Original article

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Stereo-electroencephalography (SEEG) in 65 children: an effective and safe diagnostic method for pre-surgical diagnosis, independent of age

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ABSTRACT – *Aim*. We report our experience of stereoelectroencephalography (SEEG) in 65 children with drug-resistant seizures, with a particular emphasis on young children. *Methods*. We retrospectively studied all SEEG performed between 2009 and 2011 in our centre. As SEEG can have several indications, the patients were classified into three categories, according to the probability of surgery. The contribution of SEEG to the final decision regarding surgery was evaluated for each category separately. We also compared the main demographic and surgical data of children younger than 5 years of age (Group 1; 21 children) with those older than five years of age at the time of investigation (Group 2; 44 patients). *Results*. MRI was not contributory in 20% of patients (9.5% in group 1; 25% in group 2). Electrical stimulations localised the motor area in all patients when performed (49% of patients), even in group 1 (62% of patients). SEEG led to surgery in 78% of patients (90.5% in group 1; 73% in group 2), after a second invasive investigation in 9.2 % of patients. The resection involved more than one lobe in 25% of patients (37% in group 1; 19% in group 2). Ultimately, 78% of patients with a low probability of having surgery before SEEG received surgery (88% in group 1). The surgical outcome of Engel class 1 was reported for 67% of patients (79% of patients in group 1 and 59% in group 2). No complications occurred. *Conclusion*. SEEG in children is safe and useful, and the surgical outcome in younger children is as good as, or sometimes even better than, that in older children. As a result of lower rates of complication and morbidity, SEEG appears to be more appropriate, in comparison to subdural grids, in situations where it is unclear if patients will have surgery after an invasive investigation.

Key words: SEEG, stereo-electroencephalography, surgery, presurgical, diagnosis, children, outcome

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Despite advances in imaging, invasive electroencephalograms (EEG) are still required for some children with drug-resistant focal epilepsy in order to delineate the epileptogenic region and/or to determine its relationship with the functional cortex (Cross *et al*., 2006; Harkness, 2010). Stereoelectroencephalography (SEEG) is one of the available invasive methods. Since the princeps description by Talairach *et al*. (1974) in adults, Kahane *et al*. (2006) have formalised the methodology taking into account the development of modern imaging. All teams working with SEEG deal with children (McGonigal *et al*., 2007; Tanriverdi *et al*., 2009; Gonzalez-Martinez *et al*., 2014), however, reports are rarely dedicated to SEEG in children (Cossu *et al*., 2006). Only Cossu *et al*. (2012) specifically addressed SEEG in children younger than 45 months.

SEEG is well-adapted for children. A minimum bone thickness is required in order to anchor the hollow pegs for the electrode insertion and attachment which is completed at 2 years of age and confirmed by a CT scan performed before the invasive investigation. Morbidity is low, around 2.5% in a mixed population of adults and children (Tanriverdi *et al*., 2009; Cardinale *et al*., 2013). Fatal complications are only occasionally observed and have been reported both in younger and older children (Cossu *et al*., 2012; Derrey *et al*., 2012). Morbidity is far lower relative to subdural investigations; a recent meta-analysis of children and adults reported a 2.3% risk of neurological infection associated with a 4% risk of intracranial haemorrhage and a 2.4 % risk of elevated intracranial pressure (Arya *et al*., 2013). This might make it preferable to choose SEEG when it is doubtful that invasive investigation will lead to surgery.

We addressed the issue of safety and usefulness of SEEG in our paediatric population which was investigated over three consecutive years, and the contribution of this technique in patients for whom surgery was not certain after non-invasive investigations was specifically studied. In addition, we analysed the data according to age and a cut-off at the age of five years was chosen, not because it is an important age for brain maturation or for epileptic syndromes, but because it is an age at which the child is able to express him/herself clearly and is more easily manageable.

Patients and methods

We retrospectively studied all children who had an SEEG investigation between January 2009 and December 2011 in our department. All patients underwent presurgical evaluation, surgery, and follow-up, as described previously (Taussig *et al*., 2012). SEEG was performed with DIXI® or ALCIS® electrodes, as described by Talairach *et al*. (1974) and analysed by a trained neurophysiologist (AL, MC or MC). A seizure conference validated the implantation scheme; the SEEG results were also discussed in a multidisciplinary meeting in order to make a decision on a surgical indication and the surgical procedure.

We retrospectively reviewed clinical, imaging, and electrophysiological data for all of the children. Video-EEG and SEEG recordings were reviewed by two different neurophysiologists (AL, MC or DT), independently of the neurophysiologist involved in the presurgical evaluation. *Post-hoc* analysis of the conclusions of the multidisciplinary meeting performed before the invasive investigation led to three indications of SEEG:

– Category A: a more precise delimitation the area to be resected with certainty of subsequent surgery;
– Category B: uncertainty of surgery because of unresolved questions (vicinity of functional areas or suspected wide epileptogenic zone); and
– Category C: uncertainty of the location of the epileptogenic zone either because the epilepsy was cryptogenic and the electroclinical semiology unclear or because the relationship between the lesion and the epilepsy was not obvious.

Seizure frequency and developmental outcomes were based on the last follow-up examination. Engel's classification was used to characterise the post-operative outcomes (Engel, 1993).

Moreover, we divided the children into two groups to study differences in management according to age at the time of investigation:

– Group 1: children younger than 5 years of age
– Group 2: children older than 5 years of age.

Results

Demographic data are summarized in *table 1*. Twenty-one (21) children younger than 5 years of age (group 1) and 44 children older than 5 years of age (group 2) were investigated. The mean age at onset of seizures was 29.8 months. As expected, children in group 1 had an epilepsy onset at an earlier age than in group 2 (7.4 *versus* 40.4 months). Twenty percent of the children had infantile spasms (IS) associated with focal seizures (33% in group 1 *versus* 14% in group 2). Thirty-four percent of the patients demonstrated normal development (9.5% of children in group 1 *versus* 45% in group 2). Fourteen percent of the patients had a normal MRI. Also, the MRI of 4 patients from group 2 showed previous surgical scars, providing no clear argument or justification for there to be a remaining brain lesion. In total, 20% of the children had a non-contributory MRI (9.5% in group 1 *versus* 25% in group 2).

Table 1. Demographic data.

	Entire population	Group 1	Group 2
Number of patients	65	21	44
Mean age at onset in months (range)	29.8 (0.5-132)	7.4 (0.5-29)	40.4 (0.5-132)
Mean age at SEEG in months (range)	98.6 (20-205)	39 (20-60)	127 (68-205)
History of focal seizures exclusively	50 (77%)	13 (62%)	37 (84%)
History of IS exclusively	2 (3%)	1 (5%)	1 (2%)
History of focal seizures and IS	13 (20%)	7 (33%)	6 (14%)
Normal MRI or post-operative scar	13 (20%) including 4 with post-operative scar	2 (9.5%)	11 (25%) including 4 with post-operative scar
Normal neurological examination	54 (83%)	17 (81%)	37 (84%)
Normal psychomotor development	22 (34%)	2 (9.5%)	20 (45%)
Severe mental delay	26 (40%)	10 (47%)	16 (36%)

IS: infantile spasm.

During video-EEG, several seizure types were recorded. Seventy-two percent were unifocal (76% in group 1), 26% regional multifocal (19% in group 1), and 3% generalised (5% in group 1).

