

Temporal Lobe Epilepsy

Giridhar P. Kalamangalam and Sotiris Mitropanopoulos

KEY CONCEPTS

- Temporal lobe epilepsy (TLE) is a heterogeneous condition that can be classified as hippocampal, extrahippocampal, bitemporal, or temporal-plus, depending on the degree of mesial, lateral, bilateral, or extratemporal involvement, respectively.
- Stereoelectroencephalography (SEEG) evaluation of the temporal lobe is directed to identifying TLE subtypes, in addition to mapping language-eloquent cortex in the dominant hemisphere.
- Canonical placement schemes include the temporal pole and amygdala–hippocampal complex through a lateral approach, additional posterosuperior and posteroinferior coverage adjusted for hemispheric dominance, “sentinel” electrodes in the posterior limbic and orbitofrontal paralimbic regions, the insula if specifically indicated, and bilateral placements for suspected bilateral TLE.
- As with all SEEG, the yield of stereotaxic exploration of TLE is highly hypothesis-dependent, demanding synthesis of the noninvasive data into a set of specific questions that the subsequent implant answers.

INTRODUCTION

TLE is the most common of the focal epilepsies in adults, though formal epidemiologic data are scant. Remote population studies performed by the Mayo Clinic in Rochester, MN, showed that between 1945 and 1964 there was an incidence of 10.4 per 100,000.¹ Twenty years later, a study of tertiary referral patterns found that in a cohort of 2,200, 62.2% had focal epilepsy of which 66% had TLE.² Unsurprisingly, TLE is the syndrome most discussed in the epilepsy surgery literature, in addition to being the subject of the first randomized controlled trial of resective surgery as a treatment modality for pharmacoresistant focal epilepsy.³

EPILEPSY AND THE TEMPORAL LOBE

The temporal lobe’s high epileptogenic tendency is owed to the hippocampus, the brain region with the greatest susceptibility to seizures.⁴ In studies of experimental epileptogenesis,

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ensemble synchronous activity is often triggered in the CA3 segment, where pyramidal neurons naturally fire in bursts and have dense excitatory recurrent connections.⁴ GABAergic interneuron activity keeps this tendency for runaway excitation in check, but even minor change in the excitation–inhibition balance may permit seizures to break through. CA3 hypersynchrony may underlie the sharp wave activity seen in the normal hippocampus during sleep and quiet wakefulness, thought to be essential for the laying down of auto-associative memory. Thus, it may be the hippocampus’s physiological function—the encoding of experience into memory—that also renders it vulnerable to seizure.⁴ Chronic hippocampal epilepsy arises in a number of ways. In the excitotoxic model—from status epilepticus or trauma—death of vulnerable cellular populations (interneurons, CA1 pyramidal cells, and mossy cells in the dentate hilus) provokes reorganization of intrahippocampal circuitry (e.g., mossy fiber sprouting) whose end-result is network hyperexcitability.⁵ In addition to hippocampus-specific mechanisms, focal epilepsy may arise in the temporal lobe as it does in other cortical regions—through structural reorganization from dysplasia or acquired injury, tumor-related, or via genetic mechanisms with focal expression.⁵ Seizure propagation within and outside the temporal lobe can be understood by considering its connections. The entorhinal cortex and various portions of the hippocampus are linked by a series of unidirectional excitatory connections that form the intrinsic hippocampal circuit,⁶ which may explain the long-lasting localized seizures often observed in hippocampal epilepsy. Projections from widespread associational cortical areas reach the hippocampus either directly or with few intermediate synapses; reciprocal connectivity from the hippocampus is equally widespread. One specific output pathway is the Papez (limbic) circuit: subiculum projections to the mammillary bodies via the fornix, through the mammillothalamic tract to the anterior nucleus of the thalamus, the cingulum, and finally back to entorhinal cortex. The hippocampus also connects reciprocally with the amygdala. The latter in turn is reciprocally connected to vast cortical areas including temporal neocortex, insula, and the medial and basal frontal lobe.⁷ Commissural connections between the temporal lobes are the hippocampal commissure that comprises neural projections between the adjacent bodies and crura of the fornix, and the anterior commissure, whose posterior limb connects the two amygdalae, anterior temporal poles, and inferior temporal regions.⁶ In addition to the cingulum (above), multiple major white matter association pathways terminate in the temporal lobe: the uncinate fasciculus, the inferior longitudinal fasciculus, the middle longitudinal fasciculus, the inferior fronto-occipital fasciculus and the arcuate fasciculus.⁸ The network of intrinsic and extrinsic connectivity of the hippocampus and the temporal lobe offers a structural basis for the conceptualization of TLE subtypes.

