USE OF INTRACRANIAL NEUROPHYSIOLOGIC RECORDING TECHNIQUES IN THE EVALUATION FOR EPILEPSY SURGERY IN CHILDREN

S H Lim, P Pillay, H Lüders, H Boenigk

ABSTRACT

Resective surgery is an accepted treatment modality for medically intractable focal epilepsy in children as well as in adult. During the presurgical evaluation processes, intracranial neurophysiologic recording of epileptiform abnormalities have been used much more commonly in adults and older adolescents than in infants and children. However, as infants and children are increasingly referred for early surgery in many centres, it may be necessary to study complex cases in some children with invasive electrodes in order to plan a safe and effective resection. This article gives first an overview of the rationale and indications, with case illustrations, for using these techniques. This is followed by general discussions on individual electrodes and their use in infants and children.

Keywords: Epilepsy, Surgery, EEG, Intracranial recording, Children.

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INTRODUCTION

The surgical management of epilepsy is an important therapeutic option for children with certain types of drug resistant epilepsy [1,2]. Although surgery is often postponed until adolescence or adulthood, modern advances in long-term monitoring and neuroimaging techniques should permit earlier selection of patients who could benefit from surgical treatment. Many more medically uncontrolled patients are therefore being referred for surgery at an earlier age, and an understanding of the benefits and risks of various investigative procedures in children is becoming more important.

In this article, we will limit our discussion to the use of semi-invasive and invasive intracranial EEG recording techniques that are currently employed at the Cleveland Clinic-Bethel Epilepsy Surgery Program for presurgical evaluation of patients with focal epilepsy. EEG recording techniques are considered invasive when a craniotomy is required for electrode placement (subdural grid electrodes), or when the electrodes are implanted into the brain parenchyma (depth electrodes). Other recording methods which require less invasive surgical techniques for placement of electrodes (implantation of epidural pegs or strips, and foramen ovale electrodes) are considered semi-invasive. An overview of the rationale and indications for using these techniques will be presented first. This is followed by general discussions on individual electrodes and their use in infants and children.

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LIMITATIONS OF EXTRACRANIAL EEG RECORDING TECHNIQUES

Precise localization and delineation of the extent of the epileptogenic zone is one of the main objectives of the extensive presurgical evaluation process. The epileptogenic zone is defined as that part of the brain from which seizures can arise and removal of which will result in complete cessation of seizures. Among the various methods (eg clinical, electrophysiologic and neuroimaging studies) used in the determination of the location and extent of this epileptogenic zone, interictal and ictal EEG recordings usually provide the most precise and specific information. In approximately half the cases, non-invasive extracranial EEG recordings with scalp and sphenoidal electrodes give electrophysiologic information which is convergent with all the other diagnostic tests and no further intracranial recordings are necessary[3]. This is especially the case for patients with mesial temporal lobe epilepsy in which the epileptogenic zone usually consists of the amygdalo-hippocampal complex and the immediately adjacent temporal neocortex, making precise delineation of the extent of the epileptogenic zone redundant. For the rest of the cases, however, precise delineation of the epileptogenic zone cannot be made without additional intracranial recordings. This is usually the case in young children (under age 5 years) in which mesial temporal sclerosis is relatively infrequent as a cause of medically intractable seizures. In these cases, the interictal and ictal surface EEGs do not provide sufficiently precise information to define exactly the location and/or extent of the epileptogenic zone. In addition, in some cases, the interictal and/or ictal epileptiform discharges may not be detected on the surface at all due to the inherent limitations of extracranial EEG recording techniques explained below.

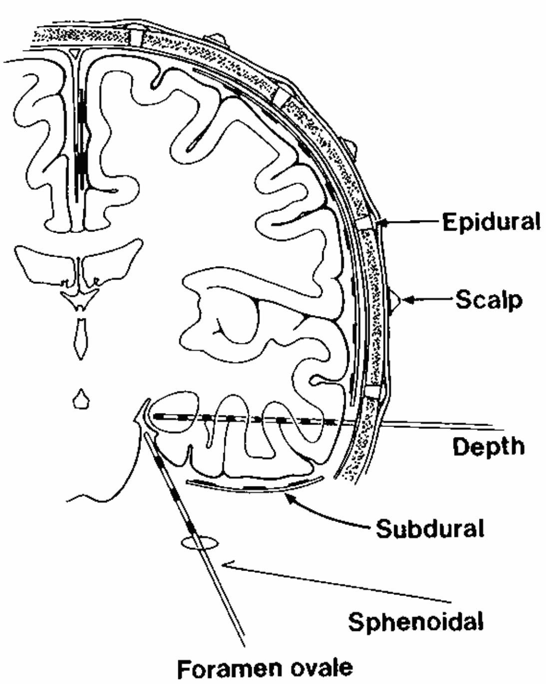
Surface EEG detects only a portion of the underlying brain electrical activities, namely those extracellular electrical events volume conducted to the scalp surface[4,5]. The amplitude of a recorded electrical signal is inversely proportional to the square of the distance between the source and the recording electrode[5]. This explains why deep seated potentials (eg in orbitofrontal, interhemispheric region or in the depth of sulci) may not be recorded at all from the surface. The EEG signal is also attenuated significantly by the impedance of the intervening brain tissue, meninges, skull and scalp. Faster EEG frequencies (>15 Hz) tend to be attenuated more by these intervening layers[6,7]. In addition, most generators are relatively widely distributed on the brain surface and in these cases the orientation of the generator plane with respect to the recording electrode greatly affects the amplitude of the recorded potential[5].