The results of the non-invasive investigations allowed us to include 12.5% of patients in category A, 38.5% in category B, and 49% in category C. Among the patients in group 1, 19% were included in category A (9% in Group 2). The same percentage of patients in both groups was included in category B (38% *versus* 39%), whereas fewer patients in group 1 were included in category C (43% *versus* 52% in Group 2).

The SEEG data is summarised in *table 2*. No complications occurred. The patients did not have to be monitored in an intensive care unit. They were usually sleepy the day after implantation, but headaches and vomiting rarely occurred and were more easily managed compared to what is often observed in patients with subdural electrodes. The mean number of implanted electrodes was 11 (range: 8-14). The mean duration of the SEEG was 5.4 days. Drugs had to be tapered off in 60% of patients (43% in group 1; 68% in group 2). No auras were recorded in patients in group 1 but were recorded in 27% of patients belonging to group 2. Electrical stimulations localised the motor area in all patients when performed (in total 49% of patients; 62 % in group 1, and 43% in group 2). In group 1, no other functional response could be elicited apart from somatosensory in one child, whereas several kinds of functional responses were elicited in group 2. Seizures were evoked in 32% of patients when performed, with the same percentage in both groups.

Detailed examples are provided at the end of the manuscript. *Case 1* shows the SEEG data of a patient with focal cortical dysplasia who, in particular, had IS associated with focal seizures. The implantation scheme and the following surgery were comparable to those of older patients. In contrast, the SEEG data described in *Case 2* showed multifocal seizures associated with a huge epileptogenic zone. They led to a multilobar resection rarely performed in older patients.

Eighteen percent of patients were deemed inoperable after the first SEEG (9.5 % in group 1 and 22.7 % in group 2). A second invasive investigation was needed for 9.2% of patients. In the end, 78% of patients received surgery (90.5% in group 1; 73% in group 2).

Data regarding surgery and follow-up are listed in *table 3*. The mean age at surgery was 97.9 months. The surgery was monolobar in 51% of patients (42% of patients in group 1 and 56% of patients in group 2). Monolobar resections were considered separate from insular surgery. As the latter was always from a temporal, parietal or frontal approach, those resections were referred to as "insular plus". Apart from insular resections, other multilobar resections were performed in 23% of patients (32% of patients in group 1 and 19% of patients in group 2).

The pathological diagnosis was focal cortical dysplasia in 51% (64% of group 1 and 44% of group 2). In about 20% of the patients, the pathological analysis was normal or inconclusive (21% in group 1; 18% in group 2).

Table 2. Stereo-EEG data.

	Entire population	Group 1	Group 2
Mean number of electrodes (range)	11.5 (8-14)	11.6 (9-14)	11.4 (8-14)
Bilateral explorations	9 (14%)	1 (5%)	8 (18%)
Patients with drug tapering	39 (60%)	9 (43%)	30 (68%)
Mean duration in days (range)	5.4 (2-19)	4.5 (2-6)	5.8 (3-19)
Electrophysiological data: ictal data			
Subclinical seizures recorded	44 (67%)	14 (67%)	30 (68%)
Auras	12 (18%)	0	12 (27%)
Only focal seizures recorded	57 (88%)	16 (76%)	41 (95%)
Only IS recorded	3 (5%)	2 (10%)	1 (2.5%)
Focal seizures and IS recorded	4 (6%)	3 (14%)	1 (2.5%)
No recorded seizures	1 (1.5%)	0	1 (2%)
Non-countable recorded seizures	3 (5%)	1 (5%)	2 (4.5%)
Mean number of recorded seizures/patient when countable*	26 (2-103)	30 (6-160)	25 (2-103)
Electrophysiological data: electrical stimulations data			
Stimulations to evoke seizures	44 (67%)	12 (57%)	32 (73%)
Evoked auras	3 (5%)	0	3 (9%)
Evoked seizures	14 (32%)	4 (33%)	10 (31%)
Speech stimulations	23 (35%)	7 (33%)	16 (36%)
Positive speech stimulations	4 (17%)	0	4 (25%)
Inconclusive speech stimulations	1 (4%)	0	1 (6%)
Motor stimulations	32 (49%)	13 (62%)	19 (43%)
Positive motor stimulations	32 (100%)	13 (100%)	19 (100%)
Other positive stimulations	25 (38%)	1 (5%)	24 (54%)
SEEG conclusions			
Patients deemed inoperable after first SEEG	12 (18%)	2 (9.5%)	10 (22.7%)
Second invasive exploration	6 (9.2%)	2 (9.5%)	4 (9%)
Number of eventual surgeries	51 (78%)	19 (90.5%)	32 (73%)

IS: infantile spasms; HH: hypothalamic hamartoma; SW: spikes and waves
* clusters were considered as one seizure, isolated IS were not counted

The follow-up period lasted on average 24 months (range: 12 to 53). The outcome of Engel class 1 was reported for 67% of patients (79% of patients in group 1 and 59% in group 2), while 17% were classified as Engel class 4 (5% in group 1 and 25% in group 2). Among patients with normal MRI, 55% were classified as Engel class 1 (100% in group 1; 43% in group 2). Thirty-six percent of patients with normal or inconclusive pathology were classified as Engel class 1 (75% in group 1; 14% in group 2).

The surgical results according to the SEEG indication are presented in *table 4*. The percentage of patients who received surgery was 87% in category A, 76% in

Table 3. Surgery data.

	Entire population	Group 1	Group 2
Number of eventual surgeries	51 (78%)	19 (90.5%)	32 (73%)
Mean age at surgery in months (range)	97.9 (21-194)	44 (21-66)	131 (72-194)
Type of surgery			
Frontal resection	10 (19.5%)	5 (27%)	5 (15%)
Parietal resection	9 (17.5%)	2 (10%)	7 (22%)
Temporal resection	7 (14%)	1 (5%)	6 (19%)
Insular *plus* resection	10 (20%)	3 (16%)	7 (22%)
HH disconnection	2 (4%)	1 (5%)	1 (3%)
Multilobar resection	12 (23%)	6 (32%)	6 (19%)
Hemispherotomy	1 (2%)	1 (5%)	0
Pathology			
Focal cortical dysplasia	26 (51%)	12 (64%)	14 (44%)
Ganglioglioma	1 (2%)		1 (3%)
DNET	6 (11.5%)	1 (5%)	5 (15%)
DNET and dysplasia	1 (2%)		1 (3%)
HS	1 (2%)		1 (3%)
HS and dysplasia	2 (4%)	1 (5%)	1 (3%)
Sequelae	1 (2%)		1 (3%)
Unclear or normal	11 (21.5%)	4 (21%)	7 (22%)
HH	2 (4%)	1 (5%)	1 (3%)
Lateralisation of the surgery			
Left	21 (41%)	8 (44%)	13 (42%)
Right	28 (55%)	10 (53%)	18 (56%)
Follow-up duration in months (range)	24.2 (12-53)	26 (12-53)	23 (12-39)
Engel class 1	34 (67%)	15 (79%)	19 (59%)
Engel class 2 and 3	8 (16%)	3 (16%)	5 (16%)
Engel class 4	9 (17%)	1 (5%)	8 (25%)

HH: hypothalamic hamartoma; HS: hippocampal sclerosis; DNET: dysembryoplastic neuroepithelial tumour

category B, and 78% in category C. A surgical treatment was decided in 88% of patients belonging to category C in group 1 and 74% of patients belonging to category C in group 2. Among patients belonging to category C, 64% were classified as Engel class 1 (87.5% in group 1; 53% in group 2).

