) Others	
intraoperative electrocorticogram and electrical stimulation for functional mapping.	

neuroimaging and other confirmatory tests may provide more reliable localizing value. When the results conflict with each other, further extensive and invasive investigations (phase II in table 4) may be necessary or the surgery should be deferred.

(1) EEG investigation

Since Baily and Gibbs (1951) first used interictal temporal lobe spikes for identifying candidates for temporal lobectomy, EEG has become the primary tool for localizing the epileptogenic region and remarkable development of electrodes, recording techniques and interpretations has been achieved.

(a) Telemetry system

Previously, multiple EEGs were recorded in the EEG laboratory under the supervision of EEG technologists which hampered the recording of ictal events. With development of the EEG telemetry system, continuous EEG recording for a long period of time became possible with minimal inconvenience to the patient and easier recording of spontaneously occurring ictal events. In the telemetry system, EEGs amplified by a preamplifier attached to the patient are transmitted to the telemetry system through either a cable or a radiofrequency system, where the EEG is digitized and stored on tape, usually on videotape. Later, the recorded tape is replayed into analogue form either on a TV screen or on EEG papers. The addition of a video camera to the telemetry system continuously records the patient's behavior on the same videotape simultaneously and they are synchronized by a clock. In this way, simultaneous interpretation of ictal EEG and ictal clinical behavior became possible for electro-clinical correlations. Replay of video tape also made it possible to analyze the patient's ictal behavior in detail for localization purposes. Recently, various computer technologies (Gotman et al, 1987; Wieser, 1987) applied to the acquisition, storage, analysis and display of EEG data in a manner that makes EEG evaluation less labor intensive and maximizes the ability to identify meaningful abnormalities.

(b) Electrodes

Considering that routine scalp electrodes only cover the cerebral convexity, other special electrodes become necessary to record EEGs from the mediobasal cerebral cortex, which is the most frequent epileptic region for complex partial seizures. Currently available electrodes can be divided into non-invasive, semi-invasive and invasive electrodes according to the risks involved with the procedures of implanting the elec-

Table 5. Electrodes

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1. non-invasive electrodes
 - a) 10-20 system scalp electrodes
 - b) closely spaced scalp electrodes
 - c) supraorbital surface electrodes
 - d) anterior temporal surface electrodes
 - e) sphenoidal electrodes
 - f) nasopharyngeal electrodes
 - g) nasoethmoidal electrodes
 2. semi-invasive electrodes
 - a) foramen ovale electrodes
 - b) epidural peg electrodes
 3. invasive electrodes
 - a) depth electrodes
 - b) subdural electrodes
 - i) grid
 - ii) strip
 - c) epidural electrodes
 - i) grid
 - ii) strip
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trodes (Table 5)

It seems redundant to describe each electrode in detail but here are some brief comments about the special electrodes utilized most frequently.

In general, non-invasive electrodes pick up EEGs remote from the actual generator and thus provide an overview of the epileptogenic mass but lack details. On the other hand invasive electrodes record EEG in close proximity to the generator and thus provide detailed information but lack information about the whole epileptogenic mass. For example, a depth electrode can pick up EEGs from neurons only in close contact with the electrode. Lack of volume conduction in brain parenchyma prohibits recording EEGs from wider areas. Considering that the epileptogenic region is not a discrete focus but spreads over a wider area, adequate coverage of the entire epileptogenic region by depth electrodes became impossible. Subdural grid electrodes provide better coverage than depth electrodes (Awad, 1991; Lüders et al, 1989) but require bilateral craniotomy for lateralization purposes which is too invasive. Therefore, scalp EEG combined with sphenoidal electrodes is certainly the prerequisite for an adequate implantation of more invasive electrodes. Sphenoidal electrodes usually pick up the EEG from the basal temporal region and supraorbital electrodes record the EEG from the orbitofrontal region. Nasoethmoidal electrodes are placed between the middle turbinate and nasal septum near the cribriform plate to reveal activities arising from the inferior frontal and

orbitofrontal lobe. Foramen ovale electrodes most extensively used by Wieser et al (1985) are placed in the ambient cistern to be in close contact with the hippocampus by using a similar technique to trigeminal rhizotomy either under local or general anesthesia. Wieser et al (1985) reported that IEDs from the medial temporal lobe were reliably recorded. For ictal recording an F.O. electrode usually recorded ictal discharges when the ictal discharges involved a wide area of the limbic structure. Thus localized ictal onset at the hippocampus seen by a depth electrode failed to be picked up by an F.O. electrode. Epidural peg electrodes or screws are placed on the epidural space through burr holes. Usually a few sets of epidural peg electrodes are placed bilaterally for the purpose of lateralization and approximate localization of the epileptic region especially in patients with extratemporal foci.