Therefore, when a focal intracranial EEG potential of interest is not detected by surface recording technique, the following factors may be responsible: (a) the scalp electrodes may be too far away; (b) the potential of interest may consist of relatively fast frequencies which are filtered out selectively by the intervening layers; and (c) the electrodes recording from the scalp may have a geometric orientation with respect to the generator surface which results in a small subtended solid angle and, therefore, a relative low amplitude potential[5]. In addition, even if an intracranial event is recorded from the surface, the possibility that it reflects propagated potentials which may be misleading cannot be excluded.

ADVANTAGES OF INTRACRANIAL RECORDINGS

Intracranial EEG recording techniques are more sensitive for the detection of epileptogenic activity because (a) of their greater proximity to the epileptogenic zone, and because (b) of their intracranial locations which reduce the electrical resistance between the source and the recording electrodes. In general, the sensitivity of the intracranial electrodes is directly related to the invasiveness of the procedure[12]. For example, for an epileptogenic zone in the mesial temporal region, the sensitivity of the electrodes increases progressively when we record from the scalp, sphenoidal, foramen ovale, subdural and depth electrodes (Fig 1).

Fig 1 - Schematic drawing of coronal section of the brain at the level of temporal lobe showing the positions of different electrodes



LIMITATIONS OF INTRACRANIAL RECORDING TECHNIQUES

Intracranial recordings are not always necessarily better than extracranial recordings. With increasing invasiveness, there is a progressively greater risk of complications ranging from essentially no complications with non-invasive electrodes, minor and usually transient complications with semi-invasive electrodes to infrequent but occasionally serious and irreversible complications with invasive electrodes[8,9]. The risk is directly proportional to the number of electrodes inserted. Also, with increasing invasiveness, recordings tend to sample electrical activity from a progressively smaller region of the brain. For example, scalp and sphenoidal electrodes permit screening of most of the convexity of the brain and the basal fronto-temporal region. This is in clear contrast to depth electrodes inserted in the mesial temporal regions which sample only activity from the mesial structures and a few points of the temporal neocortex (Fig 1). This is one of the greatest potential pitfalls of invasive EEG recording techniques, especially if the electrodes are inaccurately placed. This will lead to wrong localization or false lateralization.

Because of these limitations and particularly because of its potential risks of complication, intracranial EEG recording techniques should only be used when the epileptogenic zone cannot be delineated precisely with detailed non-invasive techniques. In choosing the type of invasive recording techniques, one should select a method that is sufficiently sensitive to answer the question defined by the non-invasive diagnostic methods, but is least invasive. One should also use the smallest number of electrodes possible because the risk of an invasive procedure is always directly proportional to the number of electrodes used.

INDICATIONS FOR INTRACRANIAL RECORDINGS

The indications for intracranial recording will be discussed subdividing the candidates for surgery of epilepsy in the following 3 groups.

Group I: Patients with bilateral mesiotemporal epileptogenic zones.

These are cases in which the presurgical non-invasive workup has localized the epileptogenic zone with relative confidence to the mesiotemporal structures and the only question still open is, if the epileptogenic zone is localized in the left or right mesiotemporal area. These patients have one or more of the following findings in the non-invasive diagnostic procedures: bitemporal independent inter-ictal epileptiform discharges, non-lateralized ictal surface EEGs, discrepancy between EEG and neuroimaging findings, discrepancy between ictal semiology and EEG findings, or ictal semiology supporting 2 seizure types arising from the left and right temporal lobes. This group constitues approximately 10-20% of patients with medically intractable epilepsy who undergo intensive monitoring and the majority of them have bilateral mesiotemporal sclerosis. These patients require evaluation with bilateral temporal depth electrodes to determine the side of seizure origin[3,8,10-16].

Case illustration

JC is a 5-year-old right-handed white male with medically intractable psychomotor seizures since the age of 4 years. The etiology is unknown. His seizures are preceded by an aura of bad taste, followed by staring, unresponsiveness, oral and gestural automatism, and non-versive head turning to the left. He has mild mental retardation. The MRI of the brain is normal.

Non-invasive monitoring with scalp and sphenoidal electrodes recorded interictal epileptiform discharges from the right (95%) and left (5%) mesial temporal regions (maximum at sphenoidal electrodes). Four typical auras were recorded but did not show EEG change. Six habitual psychomotor seizures were recorded. EEGs showed ictal changes lateralized to the left hemisphere in 5 seizures (Fig 2a), and the right hemisphere in the other (Fig 2b). None of these showed prominent contralateral involvement.

