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Epidural and foramen-ovale electrodes in the diagnostic evaluation of patients considered for epilepsy surgery

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ABSTRACT – *Purpose*. To evaluate the clinical utility of epidural and foramen-ovale recordings and associated morbidity in the pre-surgical evaluation of epilepsy. *Methods*. We retrospectively analysed 59 epilepsy patients, who underwent recordings with epidural (n = 59) and foramen-ovale electrodes (n = 46) as part of their pre-surgical evaluation between 1990-1999. The epidural and foramen-ovale evaluation was based on the results of the non-invasive EEG-video recordings in patients, in whom non-invasive evaluation failed to localise seizure onset (75%, 44 patients) or where EEG, and imaging studies were discrepant (25%, 15 patients) but allowed a testable hypothesis on the seizure onset zone. *Results*. Most patients (n = 57) were evaluated between 1990-1994. Only two patients were evaluated later. The results of the epidural (n = 559) and foramen-ovale (n = 83) electrode recordings allowed us to proceed to resective epilepsy surgery in 31% (n = 18) and to exclude further invasive evaluation in 15% (n = 9) of the patients. In 49% (n = 29) of the patients the results guided further invasive recordings using subdural and/or depth electrodes. For only three patients no additional information was gained by the electrode recordings. Temporary morbidity included local infection (epidural; n = 1) and facial pain (foramen ovale; n = 1) but no permanent complication occurred. *Discussion*. Epidural and foramen-ovale electrodes have almost been abandoned in recent years, most likely because of the improvement of neuroimaging techniques such as MRI, PET and ictal SPECT. However, in selected patients, epidural electrodes and foramen-ovale electrodes are either useful as a measure to avoid invasive evaluation or serve to guide invasive evaluation.

Key words: epilepsy surgery, epidural electrodes, foramen-ovale electrodes

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Evaluation of patients considered for resective epilepsy surgery aims at identifying and localising the epileptogenic zone. The diagnostic tests used include a first step MRI and non-invasive EEG-video monitoring (Rosenow and Lüders, 2001; Noachtar *et al.*, 2003). Non-invasive investigations successfully select most patients for temporal lobe surgery (Sperling *et al.*, 1992; Thadani *et al.*, 1995; Kilpatrick *et al.*, 1997; Winkler *et al.*,

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1999). Invasive recordings are usually indicated in the setting of non-localising surface EEG recordings and/or conflicting results of EEG-video recordings and imaging studies (So *et al.*, 1989; Noachtar *et al.*, 2003).The most commonly used invasive electrodes are stereotactically implanted depth electrodes and subdural electrodes. However these electrodes bear some risks (infection, bleeding, etc.; Van Buren, 1987; Fernandez *et al.*, 1997). To reduce these risks, epidural (Barnett *et al.*, 1990) and foramen-ovale electrodes (Wieser *et al.*, 1985) have been developed. These do not penetrate the dura and the brain and therefore, at least theoretically, pose a lower risk of bleeding and infection than subdural and depth electrodes. They were considered to be of intermediate invasiveness and thus were also labelled semi-invasive (Awad *et al.*, 1991). The clinical usefulness of foramen-ovale electrodes has been emphasized recently (Velasco *et al.*, 2006) but epidural electrodes seem to have been used less frequently in recent years (Noachtar, 2001). Therefore, we analyzed retrospectively the diagnostic yield of epidural and foramen-ovale electrodes in the evaluation of patients considered for resective epilepsy surgery, in whom non-invasive tests were not sufficient to proceed to epilepsy surgery.

Methods

The study group consisted of 59 patients evaluated with medically refractory focal epilepsies, who were evaluated with epidural electrodes and foramen-ovale electrodes. In all patients, non-invasive EEG-video monitoring was performed at our Epilepsy Monitoring Unit between 1990 and 1999, prior to the evaluation with epidural and foramen-ovale electrodes. Notably, only two patients have undergone semi-invasive recordings (foramen-ovale) since 1994. A total of 1,156 patients were evaluated by non-invasive methods during this period for presurgical evaluation of refractory epilepsy. The indications for performing epidural and foramen-ovale recordings were based on conflicting results of non-invasive EEG-video monitoring (75%, 44 of 59 patients) or discrepant results of EEG-video monitoring and neuroimaging (25%, 15 of 59 patients).