The depth electrode is implanted by the stereotaxic technique. The method of depth electrode implantation may be quite different for each center and the electrodes are either rigid or flexible. Recent development of high chrome content electrode compatible with MRI stereotaxic unit may improve the accuracy and safety of depth electrode implantation.

Subdural strip electrodes are placed through burr holes and guided into the appropriate cerebral regions. Recently, subdural strip electrodes were placed in the basal temporal region bilaterally with minimal risks (Kuzniecky et al, 1991; Privitera et al, 1990). However, the most medial temporal structures, i.e. the hippocampus, amygdala, cannot be covered by either subdural strips or grids. Subdural strips may also be used in combination with depth electrodes for better coverage of the temporal neocortex (Spencer et al, 1990; Sperling and O'Connor, 1989). Subdural grids contain 8 to 64 electrodes and are custom made to be placed through a craniotomy, thus they are more invasive than subdural strips. Subdural grid electrodes have an advantage of wider coverage of the neocortex than depth electrodes and could conduct cerebral functional mapping, which is quite useful for determination of the extent of the epileptogenic region and safe resection of the lesion (Awad, 1991; Lüders et al, 1989). However, for the purpose of lateralization, a subdural grid is too invasive for the requirement of bilateral craniotomy. Risks associated with invasive electrode implantation are approximately 4% each for depth and subdural grid electrodes but more serious complications such as intracerebral hemorrhage are certainly a major problem associated with the depth electrode (Van Buren, 1987).

(C) Interictal epileptiform discharges (IEDs)

i) Scalp EEG recorded IEDs

IEDs are electrophysiological hallmarks demonstrating the abnormal excitability of the cortex but localization based on IEDs only could be misleading because focal IEDs may not necessarily indicate that the region is the primary epileptogenic region. IEDs could be either orthodromically or antidromically projected from the primary epileptogenic region distant from the recording electrode sites and occasionally secondary or tertiary foci of abnormal hyperexcitability may generate IEDs which are initially dependent on the primary focus but perhaps become independent over time. It is generally assumed that IEDs are falsely localizing in 10 to 20% of patients (Engel et al, 1975, 1990; Mendius and Engel, 1985; So et al, 1989).

Despite the shortcomings of IEDs, few centers still operate on the basis of IEDs alone (Carey et al, 1985) but with comparable success rate; seizure free in 58% and worthwhile improvement in 25%, although it is likely that the patient population operated on in these centers may be of simpler or less complicated cases. The problems with IEDs in clinical practice are that a significant number of patients may show bilateral independent, or bisynchronous IEDs and no IEDs may be detected in some patients even in prolonged EEG recordings. These features may pose difficulties for the localization of the primary epileptogenic region. According to Chung et al (1991), degree of lateralization of IEDs was the critical factor for determining the outcome of ATL. In the study, patients with more than 90% lateralization of IEDs achieved a good outcome in 92% but only 50% of patients with less than 90% lateralization had a good outcome whether or not the patients received depth EEG investigations. However, bitemporal independent IEDs in scalp EEGs are not a contraindication for surgery because a significant number of patients still show unilateral ictal onset in depth EEG recordings.

Recently, So et al (1989), reported that depth EEG investigations in patients showing bitemporal IEDs in scalp recording revealed unilateral predominant ictal onset (greater than 80% lateralization) in 77% and 47% of them achieved satisfactory seizure control (S_z free or rare S_z) after ATL. In patients showing no unilateral predominance of depth EEG ictal onset surgical outcome was poor; satisfactory outcome was achieved in only 10% (So et al, 1989).