Fig 2a - Scalp EEG showing a left temporal regional ictal onset

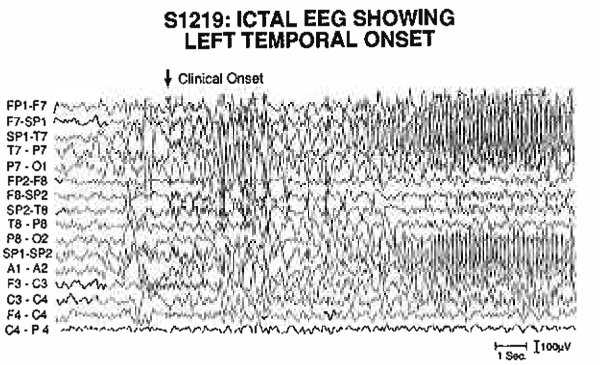
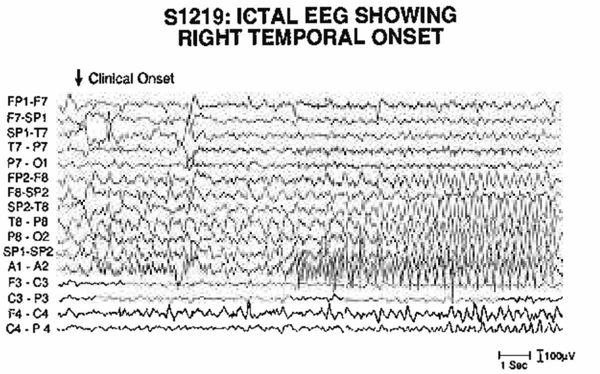


Fig 2b - Scalp EEG showing a right temporal regional ictal onset



It was felt that this patient may have bilateral mesiotemporal epileptogenic zones even though this condition is extremely rare in this age group. He is a candidate for bitemporal depth electrode implantation to determine the side of predominant seizure onset prior to planning surgery.

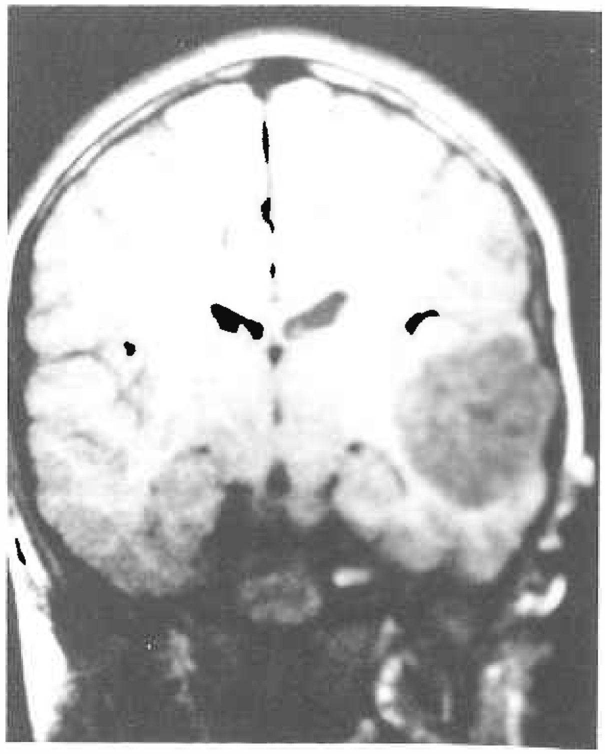
Group II: Patients with unilateral extramesiotemporal epileptogenic zone(s)

Patients in this group suffer from neocortical epilepsy. In patients with neocortical epilepsy, the epileptogenic zone is usually more extensive than in patients with mesiolimbic epilepsy. This means that a much larger area of cortex needs to be screened, especially when there is no structural lesion. In addition, the epileptogenic zone may be close to or overlap eloquent areas of cortex. In order to precisely delineate the extent of the epileptogenic zone(s) for resection and to define the functionally important cortex so as to avoid additional neurological morbidity from resection, subdural electrode recordings with functional mapping is the technique of choice[3,8,17-28].

Case illustration

DT is a 15-year-old right-handed white male with intractable psychomotor seizures since the age of 5 years. The etiology is most likely related to an astrocytoma (confirmed by biopsy) in the left temporal lobe. Neurological examination was normal. MRI of the brain showed a mass lesion in the left mid- and posterior temporal region (Fig 3a). Wada test showed bilateral representation of language and memory.

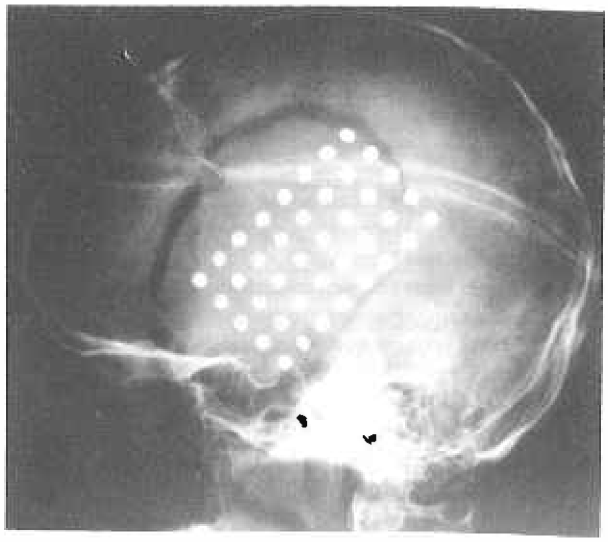
Fig 3a - MRI of the brain showing the location of the tumour



Non-invasive monitoring recorded interictal discharges from the left posterior temporal (60%, maximum at P7) and the left mesial temporal (40%) regions. Two psychomotor seizures, one with ictal EEG changes maximal in the left anteromesial temporal region and another one showing diffuse left hemispheric involvement, were recorded.