TEMPORAL LOBE EPILEPSY SYNDROMES

When the epileptic network is entirely contained in the temporal lobe, TLE is of two types—(a) mesial (hippocampal) temporal lobe epilepsy (MTLE) and (b) lateral (extrahippocampal or neocortical) temporal lobe epilepsy (NTLE)—that are quite different in several of their essential clinical characteristics. Essentially, MTLE “lives” within the mesial temporal structures, with seizure symptoms attributable to the limbic brain areas; NTLE is characterized by wider seizure spread patterns, including a tendency for secondary generalization. Due to the hippocampus’s high excitability, NTLE commonly induces a secondary MTLE, so that the overall epilepsy syndrome may exhibit mixed features. Apart from these classical variants, it is useful to consider separately the syndrome of (c) temporopolar epilepsy. The temporal pole is a paralimbic structure, lying beyond Broca’s limbic lobe.⁹ In addition to connecting with limbic structures, it is connected by the uncinate fasciculus to the inferior and basal frontal lobe, which may endow temporopolar seizures with atypical, frontal-like semiology. The commissural connections of the temporal lobe ensure that whether TLE is hippocampal or extrahippocampal, the involvement of both temporal lobes in the disease is common. It

may not be an exaggeration to consider “unilateral” TLE as a highly asymmetric bilateral TLE. More symmetric disease would be considered truly (d) bilateral TLE, a condition where surgical options are significantly different to asymmetric cases. Finally, and with reference to the temporal lobe as a whole, we mention the syndrome of (e) “temporal-plus” epilepsy (or pseudo-temporal epilepsy), that is considered in detail elsewhere in this book. This syndrome mimics the electroclinical features of TLE but in fact involves or originates from connected brain regions outside the temporal lobe (the frontal, parietal, or occipital cortex). Thus—the main message of this chapter—TLE is not a single entity. While surgery for pharmacoresistant TLE offers better outcomes overall when compared to epilepsies that arise from extratemporal structures,¹⁰ temporal lobectomy may still fail. Failures may be due to subsuming all refractory TLE under one umbrella without appreciation of individual variants.¹¹

STEREO EEG IN TEMPORAL LOBE EPILEPSY

The goal of SEEG in TLE could be summarized as syndrome (or network) identification. We say the TLE syndrome is “identified,” rather than “discovered” because of the highly hypothesis-driven nature of SEEG as a technique. Such a clinical approach was shown—with populations undergoing subdural grid electrode (SDE) evaluation—to recapitulate an iterative Bayesian formalism,^{12,13} where high- or low-probability preimplant diagnoses, based on the accretion of localizing information from successive noninvasive investigations, was associated with successful and unsuccessful invasive SDE evaluations, respectively. However, the importance of a high-probability preimplant hypothesis applies even more to SEEG than SDE due to the intrinsically sparse and scattered nature of cortical sampling with SEEG. Thus, while an SEEG implant may explore multiple hypotheses and illuminate precise network interactions, the overall endeavor aims to sharpen the preimplant bias into a diagnosis that defines surgical strategy. That is, SEEG in TLE looks for, and selects from, one of the predetermined variants (a)–(e) previously mentioned. In the dominant temporal lobe, a separate goal of SEEG is to delineate language-eloquent cortex, and this usually involves placement of additional posterior infrasylvian contacts. In addition, an SEEG implant involves a few (usually one to two) “sentinel” electrodes that are chosen for their low probability of being involved in the network. On confirmation of normalcy following the implant, these extra contacts serve to define the boundary of the network.¹⁴ We illustrate these points with the case histories below.

Mesial Temporal Epilepsy

Data

A 26-year-old right-hand female presented with a 2-year history of seizures, not adequately treated by a multidrug anticonvulsant regime. Seizures were usually nocturnal when she would waken with a “warm” feeling variably associated with *déjà vu* or an epigastric sensation that would pass off, or followed by chewing movements with occasional progression to convulsions. Interictal EEG showed a single population of right anterior temporal spikes (Figure 13.1A); ictal EEG showed a rhythmic delta onset pattern (Figure 13.1B) followed by sharper theta frequency rhythms.

MRI showed an enlarged right amygdala (Figure 13.1C) and PET, right temporal hypometabolism (Figure 13.1D). Neuropsychology showed intelligence quotient (IQ) in the average range without significant verbal-performance split, moderate frontal-executive deficits, and impaired visuospatial memory.