These results indicate that IEDs are important but are not the absolute criteria for localization of the primary epileptogenic region. Approximately 20 to 35%

of patients may show bilateral or multifocal independent IEDs in scalp EEG (Chung et al, 1991; Engel et al, 1975; So et al, 1989) but a majority of them may still show unilateral ictal EEG onset and can be helped by surgery. For patients showing unilateral predominant IEDs, invasive EEG studies may not be necessarily required. In these patients, recording of scalp EEG ictal onset coinciding with the IEDs lateralization may further increase the reliability of localizing value.

ii) Depth EEG

IEDs recorded from depth electrodes seem even less reliable than scalp recorded IEDs. Wieser et al (1979) found an agreement of only 66% between IEDs predominance and epileptogenic lobe which is in agreement with UCLA data showing correct localization by depth IEDs in 62% (Mendius and Engel, 1985). Computer analysis of depth recorded IEDs suggested that the side showing maximal spike rate during REM sleep and the side demonstrating the smallest activation in mean spike rate during light sleep or deep sleep relative to the waking period correlated significantly with the primary epileptogenic lobe which is in agreement with the hypothesis that the primary epileptogenic region contains spike generating sites which are relatively more autonomous than non-primary regions and will therefore exhibit greater stability across physiological states (Lieb et al 1980).

(d) EEG ictal onset

i) Scalp EEG

Despite the fact that most epilepsy centers always use scalp EEG ictal data for localization purposes, there are not many systematic studies investigating its localizing value. Scalp EEG patterns at ictal onset are morphologically divided into sinusoidal pattern, repetitive epileptiform potentials and attenuation of EEG background activity. However, the clinical significance of these patterns was not significantly different.

Scalp electrodes usually pick up ictal discharges much later than the actual ictal onset recorded by depth electrodes indicating that a large area of the temporal neocortex should be recruited by the spreading ictal discharges before their detection by surface electrodes. In fact, it has been well demonstrated that depth EEG showed clear ictal discharges during aura while scalp EEG was normal.

Therefore, the reliability of ictal scalp EEG seems to be depend upon the speed and direction of propagating ictal discharges, which is quite variable for individual patients. For patients whose ictal discharges rapidly

project either contralaterally or bilaterally, scalp EEG ictal onset may be mislocalizing or non-localizing. It has been previously cited that scalp EEG ictal onset preceding the patient's clinical ictal onset is a reliable evidence for localizing epileptogenic region. This is likely to be true if one considers that the earlier scalp electrodes detect ictal discharges, the closer the ictal generator is located to the recording electrodes.

However, it is often difficult to exactly pin point the clinical ictal onset even with a careful analysis of seizures recorded on video-tape. Other major problems with scalp ictal EEG are its severe contamination by muscle or movement artifacts obscuring the ictal EEG onset. Ictal EEG patterns other than the onset may also be helpful for lateralization purposes but their localizing value is not well determined. Risinger et al (1989) tested the localizing value of a focal EEG ictal onset pattern consisting of sinusoidal activities faster than 5Hz, localized at one unilateral sphenoidal electrode, and seen within 30 seconds after ictal EEG onset (Fig 1). Among 110 patients reviewed, 57 patients showed at least one ictal EEG pattern corresponding to the above criteria and the remaining 53 patients did not. Among 57 patients, 47 cases agreed with depth EEG ictal onset which resulted in 82% predictability of correct localization. On the other hand, less than 50% of patients with other scalp EEG lateralizing or focal changes were correctly predictive of accurate localization.

The predictive value of the sphenoidal sinusoidal ictal pattern was increased to 94% if all the recorded ictal patterns were uniform but decreased to 67% if the recorded EEG ictal patterns showed a mixture of focal and non-focal EEG patterns. Overall, the data suggest that scalp EEG ictal recording is not more accurate than IEDs for localization of the epileptogenic region. However, confidence for the localization increases when these two measures agree with each other, otherwise further invasive EEG investigations may be required.

ii) Depth EEG ictal onset

It is generally agreed that depth electrode recording of spontaneously occurring seizures provides the best localizing information of the epileptogenic region (Engel et al, 1990; Mendius and Engel, 1985). Spencer (1981), concluded from the literature review that the use of depth EEG enabled selection of 36% more patients for surgery by defining otherwise unidentifiable single epileptogenic focus and, furthermore, depth EEG could have prevented surgery in another 18% by demonstrating a different or an additional epilepto-

Fig. 1. Sphenoidal focal EEG onset. First arrow indicates ictal onset.

