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HOW TO RESTRICT THE EXTENT OF CORTICAL RESECTION: ECOG UTILIZATION

Direct recording of electrical activity from the exposed cortex during surgical procedures (electrocorticography – EcoG) is not only and aid to surgical therapy of epilepsy, but gives more precise information concerning the electrical manifestation of epileptic discharge. It has been employed for almost five decades in the surgical treatment of people with medically refractory epilepsy (Penfield and Jasper, 1954). The main reason for recording an ECOG has been to confirm and outline the actual site and extent of the epileptogenic process prior to resection. After the resection has been completed, ECoG has been used to determine if all the potentially epileptogenic tissue has been removed – postoresection ECoG. Equally, both of these roles have been questioned. Some studies pointed out similar outcomes in patients with total or partial removal of the irritative zone as defined by ECoG (Keene, Whiting and Ventureyra, 2000). For this reason, ECoG was abandoned in some centers, but continues to be performed in others, as an adjunctive technique in the definition of the irritative zone.

TECHNIQUE

The ECoG records the same type of cerebral potentials as the scalp electroencephalogram, except that the dispersion and attenuation of the potential by the scalp and skull is not present. In theory, this should allow for better localization of the origin of the epileptogenic tissue causing the patient's habitual seizures. Practical use of the results obtained in the operating room depends from good collaboration between neurologist and neurosurgeon. Because of the short recording time available for ECoG and the limitations of electrode placement posed by the surgical exposure, the possibility of recording ictal events is rare. The ECoG relies on the presence of interictal epileptiform discharges for the identification of the irrita-

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tive/epileptic zone. Careful preoperative planning is mandatory. The clinical history, electroencephalographic studies (both ictal and interictal), and imaging studies (MRI, interictal FDG-PET) need to be analyzed to define the area of resection and exposure needed for adequate ECoG recording prior to surgery.

The actual technique of recording an ECOG has changed little since its introduction with exception of digital EEG introduction. The clinical neurophysiologist must be able to read and interpret the recording as it is being done in the operating room. Of course, this requires that the recording apparatus be in the operating room.

Standard sixteen channel EEG equipment can give very adequate ECoG recordings but even four channels may give necessary information. Either flexible ball electrodes mounted on a fixed horseshoe frame (as Penfield disecribed (Penfield and Jasper, 1954)) or a series of electrodes implanted in a soft flexible silastic grid can be used. The advantage of the ball electrodes over strip electrodes is that they can be sterilized and reused, cutting down costs. Due to the lack of adequate sterilization techniques, silastic implanted electrode should be used only once. We mainly perform ECoG with four contacs strip electrodes, and the results are comparable with denser strip electordes. As ECoG records directly from the brain, modifications in recording sensitivities, filters, and time constants will be required. Electrodes need to be able to sit on the leptomeninges and move with the pulsations of the brain.

For accurate localization of the epileptogenic area, the electrodes need to be placed an equal distance apart. Montages should consist of a minimum of four electrodes in a straight chain (bipolar montages). If simultaneous recording from multiple chains of electrodes is planned, the electrodes must be of equal distance in both vertical and horizontal planes. This will allow for bipolar recordings to be done, as well as, referential recordings. Since we use single chain of electrodes (4 contact strip electrode), both referential and bipolar recordings are done simultaneously. Various referential electrode placements can be used (such as mastoid, cervical region, frontal region and bone flap). To record from the deeper structures (such as the mesial temporal regions) either four contact depth electrode can be inserted through the brain to reach the deeper structure or a flexible silastic four-electrode grid can be inserted under the temporal/frontal region.

Total recording time greatly varies among the centers. Methohexital and alfentanil have been reported to „activate the epileptic zone" (Wilder et al., 1971). These techniques should be done only after adequate standard recordings of the exposed brain have been done (usually 30 minutes). Careful interpretation of the areas of „activation" must be made as the potential to „activate" regions outside the true irritative/epileptic zones has been reported.

Patterns of normal acitivities on ECoG are not stable, but may constantly changing with the general excitatory state of the brain, such as that which occurs in emotional excitement or in sleep. In adults, the ECoG recording is usually done with the patient in the awake state; however, in children this is not often possible. The anaesthetic agents used for the operative procedure can have significant effects on the ECoG. Sufentanil, fentanyl, alfentanil, propofol, methohexital have been reported to produce epileptiform changes on ECoG, whereas halothane, barbituates and benzodiazepines may suppress the epileptic activity (Brain and Seifen, 1987). Both nitrous oxide and isoflurane have been reported to affect the ECOG, but more recent reports have suggested that this is not the case when low concentrations are used (Hosain et al., 1997). For these reasons, it is recommended that in patients be maintained on nitrous oxide, isoflurane and non-depolarizing muscle relaxants be used during ECOG recording. Light pentothal anesthesia or sleep has been found to favor the appearance of epileptiform spikes.