Analysis

The interictal and ictal EEG were consistent with MTLE, but several other features were atypical for a classic MTLE: the relatively short history, the experiential and autonomic features to her aura, and the tendency to generalization. Acknowledging controversy in the recent

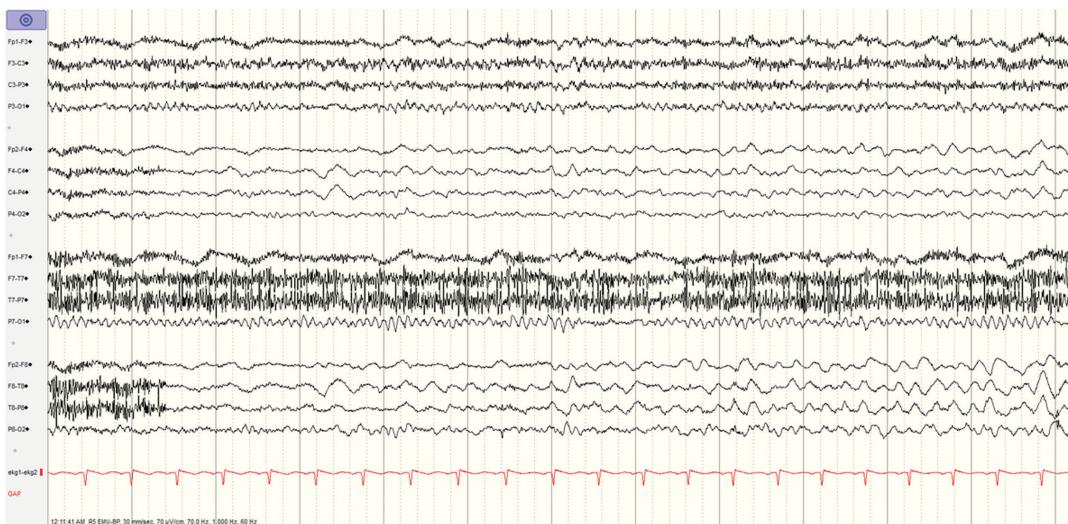
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FIGURE 13.1 (A) 10 sec EEG page, longitudinal bipolar montage, passband 1–70 Hz, 10 μ V/mm gain. Right mid-temporal maximum spikes in light sleep (arrows). (B) Right-sided ictal onset of rhythmic delta. (C) T1-weighted MRI, coronal view through anterior temporal region showing enlargement of the right amygdala (circled). (D) Fluorodeoxyglucose-PET, coronal view, showing right anterior temporal hypometabolism (circled). (E) The right temporal lobe sampled with orthogonally placed electrodes (right temporal pole, RAM, right anterior hippocampus, right posterior hippocampus, right basal temporal). Sampling extended with a single electrode targeting the right retrosplenium, and the right orbitofrontal and right posterior insular paralimbic regions (stereoelectroencephalography templates for this and following illustrations due to Dr. Philippe Kahane and Dr. Philippe Ryvlin). (F) 10 sec intracranial EEG page, showing right-sided temporal polar, amygdalar and anterior hippocampal channels in bipolar montage (passband 3–70 Hz, gain 50 μ V/mm). Noisy and isoelectric channels excluded for clarity. Spike burst synchronous in amygdala-anterior hippocampus (box) as well as independently in the temporal pole (arrows). (G) Ictal onsets in amygdala-anterior hippocampus.

RAH, right anterior hippocampus; RAM, right amygdala; RBT, right basal temporal; ROF, right orbitofrontal; RPH, right posterior hippocampus; RPIN, right posterior insular; RRS, right retrosplenium; RTP, right temporal pole.