Second arrow indicates the onset of 6 Hz rhythmic ictal discharges localized at the left sphenoidal electrode 18 seconds after ictal onset.

genic region in patients otherwise thought to have a single discharging focus amenable to resection. However, whether this conclusion is correct or not is still debatable. The frequency of using depth EEG is quite variable for different centers. Some centers may use depth EEG in all their patient population but some centers may not use it at all. It should be understood that depth EEG investigation is a major undertaking not only for the accurate implantation of the electrodes but also for the handling of the patient after implantation. Even in experienced hands, depth EEG is associated with a combined mortality and morbidity ratio of 4% (Van Buren, 1987). Considering the small but definite risks involved with depth EEG investigation, it seems reasonable to use the technique in more selected cases rather than using it routinely.

Recently Engel et al (1990) reported that in 122 patients with TLE, depth EEG correctly localized the epileptogenic region in 114 patients (93%), falsely localized in 2 patients (2%), non-localizing in 6 patients (5%). For 37 patients with congruent focal scalp-sphenoidal ictal onsets and temporal hypometabolic zones in PET, depth EEG recordings never demonstrated extratemporal or contralateral epileptogenic regions but 3 of these patients had non-diagnostic depth EEG evaluations. These results certainly indicate that ATL is justified without depth EEG investigations in a significant number of patients when specific criteria for scalp EEG and the results of neuroimaging and other tests for functional deficits are met.

Depth or other invasive EEG ictal onset can be divided into focal, regional and diffuse. Focal onset indicates initial ictal discharges being localized to one or two adjacent electrode contacts, regional onset

indicates more widely spread ictal discharges but which are limited to unilateral major lobe (Fig 2). The localizing value is certainly better with focal onset because it indicates that the depth electrode accurately covers the seizure initiating focus. Regional onset suggests that the seizure generating focus is located near the electrodes but not in close contact.

Diffuse ictal onset seen in bilateral depth electrodes does not have any localizing value. Depth EEG ictal onset following definite clinical onset indicates that the seizure generating focus is not covered by depth electrodes, thus its localizing value is not reliable.

(e) Summary of EEG investigation

Adequate non-invasive scalp EEG investigation employing sphenoidal or other special electrodes is certainly the most important initial step. When both interictal and ictal findings agree and the results from other independent tests for functional deficits and neuroimaging do not conflict, further invasive EEG study is probably not indicated. If the phase I study failed to provide reliable localizing evidence, invasive EEG investigations are required. For lateralization purpose of the epileptogenic region, several options are available: 1) bilateral F.O. electrodes with or without either epidural pegs or subdural strip electrodes. 2) bilateral subdural strip electrodes. 3) depth electrodes. For accurate localization of the epileptogenic region, subdural grid electrodes or depth electrodes with or without subdural strip electrodes may be indicated.

(2) Tests for focal functional deficits

Most epilepsy centers use a battery of multiple tests investigating different aspects of cerebral function,

Fig. 2. Ictal EEG from chronically implanted Subdural grid electrodes in a patient with seizures originating from the left occipital lobe lesion. The patient subsequently underwent left occipital lobectomy with complete seizure control and no neurological deficits but right homonymous hemianopia.

A: focal EEG onset from the 5th electrode of C-plate

B: regional EEG onset from both B and C plates

C: location of subdural grid electrodes

A plate: inferior parietal-posterior temporal and occipital region.

B plate: posterior parietal and occipital region.

C plate: medial aspect of parieto-occipital region.

Arrows indicate the resection margin of the epileptogenic region constructed after cerebral functional mapping and both interictal and ictal EEG recordings.