Intraoperative stimulation, the method of choice for more than 100 years, because of its limitation, (anesthesia, time constraints), has been substituted by extra-operative stimulation in chronically implanted patients. Although the chronic implantation of intracranial and subdural electrodes carries the risk of complications like infection, bleeding or infarction, strict antiseptic precautions and restriction of the number of implanted electrodes to the necessary minimum can considerably lower the risk. During the ECOG, electrical stimulation of the cortex has been used to localize the area of epileptic seizure onset, as well as to map the area of cortex responsible for motor, sensory and language functions. Therefore, the best method to achieve reliable and valid results is to stimulate each electrode with stepwise increasing stimulus intensities until either symptoms are elicited, or afterdischarges are produced. Moreover, individual activation thresholds vary over time 12 and depend on factors like anticonvulsant levels. To avoid false negative or false positive results, only those symptoms should be taken into account that are not associated with afterdischarges, and that are reproduced at different times.

NONLESIONAL TEMPORAL LOBE EPILEPSY

According to Rasmussen the removal of the „epileptogenic zone" (the anatomical site of seizure onset), as well as the surrounding tissue which might potentially be recruited into the critical mass of tissue, is required for a successful surgical outcome. ECoG has been reported to provide useful information for the localization in the temporal lobe at the time of surgery (Green, Duisberg and McGrath, 1949). Still, there is modest evidence that actually established the true value of the procedure in this role (Keene, Whiting and Ventureyra, 2000). All that have been published have been in the form of retrospective case studies or case series without a proper control group. Some investigators have questioned the role of this procedure (Walker, Lichtenstien and Marshall, 1960). Epileptiform discharges from the temporal lobe were similar to those recorded from the scalp electroencephalogram, consisting of isolated spikes, brief bursts of spikes or runs of sharp waves. They were often multifocal with a wide distribution over the exposed temporal cortex, and even furter. The distribution of the epileptiform potentials mainly depends from the underlying pathology. More commonly, the epileptiform discharges were reported to have been recorded from the hippocampal structures and inferiomesial surfaces of the temporal tip. To a much lesser extent, they were recorded from the lateral temporal cortices and more so from the posterior temporal cortices (Stefan et al., 1991).

Propagation of the epileptiform discharge was commonly seen from the hippocampus, to and from the subtemporal cortex (Keene, Whiting and Ventureyra, 2000). A possible explanation for the lack of consensus as to the role of the ECoG in the prediction of surgical outcome may lie in the surgical procedure itself. Most centers that have reported the use of ECoG-performed standardized temporal lobe resections. Only a few centers actually tailored the resection according to ECOG findings. In our opinion, ECoG may further extend the margins of the resection (even in pre-planned standardized temporal lobe resection) and contribute to better surgical outcome.

NONLESIONAL EXTRA-TEMPORAL EPILEPSY

Although in wide use in this indication, evidence in support of the use of ECoG in extra-temporal resections is scarce. Authors noted that in patients whose seizures originated in the frontal lobes, there was no clear relationship between the amount of epileptogenic tissue removed and a successful surgical outcome (Keene, Whiting and Ventureyra, 2000). The reason for this may lie in the anatomical and functional peculiarities of this region, which permits the epileptiform discharge to vary in location from a specific region, to multilobular or even bifrontal. Similar findings have been noted in ECOG recordings of patients with seizures arising from the centroparietal region and occipital areas. Our experience with ECoG in apparently nonlesional frontal lobe epilepsy is satisfying. For patients with non-lesional, medically refractory extra-temporal epilepsy, where the presurgical hypothesis was not „strong:, the use of subdural grid electrodes may prove to be superior. As this procedure allows ictal events to be recorded, there is a greater possibility that the epileptic zone will be identified.

LESIONAL EPILEPSY

The use of ECoG in patients in whom structural lesions have been identified on imaging studies remains controversial. Traditional wisdom based on the Montreal Neurological Institute experience holds that optimum seizure control is achieved when the lesion is removed with the surrounding epileptogenic cortex as determined by ECoG (Keene, Whiting and Ventureyra, 2000). This point of view has been supported by Pilcher *et al.* who found that eleven out of twelve patients who underwent surgery for ganglioglioma, were seizure-free at 3.1 years post-surgery compared with a literature control of twenty-one out of thirty-nine (54%) patients with ganglioglioma in whom only the lesion was resected (Pilcher et al., 1993). They noted that the epileptogenic zone was topographically distinct from the region of the tumour-involved brain. It usually encompassed a large surface area. Non-epileptiform high-amplitude slow waves were recorded on ECoG predominantly in tumour-involved cortex, while epileptiform spike discharges were recorded over normal-appearing cortex. They felt that these discharges represented the epileptogenic zone. The removal of this area increased the chance of a better outcome. Others have not felt that ECoG guidance is necessary in this group of patients. Resections have been restricted to the tumour margins as delineated on imaging studies and at the time of surgery. The literature states that if the lesion has not been completely removed, seizures will continue despite the removal of the „epileptogenic zone" (Fried, Kim and Spencer, 1994). These studies have been based on retrospective review of case series. Comparison between ECoG-guided resections and non-ECoG-guided resection for similar groups of lesions have not been prospectively done.