Of the 59 patients included in this study, 66% were male (33 patients), with a mean age of 27 years old (range of 5-49 years), and presented focal epilepsy with a mean duration of 19 years (range of 3-39 years) due mostly to unknown aetiology (32%, 19 patients), focal cortical dysplasia (17%, 10 patients), perinatal lesion (12%, 10 patients) or tumours (12%, 10 patients). Non-invasive EEG was mostly lateralized to one hemisphere (44%, 26 patients), unilateral temporal (17%, 10 patients) or unilateral temporal-parietal-occipital (10%, 6 patients). MRI was performed in all 59 patients and was abnormal in 76% (45 of 59 patients). In selected patients interictal FDG-PET (39%; 23 of 59 patients) or ictal ECD-SPECT (9%; 5 patients) was performed. Detailed data of these patients is shown in *table 1*. The decision where to place semi-invasive electrodes depended on the hypothesised seizure onset zone, derived from the non-invasive evaluation *(table 2)*. Accordingly, unilateral epidural electrodes were implanted in 45 patients with unilateral epileptogenic zones based on the results of non-invasive evaluation for further localisation, and bilateral epidural electrodes were used in 14 patients with lateralization of epileptogenic zones. The epidural and foramen-ovale recordings were intended to provide additional information with respect to the hypotheses of the epileptogenic zones and to avoid the risk of depth and subdural electrodes *(table 2)*.

Table 1. Demographics, clinical, EEG and neuroimaging data of patients evaluated with epidural electrodes (n = 59).

Gender, F/M, n (%)	26/33 (44/66)
Age, mean (range), years	27 (5-49)
Duration of epilepsy, mean (range), years	19 (3-39)
Etiology, n (%)	
- Unknown	19 (32)
- Focal cortical dysplasia	10 (17)
- Perinatal lesion	7 (12)
- Tumor	7 (12)
- Infection	6 (10)
- Trauma	4 (7)
- Hippocampal sclerosis	3 (5)
- Ischemic stroke	2 (3)
- Cavernoma	1 (2)
Non-invasive EEG, n (%)	
- Lateralized to one hemisphere	26 (44)
- Unilateral temporal	10 (17)
- Unilateral temporal-parietal-occipital	6 (10)
- Unilateral frontal	5 (8)
- Temporal not lateralized	5 (8)
- Unilateral fronto-temporal	3 (5)
- Unilateral fronto-parietal	2 (3)
- Frontal not lateralized	2 (3)
MRI, n (%)	
- Performed	59 (100)
- Results, abnormal/normal	45/14 (76/24)
PET, n (%)	
- Performed	23 (39)
- Results, abnormal/normal	21/2 (91/9)
Ictal and interictal SPECT, n (%)	
- Performed	5 (9)
- Results, abnormal/normal	5/0 (100/0)

Table 2. Indication and results of evaluation with epidural peg and foramen ovale electrodes in 59 patients with temporal (n = 17) and extratemporal epilepsy (n = 42).

Indication for epidural recording	Results (number of patients)			
	Proceed to surgery	No resective epilepsy surgery	Further subdural/ depth recordings required	Inconclusive result
Focus localization in one hemisphere	6	3	15	2
temporal *vs* parieto-occipital seizure onset	3		7	
Frontal *vs* temporal seizure onset	1	2	2	
Frontal *vs* parietal seizure onset			4	
Rt. *vs* Lt. temporal seizure onset	5	2	1	
Rt. hemisphere *vs* Lt. hemisphere seizure onset	2	2		
Rt. frontal *vs* Lt. frontal seizure onset	1			1
Total	18	9	29	3

Rt.: right; Lt.: left.

Epidural electrodes

Fifty nine patients had epidural peg electrodes, which were implanted according to a protocol published elsewhere (Barnett *et al.*, 1990; Noachtar, 2001). A total of 559 pegs and average of nine pegs (range 5-17) per patient were implanted. The peg electrode consisted of a stainless steel or platinum disc inserted in the base of a mushroom-shaped housing of silastic elastomer (Barnett *et al.*, 1990; Awad *et al.*, 1991). The peg electrode is available in different sizes and therefore can be selected according to the thickness of the skull. Peg electrodes were implanted through 3 to 5 mm burr holes. Small scalp incisions were made for scattered placement. A subgaleal scalp flap was used for closely spaced coverage or forehead montages (Noachtar, 2001). After the procedure, skull radiographs in coronal and sagittal planes were taken to evaluate the position of the epidural electrodes *(figure 1)*.