AP and LAT: Skull x-ray projection.

which is basically useful for confirmation of the lateralization or localization of the epileptogenic region made by EEG studies. Therefore, the congruence of the results of these independent tests with the results from EEG studies makes EEG localization more reliable. On the other hand, conflicts in these results lessen the reliability of EEG localization suggesting the necessity of further EEG investigations, usually invasive EEG studies. Overall, The sensitivity of these confirmatory tests is relatively lower than EEG tests but the rate of false positive results is low (Mendius and Engel, 1985).

(a) Neuropsychological tests

A battery of tests for the measurement of cognitive functions is used to seek evidence of dysfunction in either the dominant or non-dominant hemisphere or each major lobe. The verbal intelligent quotient (VIQ) and performance intelligent quotient (PIQ) derived from

the Wechsler Adult Intelligent Scale may be useful for detecting lateralized dysfunction. The Halstead impairment index derived from the Halstead Neuropsychological battery may be sensitive for temporal lobe dysfunction. The Wisconsin card sorting test is more specific for frontal lobe dysfunction (Rausch, 1987). Although there are many specialized psychological tests measuring the integrity of specific brain areas, a battery of tests is required to conclude that a localized dysfunction exists. Therefore a combination of psychological tests is more effective than any single test.

A comprehensive neuropsychological testing is also important for the objective measurement of the neuropsychological outcome after surgery.

(b) Thiopental activation test

This test is primarily performed to identify areas of focal dysfunction according to the technique described

by Lombroso and Erba (1970). The demonstration of attenuation of barbiturate induced EEG fast activity at one sphenoidal electrode correlates well with the presence of a lesion in the mesial surface of the temporal lobe. This test can easily be done at the EEG Lab during continuous EEG recording. However, the sensitivity is relatively low. Introduction of quantitative measurement of beta activity may increase the sensitivity modestly but false positive results increase slightly.

(c) Intracarotid sodium amytal test

Intracarotid bolus injection of sodium amytal (100-150mg) by a standard carotid angiographic procedure is performed to determine the lateralization of verbal and memory functions (Wada and Rasmussen, 1960). The test is quite crucial because ATL may cause aphasia or global amnesia. Resection of the speech dominant temporal lobe is usually smaller than the resection of the non-dominant temporal lobe to avoid aphasia. In MNI, the hippocampus is usually spared when memory function is lateralized to the epileptogenic temporal lobe (Gotman, 1987). The intracarotid sodium amytal test is important not only for the purpose of testing for surgical safety but also for the localization of the epileptogenic region as a confirmatory test because lateralization of memory to one hemisphere usually indicates focal dysfunction of the contralateral temporal lobe.

(d) P₃₀₀ evoked potential

P₃₀₀ is an endogenous potential evoked by simple cognitive tasks. It probably has multiple generators but the hippocampus has been implicated as one of the multiple generators (Halgren et al, 1980). Meador et al (1987) first reported the absence of P₃₀₀ in the epileptogenic temporal lobe recorded from a depth electrode placed in the hippocampus. Puce et al (1989) reported an absence of P₃₀₀ in 46 (81%) of 57 patients with unilateral TLE investigated by depth EEG. Patients with histologically proven mesial temporal sclerosis (MTS) do not demonstrate P₃₀₀ suggesting that an absence of P₃₀₀ in TLE indicates structural or functional hippocampal abnormality. However, recording of P₃₀₀ by scalp electrodes did not show any lateralization of P₃₀₀ in patients with unilaterally absent hippocampal P₃₀₀ (Puce et al, 1991). Therefore recording of P₃₀₀ is useful only in patients having depth electrode investigations.

(3) Neuroimaging

The development of computerized tomographic technique initiated by x-ray CT scan provided a great

impact on the field of epilepsy surgery.

Currently available computerized tomographic neuroimaging techniques are divided into structural neuroimaging and functional neuroimaging.