Discussion

We present a large series of 65 patients who were investigated using SEEG, which to our knowledge is the largest published series of children with SEEG. The study was conducted only recently and the

Table 4. Detailed data according to the three categories defined.

	Entire population	Group 1	Group 2
SEEG leading to surgery			
Category A	7/8 (87%)	3/4 (75%)	4/4 (100%)
Category B	19/25 (76%)	8/8 (100%)	11/17 (65%)
Category C	25/32 (78%)	8/9 (88%)	17/23 (74%)
Patients in Engel class 1			
Category A	6/7 (85%)	3/3 (100%)	3/4 (75%)
Category B	12/19 (63%)	5/8 (62.5%)	7/11 (63.5%)
Category C	16/25 (64%)	7/8 (87.5%)	9/17 (53%)

Note: Indications of SEEG: Category A: a more precise delimitation the area to be resected, with certainty of subsequent surgery; Category B: uncertainty of surgery because of unresolved questions (vicinity of functional areas or suspected wide epileptogenic zone); Category C: uncertainty of the location of the epileptogenic zone, either because the epilepsy was cryptogenic and the electroclinical semiology unclear or because the relationship between the lesion and the epilepsy was not obvious.

period of inclusion was short in order to ensure the homogeneity of management, thus the post-operative follow-up period was sometimes brief. We studied the overall population and sought particularities in young children. The age of 5 years as the cut-off was a pragmatic choice based on the experience of child management in the department. In the report of Cossu *et al*. (2012), patients younger than 45 months were described without justification of the choice of age.

No complications occurred. The morbidity reported in large series is around 2.5% in a mixed population of adults and children (Tanriverdi *et al*., 2009; Cardinale *et al*., 2013; Gonzalez-Martinez *et al*., 2014) and 2.8% in a paediatric population (Cossu *et al*., 2005). The only study focusing on children younger than 45 months reported a death among 15 patients. The low risk of complications should be balanced with the 5 to 15% complication rate for subdural investigations, retrieved from a meta-analysis in children and adults (Arya *et al*., 2013) or reported recently in children (Önal *et al*., 2003; Johnston *et al*., 2006; Blauwblomme *et al*., 2011; Taussig *et al*., 2012). The tolerance is excellent. As there is no need for immediate surgery, SEEG allows for a prolonged period for reflection and for seeking other opinions, if needed. In contrast, when the child suffers from severe epilepsy, the waiting time between the invasive investigation and surgery can be a significant disadvantage (Holthausen *et al*., 2012).

Conscious of this low complication rate, when a child suffers from drug-resistant focal epilepsy, one is inclined to perform SEEG even if the probability of a curative surgery is uncertain. Particularly in these cases, SEEG is far more appropriate than a subdural investigation because of the lower risk of complications and because of the possibility of repeating it. Indeed, being aware of the difficulties of localisation in children, one would not want to deprive the child of the opportunity of curative surgery. This is reflected by the great number of patients who belonged to category C (49% of patients) and the number of patients either deemed unsuitable surgical candidates after the first SEEG (18%) or who needed a second SEEG (9.2%). This number is higher than in published series where 10-16% of patients had contraindications after the SEEG (Guénot *et al*., 2001; Cossu *et al*., 2005; Cossu *et al*., 2006). In the series of McGonigal *et al*. (2007), one per cent of patients had two SEEG investigations. In the population of young children reported by Cossu *et al*. (2012), 7% were excluded from surgery and 7% had two SEEG investigations. In group 1, the short duration of the recording (mean 4.5 days; range 2 to 6) and the fact that drugs did not have to be tapered off in 57% of patients were supplementary arguments in favour of performing SEEG. The surgical decision itself was eventually made concerning 78% of the patients, even when SEEG was performed without certainty that it would lead to resective surgery (88% in group 1 were operated on; 74% in group 2).

Our surgical results are identical to those in the literature, with 67% patients classified as Engel class 1 (56%; Cossu *et al*., [2005], 53%; McGonigal *et al*. [2007], and 62%; Gonzalez-Martinez *et al*. [2014]).

Patients in group 1 had a much better outcome (79% Engel class 1) relative to older patients (59% Engel class 1) as well as young patients described in the study of Cossu *et al*. (2012). In the Cossu *et al*. (2012) study of 15 children including 13% cryptogenic patients, the outcome was 60% Engel class 1 and 20% Engel class 4.

Several hypotheses could be presented to explain the positive outcome in our young patients. First, 90% of the patients had symptomatic epilepsies mostly associated with focal cortical dysplasia (66% of patients who received surgery). In these patients, SEEG may allow removal of the entire malformation, which is often the condition for seizure freedom (Hauptman and Mathern, 2012). However, this is not sufficient to explain the positive results, since the two young patients with normal MRI (but FCD on pathological examination) were classified as Engel class 1. The shorter duration of epilepsy may be an important factor. One could also argue that the resections in group 1 were sometimes wider than those performed in group 2 (37% of resections included more than one lobe in group 1, including multilobar resections and hemispherotomies, compared to 19% in group 2). More patients already had neuropsychological impairment (91.5% in group 1; 55% in group 2) or a severe mental delay (47% in group 1; 36% in group 2). Furthermore, at this age, electrical stimulations were unfortunately inconclusive in predicting a focal impairment, apart from motor function.

The surgical outcome of the population belonging to category C corresponded to, on average, 64% Engel class 1, without a great difference between groups 1 (87.5%) and 2 (53%). In group 1, the surgical outcome was good, whatever parameter one considers, even normal MRI or inconclusive pathology. This puzzling result could only be partially explained, and may be related to the fact that the epileptogenic networks are not as complex in young patients belonging to group 1 as in older patients belonging to group 2. In group 2, the outcome was unsatisfactory for patients who belonged to category C (53% Engel class 1), having had inconclusive MRI (43% Engel class 1) as well as inconclusive pathology analysis (14% Engel class 1). In these patients, the pitfall could be the implantation scheme. It is probable that the epileptogenic zone was not properly explored. In both groups, however, FCD may have been overlooked by the pathologist. Thirty-six percent of patients with inconclusive pathology (50% in group 1 and 28% in group 2) indeed underwent a resection-disconnection, meaning that the most abnormal region was probably not removed. Even in those patients having undergone a resection, due to the fact that it was rarely "en bloc", the dysplastic tissue could not be sent to the pathologist.

Paediatric SEEG theoretically has the same indications as for adults, *i.e.* non-invasive data being insufficient to propose a focal resection, as summarised by Cossu *et al.* (2006). There is some disagreement between the different epilepsy teams concerning the indications in temporal lobe epilepsies, whereas a consensus exists regarding extratemporal epilepsies. In children, most patients investigated using SEEG have extratemporal epilepsy. In our group 1, temporal epilepsy was rare and only one child had a tailored (lateral) temporal resection for a cryptogenic epilepsy which turned out to be related to a FCD. On the contrary, in group 2, a tailored temporal resection was performed in 19% of patients, including two patients having had a DNT.