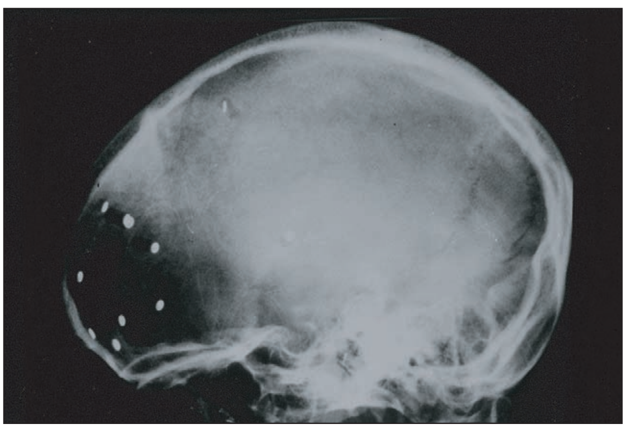

Figure 1. Lateral roentgenogram of a patient evaluated with bilateral frontal epidural electrodes only.

Foramen-ovale electrodes

Forty six patients had foramen-ovale electrodes. Thirty-seven patients were implanted bilaterally and nine unilaterally. Commercially available foramen-ovale electrodes (Ad-Tech®, Racine, WI, USA) were implanted percutaneously with the aid of a fluoroscope under light general anaesthesia, according to a previously described technique (Wieser *et al.*, 1985). After the procedure, skull radiographs in coronal and sagittal planes were taken to evaluate the position of the foramen-ovale electrodes.

EEG-video-monitoring

The EEG was recorded with 32-64-channel digital EEG machines (Vangard®, Cleveland, OH, USA) digitalized at a sampling rate of 200 Hz (12 bit), amplified and stored on computer for off-line analysis. Continuous video recordings were performed simultaneously. All seizure recordings were stored on video tapes. EEG-video monitoring lasted between three and ten days and an average of nine seizures were recorded per patient.

Results

The results of the epidural and foramen-ovale recordings were classified in four clinical categories *(table 2)*. The results included:

– epilepsy surgery without further invasive studies;

– the exclusion of epilepsy surgery without further invasive studies, which occurred if semi-invasive electrodes showed bilateral or multifocal seizure onset and the results did not support any hypothesis of a potentially resectable single epileptogenic zone which could be further explored with subdural or depth electrodes;

– the need of further invasive studies (depth, subdural);

– no complementary information gained *(table 2)*.

Epidural peg electrodes demonstrated a regional or focal

EEG seizure pattern (Noachtar *et al.*, 1999) in 28 of 59 patients, who underwent epidural peg electrode recordings. Another 14 patients showed regional seizure pattern by means of both epidural and foramen-ovale electrodes. Foramen-ovale electrodes demonstrated a temporal seizure onset in another nine patients, but in eight patients epidural and foramen-ovale electrodes failed to localise the seizure onset. In some cases, epidural electrodes were able to localise a seizure onset when the simultaneous surface recordings were either obscured by muscle artefacts *(figures 2, 3)* or were non-lateralized. The results of the epidural and foramen-ovale electrode recordings are

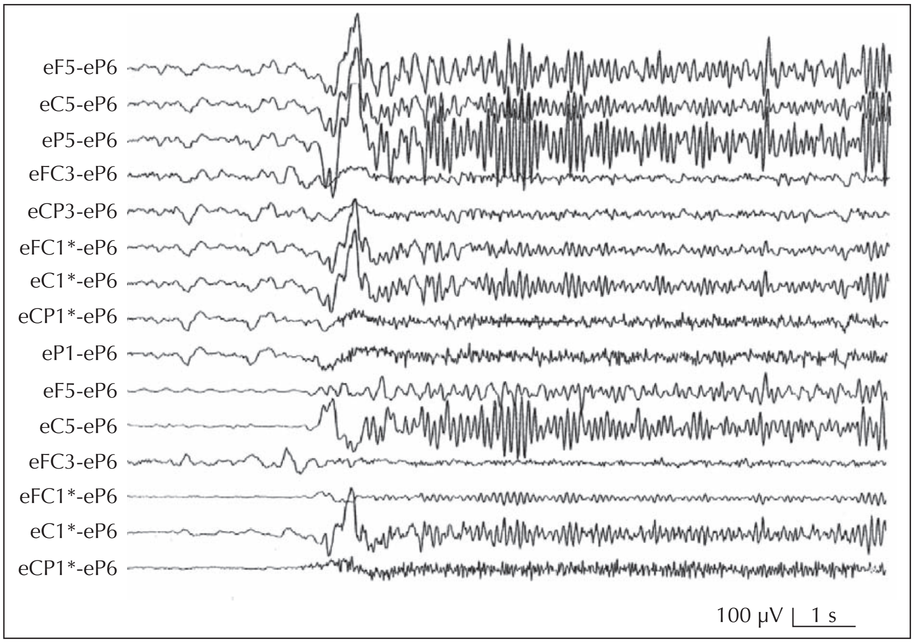

Figure 2. Epidural EEG showing a left parietal EEG seizure onset maximum at the electrode ep5.