(a) Structural neuroimaging

i) x-ray CT

The introduction of x-ray CT in 1975 visualized a gross structural lesion responsible for the patient's epileptic attacks. It has been generally cited that a mixed population of epileptic patients shows abnormal CT findings in 30-60% (So and Penry 1981). However, the majority of the abnormal findings were non-specific diffuse cerebral atrophy or focal atrophic changes not specific for localization of the epileptogenic lesion. Approximately 4 to 12% of epileptic patients have focal mass lesions (So and Penry, 1981), thus epileptic patients, especially with partial seizures, were recommended to take a CT scan at least once for a thorough evaluation. In temporal lobe epilepsy, a conventional CT scan does not cover the temporal lobe well and small tumors less than 2cm in diameter could be missed easily and mesial temporal sclerosis (MTS) cannot be detected by x-ray CT (Ormson et al, 1986). To increase the sensitivity of x-ray CT, modified techniques such as temporal lobe CT (Gammal et al, 1987), metrizamide enhanced CT (Wyler and Bolender, 1983), and high dose contrast enhanced CT (Oakley et al, 1979) have been used. But their use has largely disappeared after the introduction of MRI.

ii) Magnetic Resonance Imaging (MRI)

MRI provides better contrast imaging, freedom of tomographic orientation and an absence of bony artifacts compared to x-ray CT, which is quite useful for the visualization of the temporal lobe as well as other cerebral structures.

MRI has been extensively investigated in patients with complex partial seizures mainly of temporal lobe origin (Lesser et al, 1986; Ormson et al, 1987; Schorner et al, 1987; Sperling et al, 1986; Triulzi et al, 1988). The results generally indicated that MRI detected focal structural lesions in 25% of patients with previously normal X-ray CT (Lesser et al, 1986). However, MRI may miss a small calcified lesion (Sperling et al, 1986).

MRI is quite sensitive for foreign tissue lesions (Kuzniecky et al, 1987; Sperling et al, 1986) but detection of mesial temporal sclerosis (MTS), the most common pathological lesion in ATL, by MRI has been controversial (Ormson et al, 1987; Sperling et al, 1986). Reportedly, the most common abnormal MRI feature seen in patients with temporal lobe epilepsy has been cited

as focal increased T2-weighted signal intensity in the medial temporal region. Kuzniecky et al (1987) reported the feature as quite characteristic of severe MTS. Recently Jackson et al (1990) reported that focal T2 weighted signal intensity on the medial temporal region was found in 93% of temporal lobe seizure cases with pathologically proven MTS. On the other hand, Ormson et al (1987) reported no pathological features of MTS in patients showing focal T-2 weighted signal intensity. Brooks et al (1990) and Jack et al (1990) reported the incidence of focal T-2 weighted signal intensity being only 8% and 12% respectively in patients with histologically proven MTS. Therefore the clinical significance of focal T2-weighted signal intensity is still debatable.

It is probably a nonspecific finding of simple increased water content either caused by recurrent seizures, severe gliosis, or other structural lesions. Since Press et al (1989) demonstrated bilateral hippocampal atrophy by high resolution MRI in patients with global amnesia, volumetric measurement of the hippocampus by MRI has been claimed to be very useful for the detection of MTS. Jack et al (1990) reported that a volumetric measurement of the hippocampus in T1-weighted coronal imaging detected unilateral hippocampal atrophy in 76% of TLE cases with histologically confirmed MTS. Jackson et al (1991) recently reported that the combination of T2-weighted signal intensity, volumetric measurement and disorganized internal structure of hippocampus detected MTS in 56% of their patients.

Therefore a thorough MRI investigation may be able to detect a structural basis for the patient's epileptic seizures at least in more than 50% of patients with temporal lobe epilepsy.

(b) Functional cerebral Imaging

Measurement of cerebral function by using local glucose metabolic rate or cerebral blood flow may provide further confirmatory evidence of focal functional deficit in the epileptogenic region. The introduction of positron emission computed tomography (PET) in the field of epilepsy surgery by Kuhl and Engel (1980) opened a new dimension and the knowledge obtained by PET was directly adopted to the single photon emission computed tomography (SPECT) investigations.

i) PET

Engel et al (1982) in UCLA first reported the presence of a focal hypometabolic zone in 35 of 50 patients with complex partial seizures by using FDG-