He had invasive EEG recordings with a 5 X 8 subdural grid over the left lateral temporal convexity (Fig 3b) with the tumor situated directly below the center of the grid. Due to the size of the tumor, a basal temporal subdural grid could not be inserted. Interictally, epileptiform discharges were recorded more frequently from the electrodes posterior to the tumor (65%) (Fig 3c). Six identical psychomotor seizures were re-

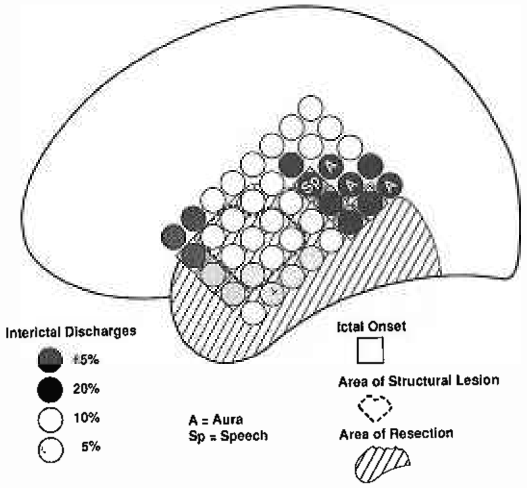
Fig 3b - Skull X-ray showing the left temporal convexity subdural plate



corded. Four seizures showed focal EEG onset in the electrodes posterior to the tumor while the other two showed regional onset in the electrodes anterior to the tumor (Fig 3c). Extra-operative functional mapping showed that Wernicke's language area was located just behind the posterior margin of the tumor but in front and above the posterior epileptogenic zone (Fig 3c). A left temporal lobectomy with removal of the mesial structures and the tumor was performed. Wernicke's area and part of the posterior epileptogenic zone remained untouched. Postoperatively he did not have speech deficit. He has had no seizures for 6 months post surgery.

This case illustrates the usefulness of subdural electrodes in defining precisely the extent of the epileptogenic zone and its relationship to the adjacent functional area.

Fig 3c - Schematic diagram showing the interictal and ictal epileptiform activities recorded from the subdural electrodes, the location of the tumor in relation to the electrodes, the results of the functional mapping, and the area of cortical resection



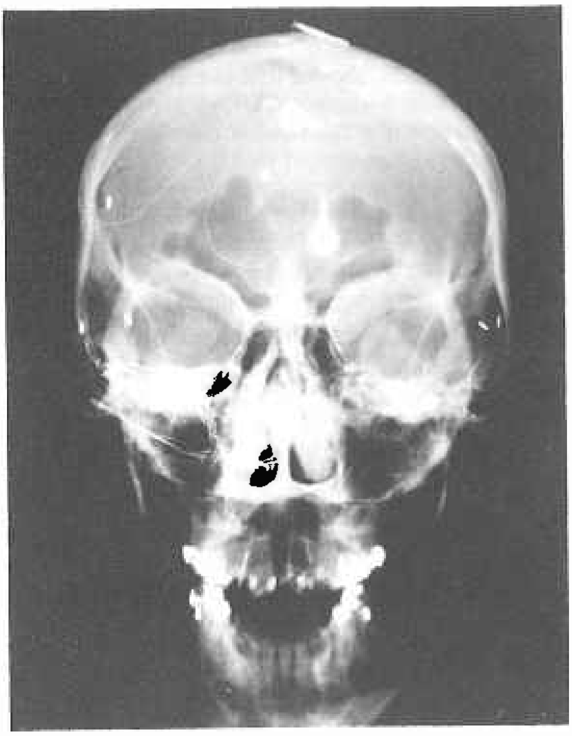
Group III: Differential diagnosis between mesiotemporal and extra-mesiotemporal epilepsy.

This group includes patients in which the presurgical diagnostic procedures cannot define if the epileptogenic zone is in the mesiotemporal or in the ipsilateral extramesiotemporal region. It includes patients in which the interictal epileptiform activities are recorded from mesio-temporal and extramesiotemporal regions on the same side, and the ictal EEG may at best lateralize but not localize the region of seizure onset. Some of these patients may have extratemporal interictal discharges or structural lesions but seizure semiology is suggestive of temporal lobe epilepsy or ictal EEGs may show maximal temporal involvement. This group of patients will benefit from simultaneous recording with foramen ovale and epidural electrodes before planning for more invasive recordings or surgery[29-33] (Fig 4a).

Case illustration

ST is a 17-year-old right-handed white male with a history of intractable seizures since age 2 years. The etiology is most likely related to severe perinatal asphyxia. He was found to have left hemiparesis and megaencephaly at several months of age. He subsequently required ventriculo-peritoneal shunt placement and many revision of the shunt. His seizures are characterized by an aura of dizziness and blurred vision, followed by jerking of the left hand without loss of consciousness. Clinically he has a mild hemiparesis. MRI of the brain revealed atrophy in the cingulate gyrus and a poorly developed corpus callosum. Wada test showed left hemispheric dominance for speech and memory.

