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Extracranial EEG work-up in epilepsy surgery: usefulness and limitations

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Extracranial interictal and ictal EEG provide essential information to diagnosis, seizure/syndrome classification and focus localization. Combined with structural and dynamic neuro-imaging and neuropsychological data, extracranial EEG will often provide sufficient information in preoperative work-up for temporal lobectomy. Ictal EEG recordings are essential to confirm the diagnosis and classification and, above all, to exclude patients with significant non-epileptic seizures from further surgical evaluation. The advantage of sphenoidal electrodes lies first and foremost in a more favorable signal/noise ratio, while their superiority to closely placed special scalp electrodes are more debatable.

Key words: scalp EEG; zygomatic electrodes; sphenoidal electrodes; ictal EEG; seizure classification; pseudo-seizures; neuro-imaging.

The primary paraclinical investigation in epilepsy is the EEG, which provides the main non-invasive "window" to the epileptic disorder. However, frequently the routine EEG is non-contributing (1), necessitating special procedures and montages in order to disclose epileptiform abnormalities.

Interictal EEG

In temporal lobe complex partial epilepsy, routine (30–60 min) interictal EEG will display "positive" findings – i.e. focal spikes and/or sharp-waves – in the awake state in 30%, and during sleep in 50–60% (2). Three procedures are useful for obtaining a higher yield of positive findings, namely
1) prolonged recordings, frequently over 24 h or more, as both epileptic seizures and interictal discharges are subject to marked circadian fluctuations (3, 4).
2) use of non-standard placements of scalp electrodes, e.g. zygomatic, anterior temporal, "surface sphenoidal", anterior cheek electrodes (5–9).
3) use of semi-invasive (but still extracranial) electrodes, e.g. sphenoidal, nasopharyngeal, naso-ethmoidal (2, 7). Combining these procedures, the interictal extracranial EEG will display positive findings in the majority of cases, in whom surgical treatment of complex partial seizures is considered. Whereas the value of repeated and prolonged EEG with different activation procedures is well-established, the comparative diagnostic yield of different special scalp electrode placements and semi-invasive electrodes has been a subject of debate. Nasopharyngeal electrodes have been abandoned by several workers (10, 11) because of rather low yield, patient discomfort and problems with artifacts. Despite the insertion being uncomfortable and the procedure requiring the presence of a physician, the sphenoidal electrode has been the most frequently used ancillary extracranial electrode. The use of a flexible stranded stainless steel or silver wire (introduced upon a lumbar puncture cannula, which is then removed) makes it possible to perform prolonged recordings up to several weeks with minimal discomfort.

Kristensen & Sindrup (2) found 16% (66/404) scalp-negative EEGs with positive findings at the sphenoidal site. However, Binnie et al. (13) found only 2/165 foci in which less than 90% of the sphenoidal spikes were not detectable on the surface. They found, however, the sphenoidal electrode of possible value in discerning between mesial and lateral temporal foci. Both studies employed the same (average) montage together with barbiturate activation, but Binnie et al. also used a scalp electrode at the entry of the sphenoidal, near the point of the zygomatic electrode; maybe this explains the difference, as zygomatic electrodes are superior to standard scalp electrodes in detecting mesial temporal foci; in an average montage, a higher amplitude of spikes at the zygomatic electrodes compared to F7/F8 correlates with sphenoidal foci (5).

Giroud et al. (12) found sphenoidal spikes in 4/6 patients with negative scalp EEG. They used, however, a bipolar montage with coronal sphenoidal and longitudinal scalp linkages: a montage which will sometimes not pick up temporal foci (10).

For extratemporal foci (mainly frontal), the problem in the standard montages is that the F7/F8 electrodes pick up potentials from the frontal lobe as well as the tip of the temporal (7). The same problem applies to the nasopharyngeal and rather seldom used naso-ethmoidal electrodes (14). Supra-orbital electrodes are easier to handle and can visualize fronto-basal foci well (7).

Ictal EEG

Besides increased possibilities for quantitatively recording interictal discharges, the main purpose of intensive neurodiagnostic monitoring is to record seizures. Technically, it can be performed as:
- prolonged hard-wire EEG with a more or less static patient, with or without video recording of the clinical episodes;
- ratio or cable telemetry, with or without video; the EEG can be stored on paper, magnetic tape or on a videotape together with the clinical picture of the patient;
- ambulatory cassette-EEG.

For presurgical work-up, only the two techniques first mentioned are used in most centers; however, some investigators also have employed 8 channel cassette EEG in connection with depth-electrode EEG (DEEG) (15).

The purpose of ictal EEG recordings are fourfold:
1) to ascertain the diagnosis of epilepsy;
2) to clarify whether the seizures recorded are in fact the patient's habitual ones;
3) to classify seizure type;
4) to determine focal/regional seizure onset.

Even the best clinical seizure description cannot always distinguish with certainty between epileptic and pseudo-epileptic seizures; the latter are encountered in 20–30% of patients referred to specialized epilepsy centers for evaluation of intractable seizures, including pre-surgical work-up (16–18). Conversely, unexpected frontal lobe seizures previously regarded as pseudo-seizures may be detected; these seizures are not infrequently without discernible ictal EEG abnormalities (19). Video-EEG recorded seizures can be shown to observers of habitual seizures for verification or the opposite.