PET. Among 35 patients, 28 patients showed agreement with depth EEG localization, 3 patients disagreed and in the remaining 4 patients depth EEG did not localize the epileptogenic region. Among 3 patients with disagreement, 2 patients were confirmed to show a focal hypometabolic zone due to depth electrodes implantation and one patient was found to be mislocalized by depth EEG. Therefore, PET and depth EEG were found to be complementary to each other. Since then PET has been performed before depth electrodes implantation and, in a recent UCLA series, false localization by PET was seen in only one case but the patient had a non-epileptogenic structural lesion compatible with the focal hypometabolic zone (1990). The structural basis for hypometabolic zones has suggested a significant correlation with MTS but the size of the hypometabolic zone was much larger than the size of MTS suggesting other functional disturbances (Engel et al, 1982). Frost et al (1988) demonstrated an increased opiate receptor density in the area of the hypometabolic zone suggesting a neurotransmitter basis for the hypometabolic zone.

The results of PET in other epilepsy centers are quite comparable with those of the UCLA group, showing a focal hypometabolic zone in approximately 70% of patients. Comparison studies of PET with MRI suggested that PET is more sensitive than MRI except for foreign tissue lesions (Sperling et al, 1986).

The spatial resolution of PET has improved significantly from 17mm to 7mm in the recent generation PET scanners. In addition, development of software programs enabled the superimposition of PET imaging onto MR imaging, thus exact anatomical localization of the hypometabolic zone in PET became possible.

SPECT

With the development of new radiopharmaceutical agents acting as cerebral blood flow agents, cerebral perfusion study by using SPECT became possible (Holmes, 1986).

Compared to PET, facilities for SPECT are widely available and are much less expensive, thus more wide clinical use can be expected. In addition, the cost and quality of imaging was significantly improved by the development of Tc99m compound. Another advantage of SPECT is that ictal or postictal SPECT imaging can be done much more easily than PET (Lee et al, 1986). For PET, obtaining ictal study is practically very limited because the half of positron compound is very short (113 minutes for F-18 FDG), thus ictal study can be done only in unusual occasions such as status epilep-

Fig. 3. Interictal HIPDM-SPECT in a patient with right temporal lobe seizures. Regional cerebral perfusion was decreased in the right temporal lobe during AED treatment, which had been increased during AED withdrawal. The patient did not have any seizure activity within 24 hours of interictal studies.

A: transaxial slices

B: coronal slices

ticus, induced seizures, or when the patient developed seizures fortuitously immediately after the injection of positron compound (Chapman, 1983). Also, because the final image of PET basically represents the average of approximately 40 minutes of metabolic rate, ictal hypermetabolism is often canceled by postictal hypometabolism. Therefore, the final image of ictal PET shows quite diverse patterns of mixtures of hypo and hypermetabolism (Engel et al, 1983). On the other hand radiopharmaceuticals for SPECT blood flow imaging have a longer half life; 13 hours for I-123 compounds and 6 hours for Tc99m (Holman et al, 1985), which make it easier for injecting these compounds during ictal or immediate postictal stage by preparing the agents at the bedside. Brain uptake of the radiopharmaceuticals (Holman et al, 1985; Kung et al, 1983; Sharg et al, 1986) is rapid and its peak concentration remains stable at least for 60 minutes, which provides better temporal resolution for transient ictal phenomena and enough time for scanning procedure. Initial SPECT studies were mainly investigated by using I-123 compound (Holman et al, 1984; Kung et al, 1983; Lee et al, 1986; 1987; 1988; Sanabria et al, 1983; Sussman et al, 1986); IMP and HIPDM. Interictal SPECT studies

reported focal hypoperfusion in approximately 60% of patients with CPS (Sanabria et al, 1983; Sussman et al, 1986; Weyne et al, 1990). However, recent studies using HMPAO with a higher spatial resolution scanner reported approximately 50% sensitivity (Rowe et al, 1989), thus the sensitivity of interictal SPECT seems to be a little lower than that of PET. However, one interesting feature of interictal SPECT is that the cerebral blood flow in the epileptogenic region is not necessarily constant. Lee et al (1988) reported a few cases which have shown a change of rCBF from decreased to increased in the epileptogenic region when interictal SPECT was repeated especially during the stage of AED withdrawal (Fig 3). The clinical significance of this finding is not clear but it may suggest that the demonstration of alteration of focal rCBF in repeated SPECT may provide confirmative evidence of the epileptogenic region just like combined interictal and ictal SPECT studies.