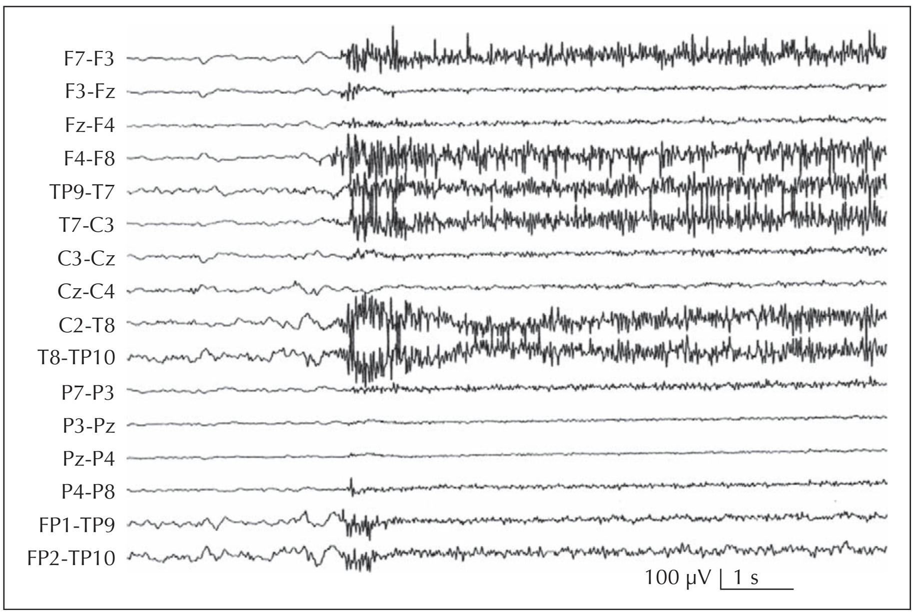

Figure 3. Same seizure as in *figure 2*. The simultaneously recorded surface EEG (displayed in a bipolar transverse montage) shows muscle artifacts at the onset of a tonic seizure but no unequivocal regional EEG seizure pattern.

summarised in *table 2*. Forty-two patients had extratemporal and 17 temporal lobe epilepsies. The result of epilepsy surgery (a two-year seizure-free period) was excellent in 12 of the 18 (66%) patients who underwent resective epilepsy surgery without further invasive evaluation *(table 2)*. Epilepsy surgery results were excellent in 12 of 23 (52%) patients in whom further invasive EEG evaluation with depth and subdural electrodes was needed for planning of resective epilepsy surgery *(table 2)*. Temporary morbidity included local infection (epidural; n = 1) and facial pain (foramen ovale; n = 1) but no permanent complication occurred.

Discussion

In our series, the use of the foramen-ovale and epidural peg electrodes provided information to guide further subdural or depth electrode recording (49%), to proceed to surgery without further invasive investigation (31%) or to disqualify the patient from further invasive evaluation (15%). For only three patients, no additional information was gained by the electrode recordings. In another series of 30 patients, in whom epidural peg electrodes were implanted, epilepsy surgery could be performed without any further invasive procedures in only eight patients, in whom seizure onset was established in the mesial temporal structures by means of foramen-ovale electrodes (Awad *et al.*, 1991). In seven of the 30 patients, the epidural evaluation demonstrated multifocal seizure onset and ruled out resective epilepsy surgery (Awad *et al.*, 1991). Another 15 patients needed further invasive methods, but the subsequent subdural electrodes were more limited or focused as a result of the epidural recordings (Awad *et al.*, 1991). Epidural electrodes are usually used to cover the lateral temporal cortex and extensive areas of the extratemporal convexity. Foramen-ovale and epidural electrodes are frequently used in patients with temporal epilepsy to determine information about lateralisation, which could not be obtained with non-invasive EEG, and to avoid depth electrodes, which are more invasive. The epidural peg electrodes cover the lateral aspect of the temporal cortex, whereas the foramen-ovale electrodes record activity arising from the mesial temporal structures (Noachtar, 2001; Holthausen *et al.*, 1994).