Fig 4a - Skull X-ray showing the position of epidural pegs and foramen ovale electrodes



The non-invasive extracranial monitoring recorded ill-defined sharp transients over the right frontal region (maximum at F4). Ten habitual seizures were recorded, 4 of which were preceded by a feeling of nausea. During the seizures, he had semi-rhythmic "jerking" of left arm, was able to talk and did not show definite impairment of responsiveness. Ictal EEGs showed right hemispheric involvement but could not be more precisely localized. At that time, it was felt that he had a diffuse epileptogenic zone in the right frontal lobe and his habitual seizures were of right perirolandic in origin. There was no suspicion of temporal lobe epilepsy.

He underwent semi-invasive monitoring with bilateral epidural pegs (more electrodes were placed over the right fronto-centro-temporal region) and foramen electrodes to better define the epileptogenic zone. Interictally, he had independent discharges recorded from the right mesial temporal region, in addition to those recorded from the right lateral temporal and right fronto-central regions (Fig 4b). Ten habitual seizures were recorded. This time he demonstrated dystonic posturing in addition to what appeared to be an automatism of the left upper extremity. Variable impairment of responsiveness was seen in 3 of the seizures. Ictal speech was again recorded. Ictal EEG changes consistently appeared first in the right foramen ovale electrodes before involving the right lateral convexity epidural electrodes (Fig 4c). The patient had a standard right temporal lobectomy and has been seizure free for 9 months.

This case illustrates the usefulness of simultaneous recording with epidural peg and foramen ovale electrodes in differentiating mesiotemporal from extramesiotemporal epilepsy. In addition, without this intermediate evaluation stage, the patient would have been subjected to unnecessary invasive recordings with subdural electrodes.

SUBDURAL AND EPIDURAL GRIDS/STRIPS ELECTRODE

1. Design of electrodes and method of placement

These electrodes are usually made of small (2-4 mm diameter), relatively thin (<1 mm) discs of stainless steel, platinum or

Fig 4b - Independent interictal epileptiform discharges recorded from the right foramen ovale electrodes (maximum at F02) and epidural pegs (maximum at ET8, EFT10, and EFC4). FO: foramen ovale; E: epidural

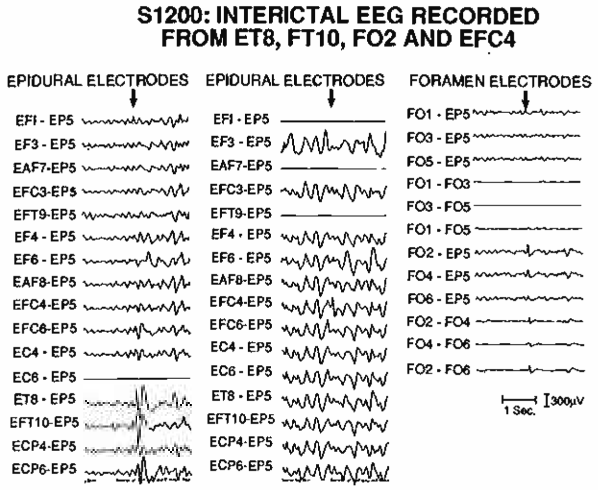
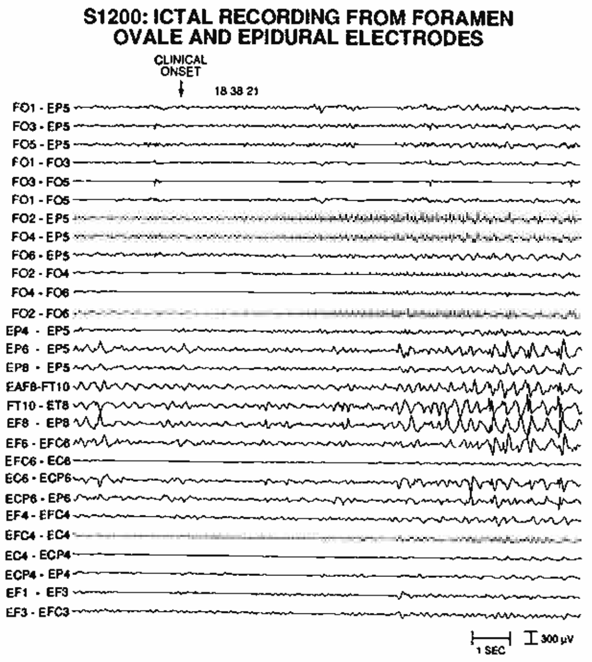


Fig 4c - Ictal epileptiform discharges recorded from F02 before involving the right centro-temporal epidural electrodes