An advantage of SPECT over PET is its easier capability of ictal SPECT. Simple demonstration of decreased rCBF in an interictal study does not prove that the region is epileptogenic because non-epileptogenic lesions may also show decreased rCBF.

Fig. 4. Interictal and ictal HIPDM-SPECT in a patient with right temporal lobe seizures. Interictal study showed decreased cerebral perfusion in the left temporal lobe which changed into focal hyperperfusion during ictus.

Therefore a thorough EEG investigation is still important to prove that the lesion is in fact epileptogenic. On the other hand, demonstration of increased rCBF by ictal study in the focal region which showed decreased rCBF in a previous interictal study provides clear evidence of epileptogenicity (Lee et al, 1988) (Fig 4). The sensitivity of ictal SPECT is very high because rCBF during ictal stage usually increases by 2 to 3 times. Lee et al (1988) reported that among 14 patients with unilateral temporal lobe epilepsy, focal increase of rCBF in the epileptogenic region was seen in 13 patients even during secondarily generalized tonic-clonic seizures (Lee et al, 1987). In two patients with bitemporal foci, ictal study showed no definite focal increase of rCBF. Recently Weyne et al (1990) indicated that combined interictal and ictal I-123 HIPDM-SPECT successfully localized the epileptogenic region in 93% of patients with temporal lobe epilepsy.

Recently, SPECT imaging in epilepsy has mainly used Tc-99m compounds because Tc-99m is widely available, cheaper than I-123, and higher doses can be safely injected for better spatial resolution (Sharp et al, 1986). However, the half life of HMPAO, the most

commonly used agent, is only 15 minutes. Therefore, for ictal study, HMPAO is kept at the bedside in a dry powdered form. When the patient develops a seizure, a nurse should first mix HMPAO and Tc-99m solution before its intravenous injection, which takes a little more time than a direct injection of prepared solution. It is our experience that Tc99m-HMPAO is usually injected during immediate postictal stage not during the ictus. It is obvious that increased rCBF during ictus rapidly returns to its baseline or hypoperfused state during the postictal stage. Therefore, postictal HMPAO-SPECT may show either hyper, hypo or normo perfusion which can make its interpretation somewhat difficult. It is certainly likely that earlier IV injection of HMPAO may show a focal hyperperfusion in the epileptogenic region.

Rowe et al (1989) reported that combined interictal and postictal HMPAO-SPECT correctly localized in 73% of their cases, which is significantly lower than HIPDM-SPECT. This shortcoming of HMPAO may be resolved with Tc99m ECD (Walovitch et al, 1988), which is very stable in dissolved solution although ictal ECD-SPECT study has not been reported yet.

Development of new radiopharmaceuticals and combination of interictal and ictal SPECT may significantly improve the localization of the epileptogenic region at least in temporal lobe epilepsy. Ictal SPECT in extratemporal cases has not been extensively investigated yet but seems much less sensitive in our experience. We certainly need more research in this field.

CONCLUSION

Epilepsy surgery, especially focal resective surgery including ATL provides a reasonable chance of relief from recurrent seizures. The cost of epilepsy surgery including presurgical evaluation is high but requires highly trained personnel and organized teamwork. The cost of epilepsy surgery is easily justified when a significant number of patients can be freed from the continuous threatening of their social existence due to recurrent seizure attacks. In North America the annual number of epilepsy surgery cases rapidly increased from 100 cases to 1500 cases over the past decade. In Korea, approximately 6000 to 10,000 patients can be helped by epilepsy surgery but only 10 operations per year are performed. We certainly need more epilepsy surgery programs but with a high quality medical standard to provide adequate medical help.

We should admit that epilepsy surgery is risky not only because of surgical technique itself but also the possibility of mislocalization of the epileptogenic region. Therefore epilepsy surgery cannot be done casually but requires a thorough investigation made by qualified and competent specialists. Considering that epilepsy is a major chronic illness affecting mainly young and productive social populations, many countries including neighboring Japan have been active for organizing epilepsy centers where comprehensive medical, surgical and rehabilitation programs can be provided. In our social environment, support for the program by the government or other social institutions is certainly a high priority.

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