The decision to perform SEEG and the planning of electrode placement were founded on electroclinical correlations. Ictal semiology has a strong importance in adults. However, a precise description of the successive occurrence of ictal features is difficult in the paediatric population, particularly when very young (Holthausen *et al.*, 2012). An analysis of the ictal semiology is challenging since motor signs, versive movements, autonomic manifestations, and loss of contact are the only easily identifiable features. The difficulty of interpreting the semiology enhances the value of non-clinical data, *i.e.* EEG and MRI. Based on scalp video-EEG data, the most important argument for performing a SEEG appeared to be a clear-cut ictal onset, which was unifocal in 72% of children (76% in group 1) or regional multifocal in 26% (19% in group 1).

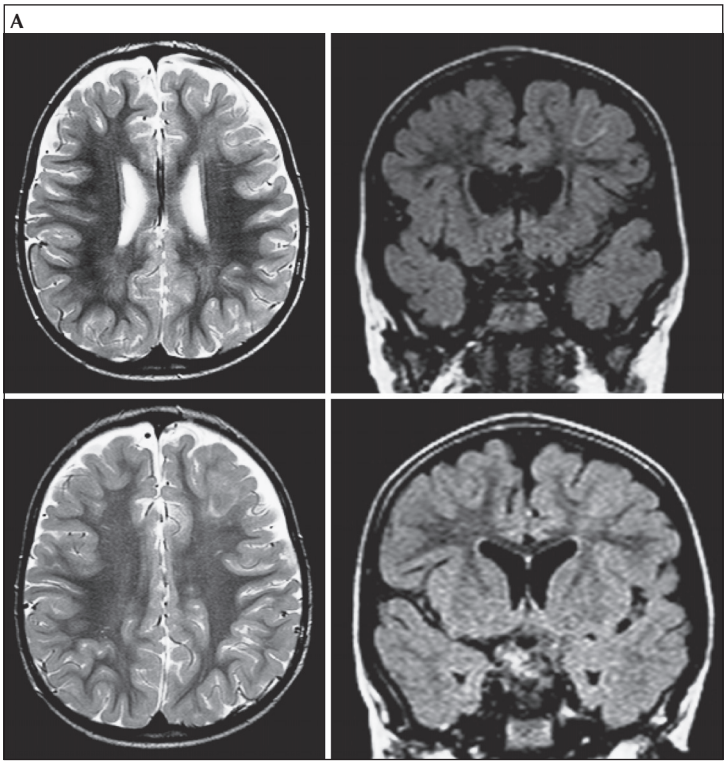
Few functional areas can be explored in young children. Localising the motor cortex during SEEG is often the only functional mapping available in young children. Electrical stimulations were indeed able to elicit motor responses in 100% of patients in whom they were performed in both groups. In group 1, 50-Hz stimulations (1050 μs, 3 seconds) were used during sleep in children unable to cooperate while awake, in order to avoid movements (threshold: 0.8 to 3.6 mA). Single-pulse stimulations in awake and cooperative patients were used in group 2. Those two techniques could not be compared because of the retrospective nature of this study. Few publications have addressed functional stimulations in SEEG, although all teams dealing with SEEG use them routinely (Chassoux *et al.*, 2000; Cossu *et al.*, 2005). In the series of Cossu *et al.* (2012), 3 of the 15 young patients had no motor response, but no details were given about the parameters of the stimulations (Cossu *et al.*, 2012). These difficulties in eliciting motor response have been reported with subdural electrodes for patients younger than 4 years of age (Alvarez and Jayakar, 1990; Haseeb *et al.*, 2007; Taussig *et al.*, 2012). Alvarez and Jayakar (1990), however, did not study patients between 1 and 4 years of age. These difficulties are not contradictory to our results because stimulations with depth and subdural electrodes require different parameters. Furthermore, Jayakar *et al.* (1992) showed that young children require an adapted paradigm. Speech areas could never be detected by electrical stimulations in group 1, although they were

considered reliable in 33% of patients. In group 2, they were performed in 16 patients (36%) and were positive in 4 (25% of patients). A sensitive response was reported by only one patient younger than 5 years of age, in the primary sensory cortex. In group 2, 24 patients reported sensitive responses to electrical stimulation (sensory, visual, and insular responses).

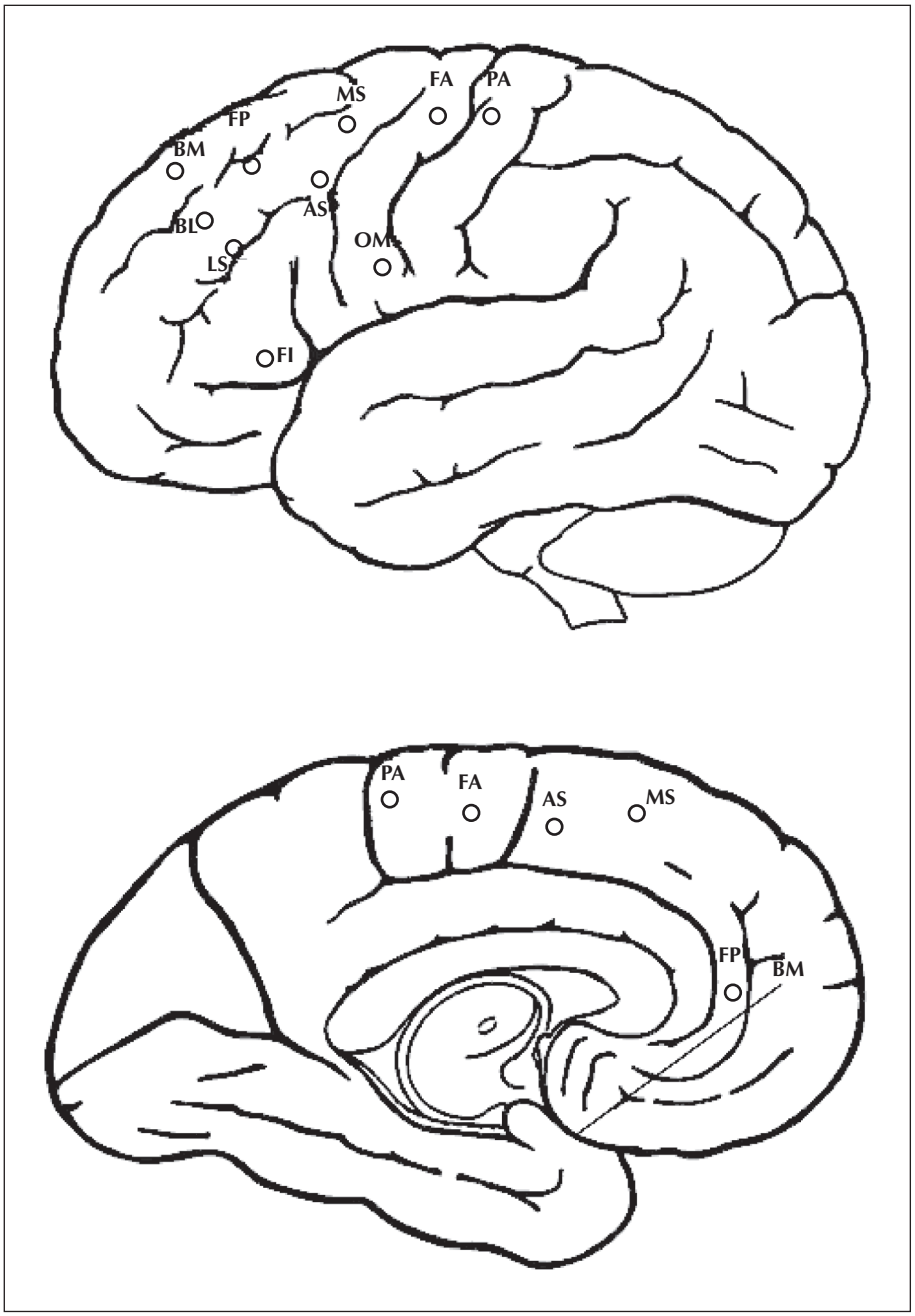
SEEG is feasible and well-tolerated in children older than 2 years of age; the thin nature of the bone before this age renders SEEG investigation difficult. SEEG is the method of choice in cases when the surgical indication looks doubtful before the invasive investigation is performed. Electrical stimulations are efficient in localising the motor area, but other functional responses are unlikely to be evoked before the age of 5 years. The post-operative outcome is much better in younger children, thus one should not hesitate to perform SEEG before 5 years of age when surgical treatment is being considered. The outcome is also better in symptomatic patients than in cryptogenic patients. This is the reason why, in the future, one should try to include other non-invasive data for cryptogenic patients, in particular, positron emission tomography, when conceiving the implantation scheme, to reduce the risk of performing two invasive investigations or unsuccessful resection, since a part of the epileptogenic zone may not have been investigated. □