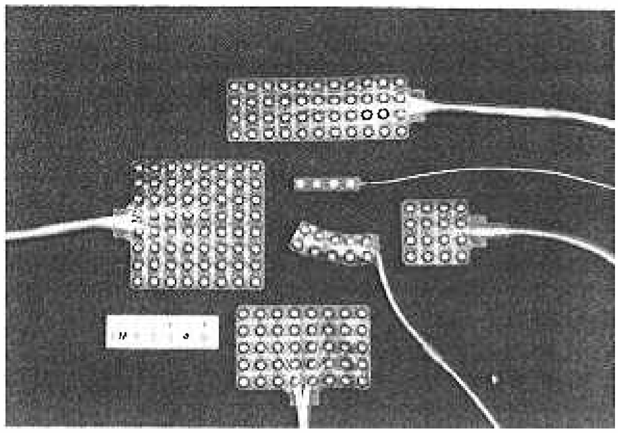
nichrome (80% chrome and 20% nickel), which are embedded in a sheet of medical grade silastic (approximately 1.5 mm thick). Platinum or nichrome electrodes have the advantage that they produce significantly less artifact during MRI studies. These discs are arranged in strips or grids with an interelectrode distance of 1 cm. Each electrode is soldered to a stainless steel multi-stranded wire which is insulated with a teflon coating. All the wires form a bundle which is covered with a thin silastic tube and terminates in one or more connectors.

These electrodes can be manufactured in different shapes and sizes (Fig 5) to cover different brain regions. Through a craniotomy, these electrodes can be placed subdurally or epidurally over the convexity, or into the basal temporal, basal frontal or interhemispheric regions. Subdural placement of the grid is preferred at the Cleveland Clinic-Bethel Epilepsy Surgery Program because the electrodes are closer to the cortex, and adequate functional mapping can be performed without causing pain due to electrical stimulation of the dura.

2. Advantages and indication

In patients with focal neocortical epilepsy, subdural or epidural grid/strip electrodes have the advantage over other types of electrode in that they can be implanted subacutely over

Fig 5 - Different sizes and shapes of subdural electrodes



extensive areas of neocortex to record interictal and ictal epileptiform abnormalities. This permits relatively precise delineation of the epileptogenic zone(s). In addition, they allow electrical stimulation and recording of evoked potentials which represent the most powerful method to define the eloquent cortex surrounding the epileptogenic focus[3,8,17-24,27]. In many cases with neocortical epilepsy, this information is essential to permit safe removal of the epileptogenic zone without producing neurological deficits.

3. Limitations and disadvantages

These electrodes cannot be placed in the immediate proximity of epileptogenic foci which are relatively deep seated such as the amygdalo-hippocampal complex, and deep sulci or fissures (Fig 1). In this regard, it is important to remember that a high percentage of the neocortex, even the one lying over the convexity of the hemispheres, will not be covered directly by subdural electrodes because of the numerous infoldings of the cortex. Only depth electrodes which are inserted directly into brain can record from the immediate proximity of these areas.

Ideally, the grid of subdural electrodes should be placed in such a way that the epileptogenic zone is located close to the center of the grid. Unfortunately this objective is very difficult to achieve. The most frequent reason for misplacement of a grid of subdural electrodes is insufficiently precise definition of the location of the epileptogenic zone (in the absence of a structural lesion) by the non-invasive presurgical workup. In many cases this problem may be overcome by the use of epidural peg electrodes which permit better definition of the approximate location of the epileptogenic zone so as to guide the subsequent placement of subdural electrodes[17,33]. In other instances, inadequate placement of the plate of subdural electrodes is due to technical difficulties.

Another disadvantage of this technique is the risk of complications (4.4%-14%) like infections, transient rise of intracranial pressure, hemorrhage, aseptic bone flap necrosis, or transient hemiparesis[8,9,27].

4. Considerations in children

As children have difficulty tolerating craniotomy under local anaesthesia, extraoperative intracranial EEG recording and cortical stimulation are preferred. The efficacy of subdural or epidural grids in determining the extent of epileptogenic zone is equally good in children and adults[24,27,28]. This is due to the fact that children above 5 years of age have their head size approaching 90% of that of adult and, therefore, there is no problem in placing as many subdural electrodes as are usually placed in adults. However, in infants and very young children, there are limitations regarding cortical stimulation studies. This is probably related to the relative inexcitability of the cortex in this age group[22,24,28]. Other factors such as poor co-operation, language immaturity or delayed cognitive development are also interfering occasionally with the cortical mapping studies[24]. However, evoked potentials to median nerve stimulation can easily be obtained at any age and are helpful to localize the somatosensory area[24,28].

EPIDURAL PEG ELECTRODES

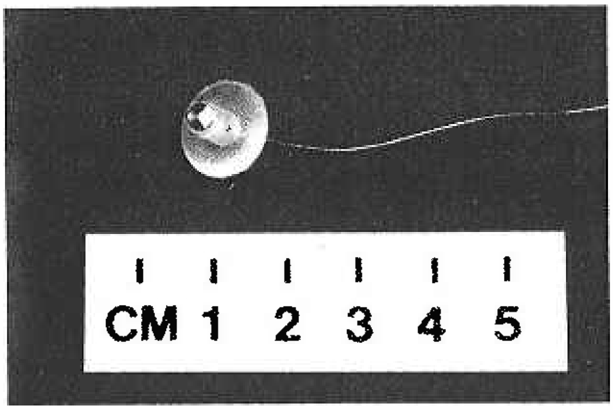
1. Design of the electrodes and method of placement

One version of epidural electrodes includes small flexible silastic mushroom-shaped pegs with an electrode disc on the bottom of the stalk and a wire emerging from top of the cap (Fig 6). The stalk is inserted through a small twist drill hole so that the electrode disc lies on top of the dura, the cap lies over the bone and under the scalp, and the wire is pulled out away from the small incision[17,33].