No permanent sequela were found in our series. Temporary morbidity included local infection (epidural; n = 1) and facial pain (foramen ovale; n = 1). Since the epidural space is not dissected when foramen-ovale electrodes and epidural electrodes are used, the theoretical risk of these electrodes is lower than with electrodes which invade the brain, such as depth electrodes or subdurally placed electrodes. Complications of epidural electrodes include rare epidural bacterial infections, small brain abscesses, and mild seventh cranial nerve palsies (Kuzniecky *et al.*, 1990; Awad *et al.*, 1991; Noachtar *et al.*, 1993). Epidural peg electrodes are covered by the galea, which we believe is conducive to reducing the risk of infection. In a series of 130 temporal lobe patients who underwent foramen-ovale electrode recordings, 7% had transient hypo/dysaesthesia localised in a corner of the mouth and one patient presented a serious complication consisting of a mild subarachnoid haemorrhage (Wieser and Hajek, 1994).

Noteworthy, semi-invasive recordings with either epidural or foramen-ovale electrodes have been almost abandoned in our institution for 15 years. The use of epidural electrodes has widely declined since the advent of functional imaging studies (PET, ictal SPECT) and the improvement of MRI techniques. Interictally, epileptogenic zones, particularly in the temporal lobe, are frequently associated with reduced regional cerebral metabolism, which can be detected with [18 F] fuorodeoxyglucose-PET (Engel *et al.*, 1990). Ictal SPECT studies in temporal and extratemporal epilepsy clearly localise regions of increased cerebral perfusion (Duncan, 1997). In extratemporal epilepsies, ictal SPECT localises better in patients with frontal, rather than with parieto-occipital seizure onset probably due to rapid spread of epileptic activity (Noachtar *et al.*, 1998). The management of intractable epilepsy has changed over the past two decades with the advent of high-resolution imaging. The concordance of interictal and ictal EEG localisation with respect to the MRI lesion is good in temporal lesions, but poorer in extratemporal lesions (Noachtar and Borggraefe, 2009). If a structural lesion is found and its location is consistent with clinical and EEG data regarding the epileptogenic zone, removal of the lesion and surrounding cortex may be sufficient to control seizures. In other cases, removal of additional cortex, identifiable with intraoperative or extraoperative invasive recording, may be necessary. This is frequently the case in patients with epilepsy caused by more diffusely epileptogenic cortex such as cortical dysplasia (particularly if MRI is negative), post-traumatic lesions, and early cerebrovascular insults (Noachtar and Borggraefe, 2009).

Some epilepsy centres still use foramen-ovale electrodes to lateralize temporal lobe epilepsies and to document the spread to the temporal lobe in extratemporal lobe epilepsies (Velasco *et al.*, 2006). Moreover, recent studies have shown that frameless stereotactic foramen-ovale electrode placement, by use of neuronavigation in conjunction with a non invasive mechanically-aligned maxillary fixation system, improved patient safety and interventional success (Ortler *et al.*, 2008).

In conclusion, foramen-ovale electrodes and epidural pegs may provide valuable information in the evaluation of patients considered for epilepsy surgery. For selected patients, they help to avoid more invasive electrodes which have a higher morbidity. For other patients, better planning of further invasive evaluation with subdural or depth electrodes is made possible with the results of epidural and foramen-ovale recordings. This is particularly true for patients with temporal lobe epilepsy in whom lateralization is required. However, the recent advances of imaging techniques such as MRI, interictal PET, and ictal SPECT have considerably reduced the number of patients particularly with extratemporal epilepsies, in whom epidural electrodes have been used in our centre. □

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Disclosure.
None of the authors has any conflict of interest to disclose.

References

Awad IA, Assirati Jr JA, Burgess R, Barnett GH, Lüders H. A new class of electrodes of 'intermediate invasiveness': preliminary experience with epidural pegs and foramen ovale electrodes in the mapping of seizure foci. *Neurol Res* 1991; 13: 177-83.

Barnett GH, Burgess RC, Awad IA, Skipper GJ, Edwards CR, Lüders H. Epidural peg electrodes for the presurgical evaluation of intractable epilepsy. *Neurosurgery* 1990; 27: 113-5.

Duncan JS. Imaging and epilepsy. *Brain* 1997; 120: 339-77.

Engel Jr J, Henry TR, Risinger MW, *et al.* Presurgical evaluation for partial epilepsy: relative contributions of chronic depth-electrode recordings versus FDG-PET and scalp-sphenoidal ictal EEG. *Neurology* 1990; 40: 1670-7.