Case 1. Stereo-EEG data of focal epilepsy in a 36 month-old child

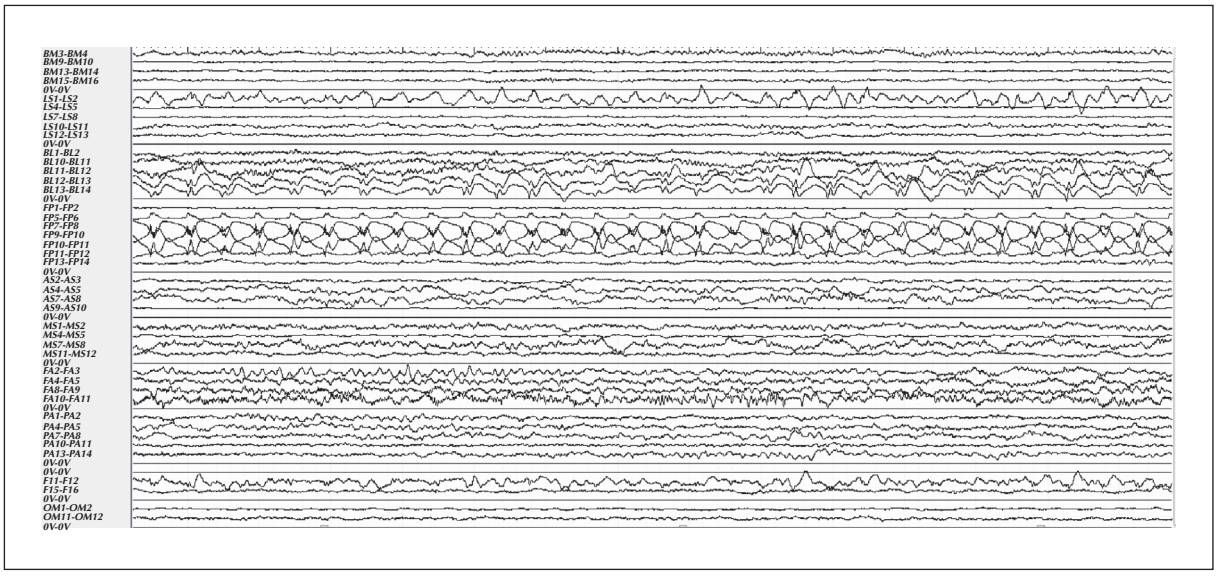
Onset of epilepsy occurred at the age of five months. The semiology of the seizure from the onset was as follows: he warned his parents, he appeared to be afraid and had hypertony of all four limbs, followed by infantile spasms. He had occasional postictal right hemiparesis. Epilepsy was drug-resistant, with a daily recurrence of seizures at the time of the invasive investigation. The patient appeared to be left-handed. He did not have any neurological deficit, but speech was delayed. On the video-EEG, wakefulness and sleep were well organised. He had interictal left fronto-central spikes and waves and seizures began in the same region. He also had spasms occurring independently of focal seizures. MRI showed a hypersignal in the left superior frontal sulcus suggestive of focal cortical dysplasia sulcus. SEEG was performed to circumscribe the seizure onset zone and to clarify its relationship with the motor cortex (category A). It led to a focal frontal lobe resection, including the lesion, and also a resection of the mesial frontal cortex opposite. Pathology showed focal dysplasia type IIb, and the patient has now been seizure-free for 34 months without treatment. He is presently attending kindergarten.



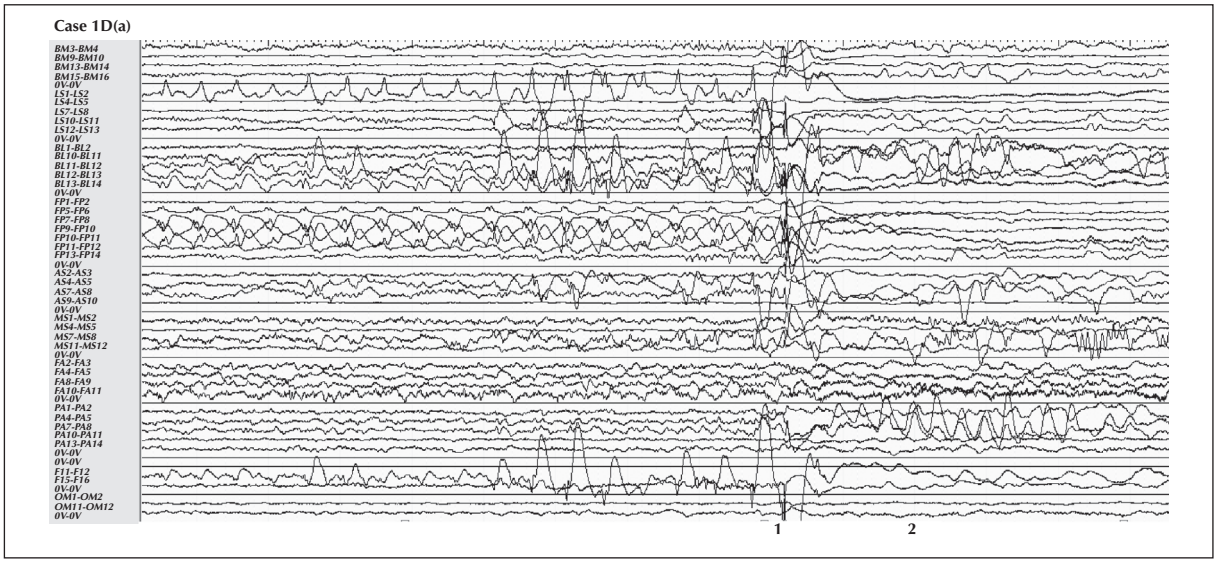
Case 1A. Preoperative MRI showing the lesion in the left superior frontal sulcus.