2. Advantages and indications

Epidural pegs may be inserted over widespread areas in one or both hemispheres. As discussed earlier, these electrodes are

Fig 6 - Epidural peg electrode



used in the intermediate workup stage to allow better definition of the location of the epileptogenic zone in patients with suspected neocortical epilepsy, and to allow more accurate placement of the grid of subdural electrodes if indicated subsequently[17]. In some cases, the information obtained from the epidural recordings may reject candidates for more invasive evaluation because of finding of a more diffuse or multifocal epileptogenic zone(s).

3. Limitations and disadvantages

Epidural peg electrodes usually do not permit precise definition of the epileptogenic zone. Functional mapping is also limited to recording of evoked potentials because of pain induced during electrical stimulation on the dural matter. Infection and bleeding may occur very rarely[17].

4. Considerations in children

This technique is very helpful in the evaluation of multifocal or extra-temporal epilepsy which are more common in children. However, the reported experience in infants and children is limited. At the Cleveland Clinic-Bethel Epilepsy Surgery Program, it has been used in children as young as 8 years old. The major potential problem in children under 2 or 3 years of age is skull thickness. They have relatively thin calvaria which usually is not adequate to anchor the pegs so that they stay in place. As the anterior fontanelle may persist up to 18 months, placement of midline epidural pegs may have to be avoided.

FORAMEN OVALE ELECTRODES

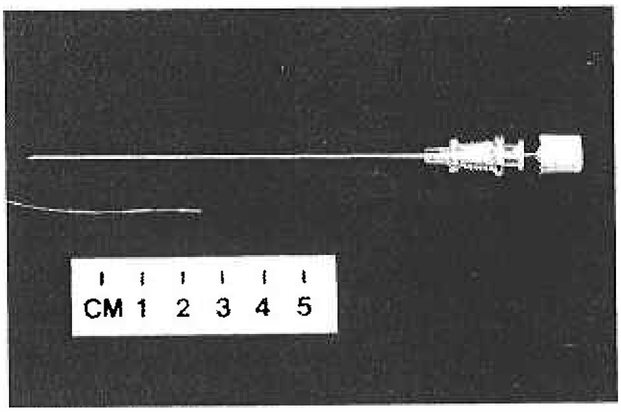
1. Design of electrodes and method of placement

The electrodes consist of three stainless steel or platinum pellets embeded in a teflon tube (Fig 7). The contacts are usually 1.5 centimeters apart and the wires run through the teflon tube and exit the tube at a connector. The electrodes are inserted percutaneously through a small incision in the cheek, advanced up through the foramen ovale under fluoroscopic guidance and into the subdural space next to the mesial temporal structures.

2. Advantages and indications

As the electrodes are in close proximity to the mesiolimbic structures, they are ideally suited for the study of patients with

Fig 7 - Foramen ovale electrode



mesio-temporal epilepsy[17,30-32]. In some cases the information obtained from the use of these electrodes is sufficiently precise to proceed directly with resective surgery[31,32] avoiding the need for a more invasive, and therefore, also more risky evaluation. When combined with epidural peg recordings, they are extremely useful to differentiate mesiotemporal from extramesiotemporal epilepsy.

3. Limitations and disadvantages

There is still insufficient evidence to define if these electrodes are as precise as depth electrodes for lateralizing seizure onset in patients with bilateral mesiotemporal epilepsy. Potential complications include occasional transient trigeminal neuralgia, infection and rare subarachnoid hemorrhage. All these complications are extremely rare.

4. Considerations in children

An extensive series of foramen ovale electrodes in children is not yet available. The youngest reported patient was 9 years old[31], and the Cleveland Clinic-Bethel Epilepsy Surgery Program's experience includes an 8-year-old patient. There appears to be no special contra-indication to the use of these electrodes in younger patients.

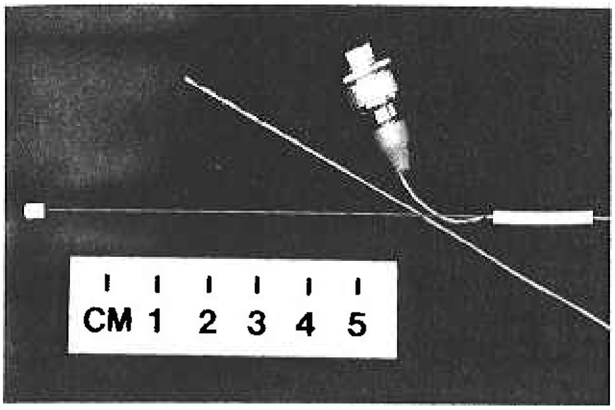
DEPTH ELECTRODES

1. Design of electrodes and method of placement

The electrodes consist of multiple contacts of approximately 3 to 5 mm in diameter with inter-contact intervals of 0.5 cm starting from the tip. The number of contacts is usually 6 to 12 (Fig 8a). The materials for electrode contacts are stainless steel, nichrome alloy and platinum. The latter two have the advantage of allowing magnetic resonance imaging for verification of electrode position with relatively less distortion artifacts.