Fernandez G, Hufnagel A, Van Roost D, *et al.* Safety of intrahippocampal depth electrodes for presurgical evaluation of patients with intractable epilepsy. *Epilepsia* 1997; 38: 922-9.

Holthausen H, Noachtar S, Pannek H, Ebner A, Tuxhorn I. Foramen ovale and epidural peg electrodes. *Acta Neurol Scand Suppl* 1994; 152: 39-43.

Kilpatrick C, Cook M, Kaye A, Murphy M, Matkovic Z. Non-invasive investigations successfully select patients for temporal lobe surgery. *J Neurol Neurosurg Psychiatry* 1997; 63: 327-33.

Kuzniecky R, Faught E, Morawetz R. Surgical treatment of epilepsy: initial results based upon epidural electroencephalographic recordings. *South Med J* 1990; 83: 637-9.

Noachtar S, Holthausen H, Sakamoto A, Pannek H, Wolf P. Semi-invasive Elektroden in der epilepsiechirurgischen Diagnostik. In: Stefan H, editor. Epilepsie 92. Berlin: *Deutsche Sektion der Internationalen Liga gegen Epilepsie*, 1993:148-52.

Noachtar S, Arnold S, Yousry TA, Bartenstein P, Werhahn KJ, Tatsch K. Ictal technetium-99m ethyl cysteinate dimer single-photon emission tomographic findings and propagation of epileptic seizure activity in patients with extratemporal epilepsies. *Eur J Nucl Med* 1998; 25: 166-72.

Noachtar S, Binnie C, Ebersole J, Mauguiere F, Sakamoto A, Westmoreland B. A glossary of terms most commonly used by clinical electroencephalographers and proposal for the report form for the EEG findings. The International Federation of Clinical Neurophysiology. *Electroencephalogr Clin Neurophysiol Suppl* 1999; 52: 21-41.

Noachtar S. Epidural electrodes. In: *Lüders HO, Comair Y, es. Epilepsy surgery*. New York: Lippincott Raven, 2001.

Noachtar S, Winkler PA, Lüders HO. Surgical therapy of epilepsy. In: Brandt T, Caplan C, Dichgans J, Diener J and Kennard C, eds. *Neurological disorders: course and treatment*. San Diego: Academic Press, 2003: 235-44.

Noachtar S, Borggraefe I. Epilepsy surgery: A critical review. *Epilepsy Behav* 2009; 15: 66-72.

Ortler M, Widmann G, Trinka E, *et al.* Frameless stereotactic placement of foramen ovale electrodes in patients with drug-refractory temporal lobe epilepsy. *Neurosurgery* 2008; 62: ONS481-8; discussion ONS8-9.

Rosenow F, Lüders H. Presurgical evaluation of epilepsy. *Brain* 2001; 124: 1683-700.

So N, Gloor P, Quesney LF, Jones-Gotman M, Olivier A, Andermann F. Depth electrode investigations in patients with bitemporal epileptiform abnormalities. *Ann Neurol* 1989; 25: 423-31.

Sperling MR, O'Connor MJ, Saykin AJ, *et al.* A noninvasive protocol for anterior temporal lobectomy. *Neurology* 1992; 42: 416-22.

Thadani VM, Williamson PD, Berger R, *et al.* Successful epilepsy surgery without intracranial EEG recording: criteria for patient selection. *Epilepsia* 1995; 36: 7-15.

Van Buren J. Complications of surgical procedures in the diagnosis and treatment of epilepsy. In: Engel JJR, ed. *Surgical treatment of the epilepsies*. New York: Raven, 1987: 465-75.

Velasco TR, Sakamoto AC, Alexandre Jr V, *et al.* Foramen ovale electrodes can identify a focal seizure onset when surface EEG fails in mesial temporal lobe epilepsy. *Epilepsia* 2006; 47: 1300-7.

Wieser HG, Hajek M. Foramen ovale and peg electrodes. *Acta Neurol Scand Suppl* 1994; 152: 33-5.

Wieser HG, Elger CE, Stodieck SR. The 'foramen ovale electrode': a new recording method for the preoperative evaluation of patients suffering from mesio-basal temporal lobe epilepsy. *Electroencephalogr Clin Neurophysiol* 1985; 61: 314-22.

Winkler PA, Herzog C, Henkel A, *et al.* Noninvasive protocol for surgical treatment of focal epilepsies. *Nervenarzt* 1999; 70: 1088-93.