Cortical dysplastic lesions are often associated with severe, partial epilepsies of childhood and can prove refractory to medical management leading to the need for surgical resection. Palmini *et al.* have reported long runs of epileptiform discharges on ECOG consisting of repetitive electrographic seizures, repetitive bursting discharges or continuous rhythmic spiking (Palmini et al., 1995). They felt that these discharges were often co-localized with the magnetic resonance imaging-defined lesion. The completeness of resection of the epileptiform activity on ECoC correlated with the surgical outcome. Focal cortical dysplasia is highly and intrinsically epileptogenic, and intraoperative ECoG identification of this intrinsically epileptogenic dysplastic cortical tissue is crucial to decide the extend of excision for best seizure control.

CONCLUSION

ECoG has a number of inconvenient aspects: the area that can be sampled is limited by the exposure during surgery, and some regions, such as the mesial temporal structures or the medial surface of the brain, are difficult to reach (intraoperative recording from depth electrodes may solve this issue). ECoG prolongs the time of the intervention and requires immediate decision making. In addition, the particular circumstances of the recording during surgery (surgical trauma to brain surface, anesthetic agents that reduce or enhance spikes) may alter the amount and location of the epileptiform abnormalities. For several decades, ECOG recordings have been routinely used in the surgical management of patients with medically refractory epilepsy. Using this technique, confirmation of epileptiform activity on pre-operative scalp electroencephalogram has usually been demonstrated at the time of surgery. It also allows for direct exploration and recording of the mesial surfaces of the cerebral cortex. With this information, tailored resections of epileptogenic tissue can be performed. Whether tailored resections have better outcome than standard resections of the temporal lobe, remains unclear. In order to answer this question, carefully designed, controlled prospective study will need to be done. It is quite possible that the results of ECoG-guided and standard temporal resection will be very similar, when the size and extent of the surgical resection will turn out to be the same in both groups. The role of ECoG in extratemporal and lesional resection is different in the case of temporal resection. The ECoG appears to be beneficial in lesional resections in patients with refractory epilepsy. ECoG use in patients with dual pathology remains unclear. Controlled prospective studies again would be helpful. Extratemporal resections need to be well planned prior to surgery.

Imaging studies such as MRI and PET have proven helpful in localizing the site of epileptogenicity. The degree of electrographic spread of epileptiform discharges suggests that chronic intracranial recordings may be needed to provide more accurate and complete information about the seizure origin than intraoperative ECOG. As an general conclusion ECoG may still contribute to a better delineation of the irritative zone in selected cases, particularly in patients who have not been evaluated with chronic invasive recordings.

REFERENCES

[1] Brain, J. and Seifen, A. (1987) 'Tonic-clonic activity after sufentanil', *Anesth Analg,* vol. 66, pp. 481–483.

[2] Fried, I., Kim, J. and Spencer, D. (1994) 'Limbic and neocortical gliomas associated with intractable seizures: a distinct clinico-pathological group. ', *J Neurosurg*, vol. 34, pp. 815–823.

[3] Green, J., Duisberg, R. and McGrath, W. (1949) 'Electrocorticogra-phy in psychomotor epilepsy', *Electroencephalogr Clin Neurophysiol*, vol. 3, pp. 293–299.

[4] Hosain, S., Nagarajan, L., Fraser, R., Van Poznak, A. and Labar, D. (1997) 'Effects of nitrous oxide on electrocorticography during epilepsy surgery', *Electroencephalogr Clin Neurophysiol*, vol. 102, pp. 340–342.

[5] Keene, D., Whiting, S. and Ventureyra, E. (2000) 'Electrocorticography', *Epileptic Disord*, vol. 2, pp. 57–64.

[6] Palmini, A., Gambardella, A., Andermann, F., Dubeau, F., deCosta, J., Olivier, A., Tampieri, D., Gloor, P. and Andermann, E. (1995) 'Intrinsic epileptogenicity of human dysplastic cortex as suggested by corticography and surgical results', *Ann Neurol*, vol. 37, pp. 476–487.

[7] Penfield, W. and Jasper, H. (1954) 'Electrocorticography', in Penfield, W. and Jasper, H. *Functional anatomy of the human brain*, Boston: Little Brown.

[8] Pilcher, W., Silbergeld, D., Berger, M. and Ojemann, G. (1993) 'Intraoperative electrocorticography during tumor resection impact on seizure outcome in patients with gangliogliomas', *J Neurosurg*, vol. 78, pp. 891–902.

[9] Stefan, H., Quesney, L., Abou-Khalil, B. and Olivier, A. (1991) 'Electrocorticography in temporal lobe epilepsy surgery', *Acta Neurol Scand*, vol. 83, pp. 65–72.

[10] Walker, E., Lichtenstien, R. and Marshall, R. (1960) 'A critical analysis of electrocorticography in temporal lobe epilepsy', *Arch Neurol*, vol. 2, pp. 172–182.

[11] Wilder, B., Musella, L., Van Horn, G. and Schmidt, R. (1971) 'Activation of spike and wave discharge in patients with generalized seizure', *Neurology*, vol. 21, pp. 517–527.