Not infrequently, the classification of the seizures is either imprecise or incorrect (20). For exact seizure evaluation, it is essential that the patient is under close surveillance by experienced nursing staff for monitoring of behavior and consciousness level during seizures. There is no unanimity as regards the number of recorded seizures necessary to ascertain both seizure type and focal onset. Between 5 to 10 habitual seizures are usually recommended, if possible (21).

If intensive monitoring is not feasible on an outpatient basis, admission and tapering AEDs to about half dosage will readily produce seizures without too high a risk of status epilepticus or withdrawal/post-ictal psychosis. There is in general no substantial problems of provoking atypical and erroneous seizures (22, 23).

The *contribution* of the scalp EEG (interictal and ictal) in the pre-surgical work-up can be estimated in two ways:
1) how much do the findings (lateralization/localization) converge with other investigations: invasive EEG studies, static and dynamic neuroimaging? Several studies (24–27) have found a marked correlation between ictal/interictal EEG, and functional neuroimaging, which could allow a "bypass" of intracranial EEG recordings in about 40% of cases (24). In general, studies of flow and metabolism had the greatest yield, MRI lower and CT rather low.
2) To what extent does surgical seizure prognosis correlate with scalp EEG data? Barry et al. (28) found a marked correlation between strictly localized temporal interictal spikes, especially when unilateral (>95%: all these patients improved after surgery); bilateral temporal spiking was a much more favorable predictor (76% improved) than unilateral temporal spiking with extratemporal spread (36% improved). All 48 patients had ictal EEGs, of whom 19 depth-electrode EEG (DEEG). Thus, localization was more important than lateralization.

Chung et al. (29) found a close correlation between >90% lateralization of interictal spikes, and outcome after surgery (92 vs. 50% improved); 31 had DDEG studies. Using a cut-off figure of 95%, Walczak et al. (30) had similar findings (92% vs. 53%) in their rather mixed series of 100 patients, with ictal EEGs in 57. For patients with extratemporal spread of the focus, there was a non-significant trend towards improvement with the advent of ictal EEG. None of the three last-mentioned studies had neuro-imaging except CT.

In their prospective study, Sperling et al. (31) used interictal sphenoidal (>90% lateralized) spikes and ictal sphenoidal seizure onset as the primary criteria in an algorithm for temporal lobectomy on non-invasive basis. Fulfilling this, 80% of

51 patients were seizure-free after surgery. MRI was used in all cases.

A recent study (32) has gone the retrograde way by analyzing ictal scalp EEGs from a series of patients who became seizure-free after surgery. They found a highly reliable localization, especially for rhythmic theta during seizures and postictal findings, and much more for temporal (76–83%) than for extratemporal (47–65%) seizures. However, this backward approach to the pre-operative data provides no information of predictive value for surgical prognosis.

Is ictal EEG necessary for focus localization?

Engel et al. (24) state the interictal scalp EEG may be misleading in 10–20% of cases as regards focus localization. Ictal EEGs with scalp/sphenoidal electrodes gave more reliable data, as only 5/108 of their patients had false lateralization on this recording. Other investigators (33) have found the interictal scalp EEG rather unreliable.

Thus, neither interictal nor ictal extracranial EEG can predict the focus with 100% certainty, but that applies even to intracranial EEG (34). All EEG data must therefore be evaluated in relation to clinical as well as other paraclinical information, first and foremost MRI, SPECT and PET, and intracarotid amobarbital tests.

Not all authors regard ictal EEG recordings as a must (35). The results from centers using and not using ictal EEGs appear comparable. Maybe differences in patient selection play a rôle – this is a matter which often makes comparison between different surgical centers difficult. Technically, the same montages can be used for both ictal and interictal EEG. Recently, the anterior cheek electrode (9) has been shown comparable to the sphenoidal for ictal recordings, albeit with a lower signal/noise ratio. However, it will frequently be advisable to use as many sets of ancillary electrodes as possible in order to increase the possibility of recordings which are not too contaminated by artifacts.

Digital EEG has the advantage of remodelling the montages, studying phase reversals and other focal features in different montages even in the same recording. In general, bipolar recordings are recommended, as especially average montages not only are subject to more artifacts, but also impose difficulties in focus localization, because of disturbance of the reference electrode "zero" from focal high-voltage activity.

The superiority of ictal versus interictal EEG may be rather limited with respect to surgical outcome from anterior temporal lobectomy. In the author's opinion, however, ictal EEG is a must in pre-surgical work-up. The not negligible risk of producing disasters by performing surgery upon patients with pseudoseizures as their sole or dominating feature is justification enough for the cost and patient stress involved. Furthermore, seizure classification on clinical grounds alone is not infrequently imprecise or incorrect.

It is not clear whether sphenoidal electrodes have substantial advantages over scalp electrodes, but in maximizing the possibilities for focus localization, multiple additional electrodes are important.

Further development of quantitative techniques, e.g. dipole modelling (36) may in the future increase the total information gained from extracranial EEG studies.

In cases where information obtained from non-invasive interictal and ictal EEG studies combined with neuro-imaging is not sufficient, the information obtained will often be helpful in planning implantation of intracranial electrodes.

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