Depth electrodes can be placed through burr holes or twist-drill holes in a variety of locations but are used primarily for the evaluation of epileptogenic zones in the mesial structures of the temporal lobe. Their precise placement requires the use

Fig 8a - Depth electrodes

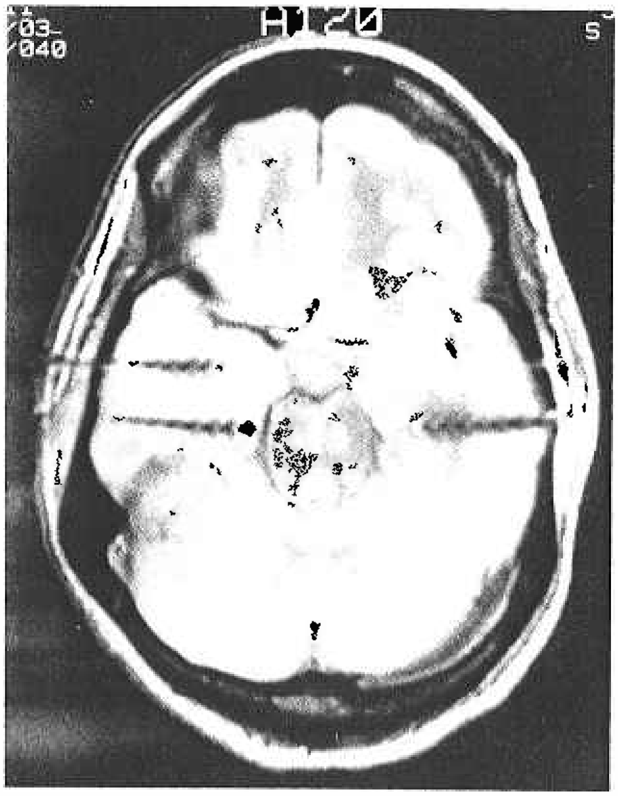


of MRI-guided stereotactic methods. At the Cleveland Clinic, the Cosman-Roberts-Wells and Kelly/Compass stereotactic system have been used in conjunction with MRI-guidance to place the depth electrodes. The trajectory of electrode implantation is largely determined by the stereotactic system favored by the neurosurgeon[10-16]. The longer the trajectory pathway, the greater the chance of inaccurate placement and the greater the risk for complications. For these reasons, the orthogonal approach in the horizontal plane to the mesial temporal structures is currently employed in many centers (Fig 8b). This approach also permits sampling from mesial and lateral temporal sites [10-12,16,34]. A single epidural peg electrode concurrently placed in the midline is used as the reference.

2. Advantages and indications

With accurate placement, depth electrode recordings offer definite advantage over all other types of recording techniques in

Fig 8b - Axial view of an MRI showing the position of bitemporal depth electrodes



confirming seizure onset, by earlier detection of electrical events, starting in the mesial temporal limbic structures[11-16]. As discussed earlier, bilateral temporal depth electrodes are extremely useful in lateralizing seizure onset in patients with mesiotemporal epileptogenic zones. Extratemporal depth, subdural strip, or epidural peg electrodes have been used, in conjunction with mesiotemporal depth electrodes, to confirm or exclude a mesiotemporal epileptogenic zone in patients in which the non-invasive diagnostic evaluation could not decide between a mesiotemporal and an extramesiotemporal epileptogenic zone.

3. Limitations and disadvantages

Depth electrodes record from the most restricted portion of the brain because of their limited number of sites of sampling. Events which are truly focal in origin can be falsely localized or lateralized if studied with inappropriately placed depth electrodes. In addition, depth electrodes can only sample isolated points of the neocortex and therefore can provide incomplete information regarding possible independent epileptogenic zone(s) of the neocortex. Depth electrodes also do not allow functional mapping. They have a 0.5-5% morbidity mainly from haemorrhage and infections and fatal complications have also been reported[9,11].

4. Considerations in children

Infants and children usually have extramesiotemporal epilepsy. Mesio-temporal epilepsy, especially bitemporal epilepsy, is uncommon in children under 10 years of age[35]. This is certainly one of the reasons for the lack of experience in using depth electrodes in this age group. However there is no special contraindication to their use in young children. Stereotactic head frames may be placed without difficulty in children above 5 years of age, as their head size at 5 years is 90% of adult size.

CONCLUSIONS

Although semi-invasive and invasive neurophysiologic techniques have been used much more extensively in adults and adolescents than in children and infants, their demand will increase as more patients are being referred for early surgery. Despite the limited experience with these techniques in young patients, it appears that they are as effective and well tolerated in children as in adults. Semi-invasive and invasive electrodes, however, have a definite risk of complications. Therefore, the need for these techniques should be always evaluated carefully, and for each case the least invasive technique which permits adequate localization and definition of the epileptogenic zone should be chosen.

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