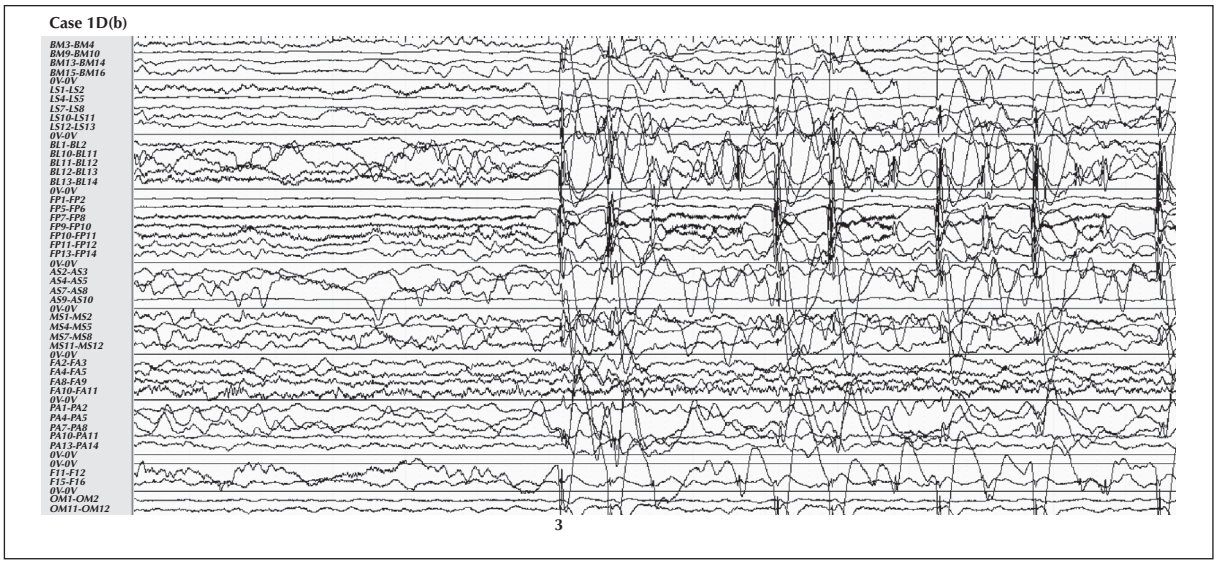
Case 1B. Implantation scheme. Note that the electrodes have an oblique insertion. Contacts 13 to 15 of electrode BL and contacts 7 to 9 of electrode FP were used to investigate the lesion. FA was located in the precentral gyrus, close to the central sulcus, as electrical stimulation of contacts 3 to 13 elicited motor responses.

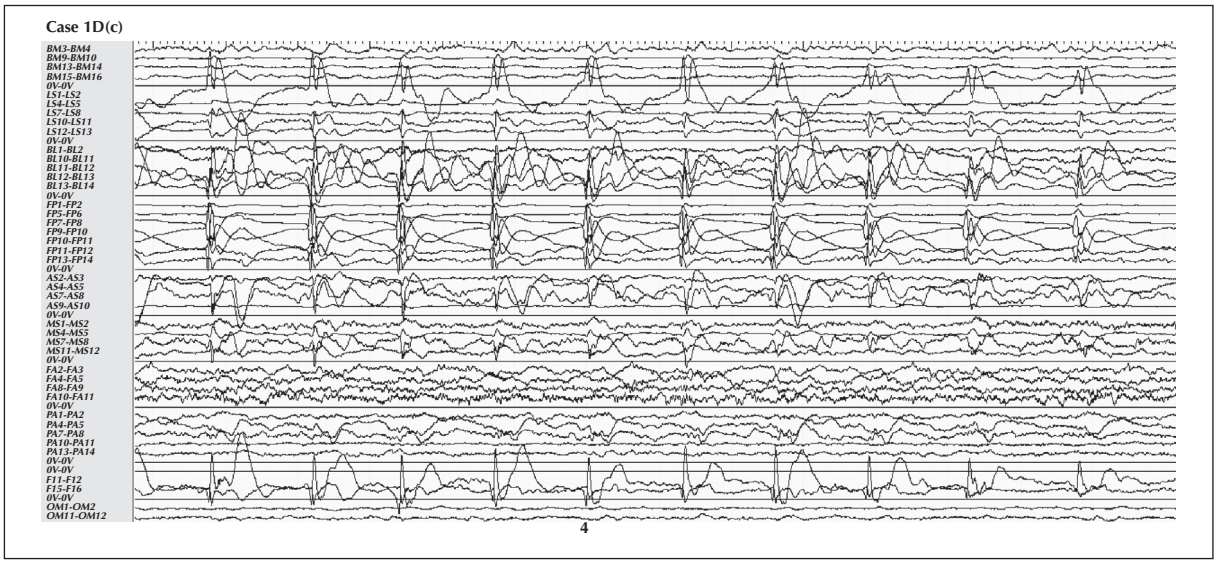


Case 1C. Interictal wakefulness. Continuous spike-and-wave activity on contacts FP 5-11 and BL 13-14.



Case 1. Example of a seizure recorded with SEEG.





Case 1D. Example of a seizure recorded with SEEG.
(a) Ictal onset: (1) spasm (unfortunately a myogram was not recorded because there were not enough entries in the headbox), followed by fast activity on FP 5-11 and LS 1-2. Note, before the seizure onset, the diffusion of spikes and waves at LS 1-2; (2) clinical onset with a behavioural modification followed by abduction of the arms.
(b) Seizure continuation: (3) asymmetric spasms with right hypertony, and polyphasic potential beginning on FP 7-11, followed by a burst of fast activity on FP 7-11.
(c) End of the seizure: (4) end of clinical spasms. Persistence of polyphasic potential on FP 5-11, BL 13-14 and LS 1-2.

Case 2. Stereo-EEG data of a 4-year-old child with multifocal epilepsy

Onset of epilepsy occurred at the age of four days. The first seizures were characterised by cyanosis and gaze deviation to the right. They were partially controlled by antiepileptic treatment. At the age of four months, the child had regression associated with infantile spasms (IS). IS were effectively treated, but focal seizures persisted despite several antiepileptic drugs.

At the time of SEEG, the patient had daily seizures. He stopped his activity, had gaze deviation to the right, or stared with mouth-watering and mumbling. The patient was not yet lateralised. He had no focal deficit, but a severe developmental delay without any speech and an inability to play.

Video-EEG showed right anterior temporal and temporo-parieto-occipital bilateral asynchronous spike-waves. Seizure onset was either in the left or right occipital lobe or bilateral.

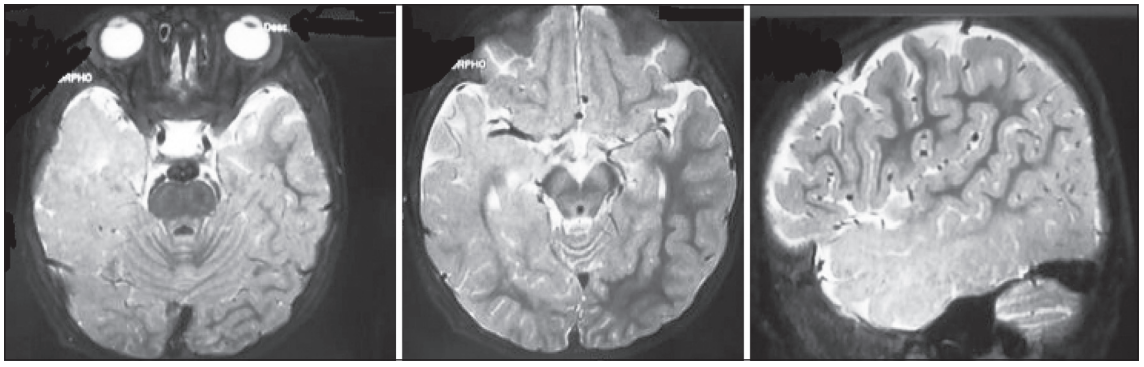
MRI showed a malformation which was obvious in the right temporal lobe and ill-defined in the occipital lobe. The left temporal and occipital lobes appeared normal.

SEEG was performed to test the hypothesis that epilepsy was related to the right temporal malformation, despite the lack of clear-cut electroclinical correlations (category C). Electrodes were implanted in order to circumscribe the malformation and to exclude a contralateral onset.

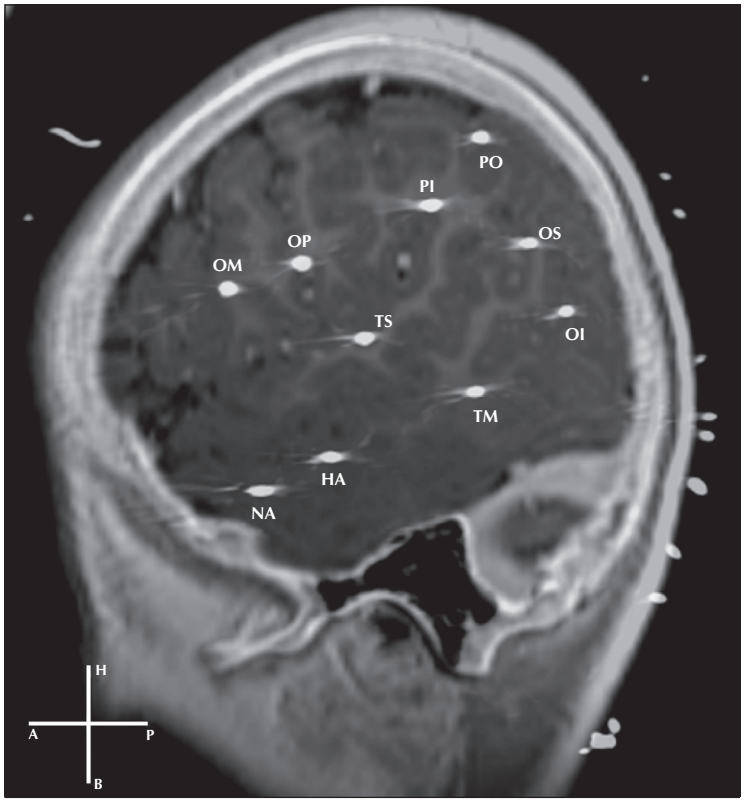
SEEG showed multifocal interictal abnormalities and several seizure types (three are shown). This led to right temporal resection associated with a posterior parietal and occipital disconnection.

Pathology showed focal cortical dysplasia associated with hippocampal sclerosis (Type IIIa according to Blümcke *et al*. [2011]).

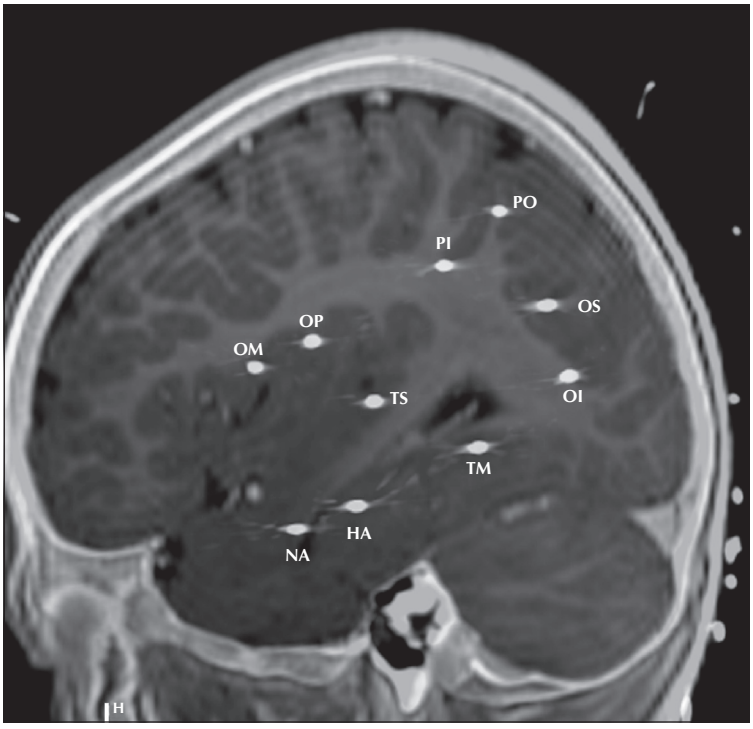
At the last follow-up visit, 34 months after surgery, the patient was seizure-free without any medication. He was able to speak with short sentences and displayed improved social interactions.



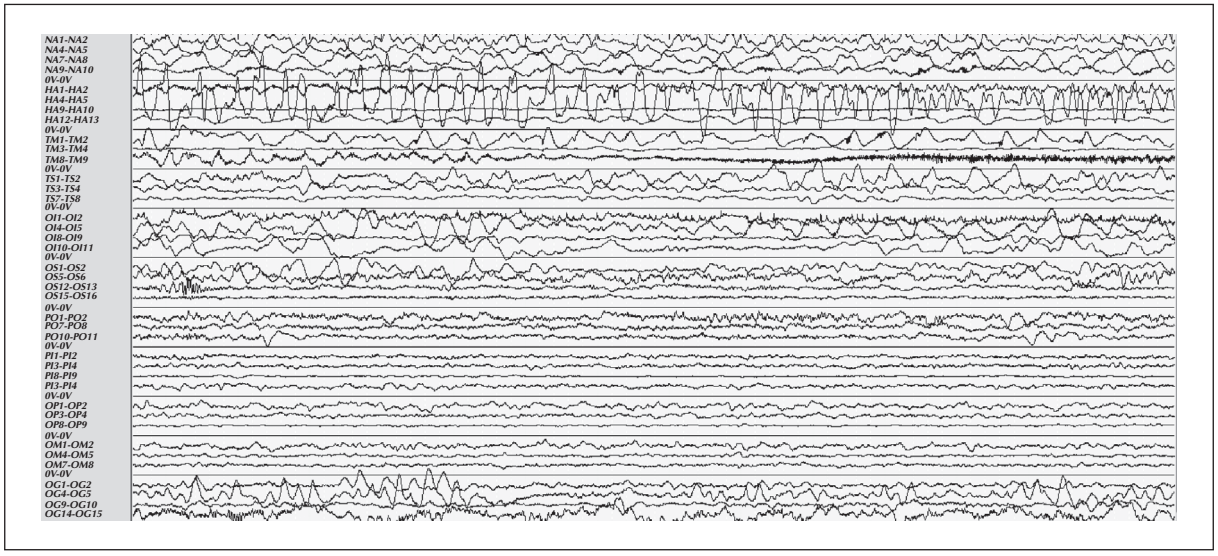
Case 2A. Preoperative MRI.



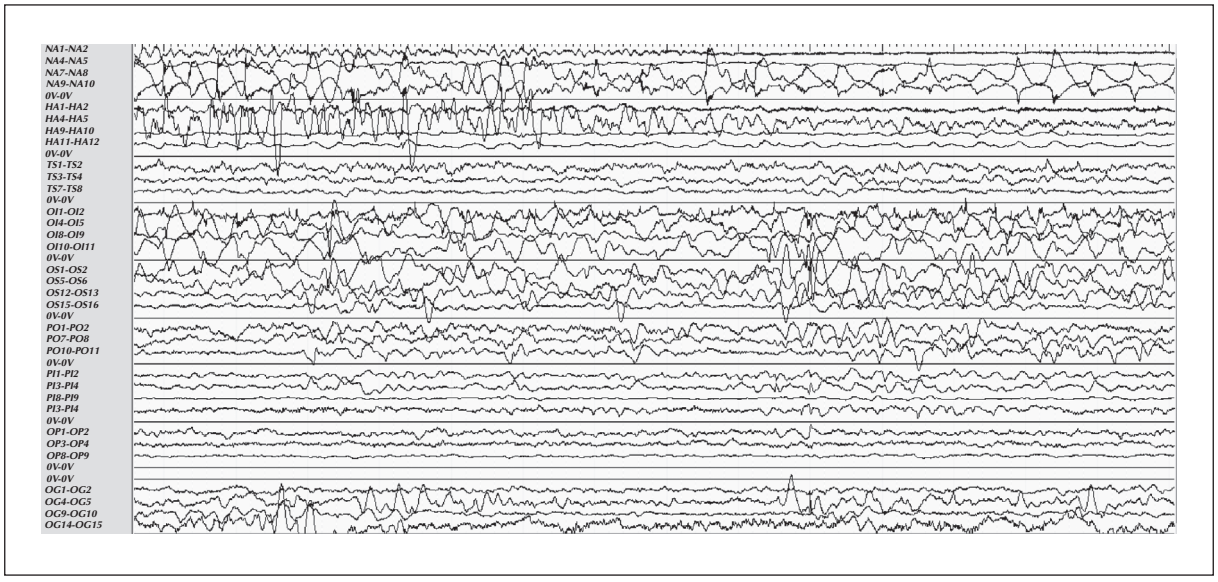
Case 2B. Post-SEEG CT scan merged with preoperative MRI showing the position of the electrodes (lateral view of the cortex; electrode OG, left occipital is not visible). Note that the electrodes have an oblique insertion. A technical problem in the operating room prevented the insertion of an electrode in the post-central gyrus.



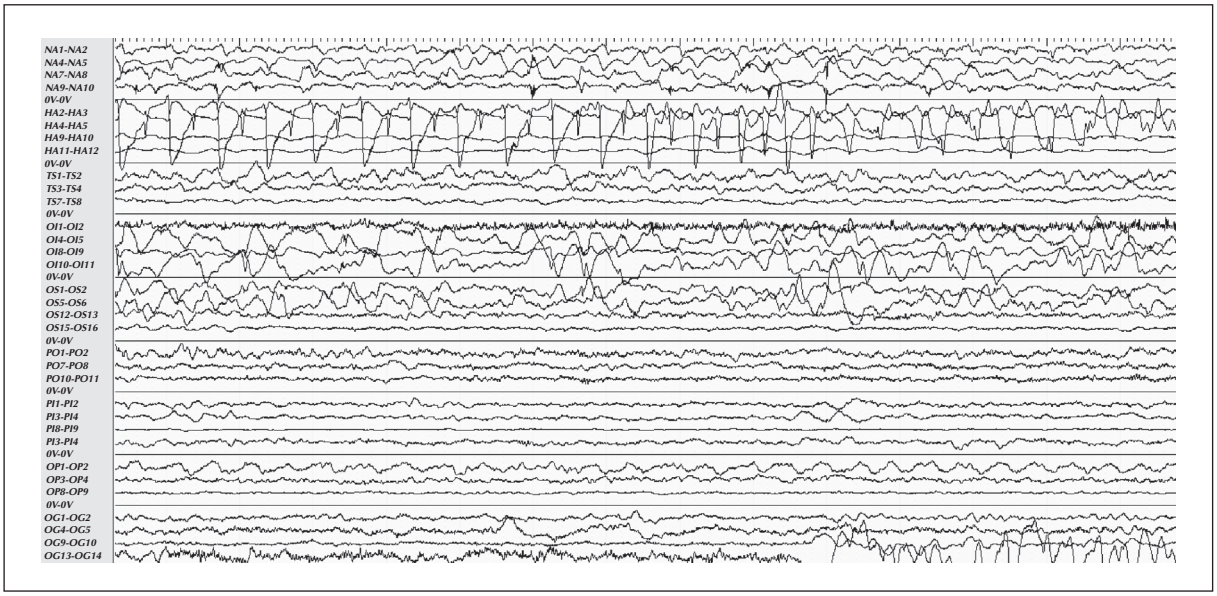
Case 2C. Post-operative CT scan merged with preoperative MRI showing the position of the electrodes (view through hippocampus and insula, electrode OG, left occipital is not visible).



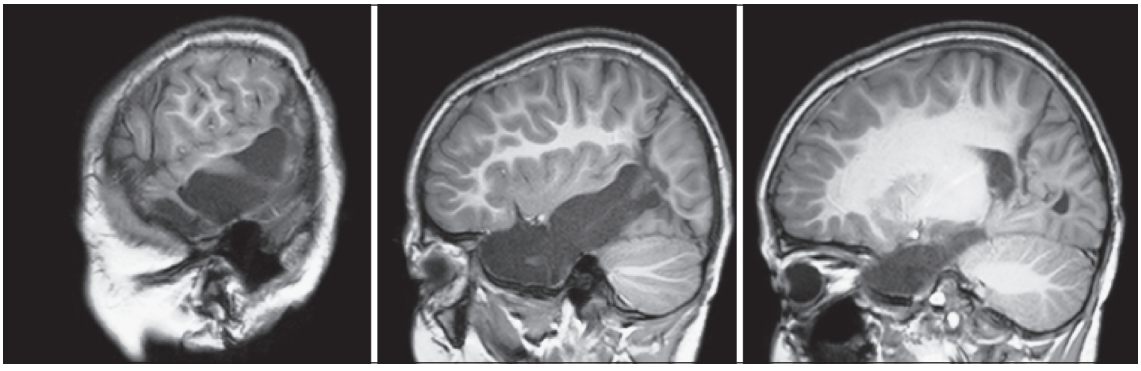
Case 2D. One type of seizure onset: fast discharge at the lateral contacts of TM (inferior temporal sulcus).



Case 2E. Second type of seizure, starting with fast discharge on NA 1-2 and HA 1-2 (amygdala and anterior hippocampus).



Case 2F. Third type of seizure, starting with fast discharge OI on 1-2 (infracalcarine region) while interictal rhythmic spikes and waves were detected in the anterior hippocampus (HA 1-5).



Case 2G. Post-operative MRI showing the resection and the disconnection.

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