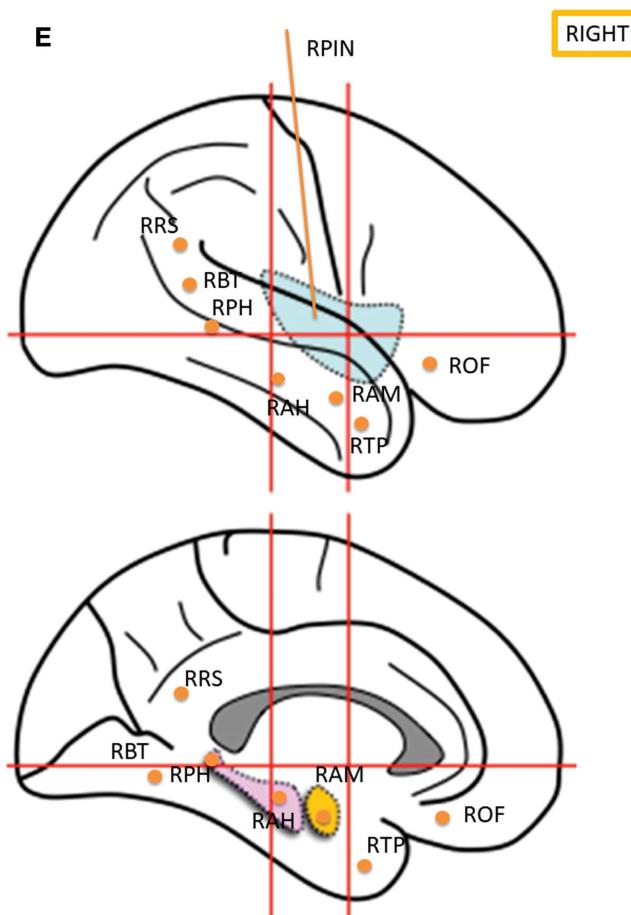
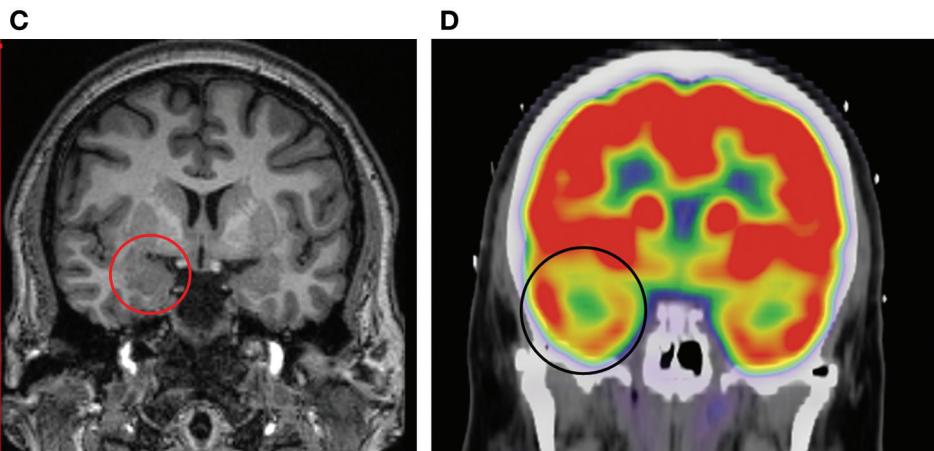
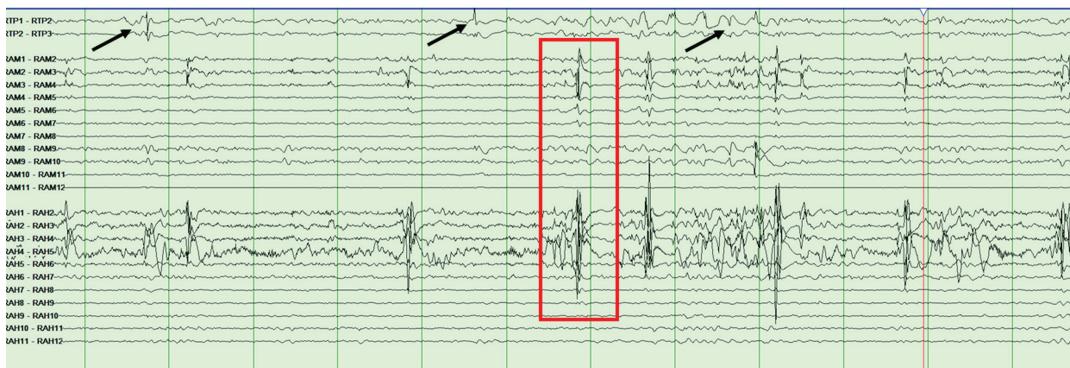


FIGURE 13.1 Continued

F**G****FIGURE 13.1** Continued

literature,^{15,16} the enlarged amygdala was not interpreted as a relevant “lesion.” Thus, the non-invasive data suggested nonlesional right TLE, with the relative contributions of the mesial and lateral temporal structures undefined.

Implant

The right temporal lobe was sampled orthogonally to target the amygdala, hippocampus, and temporal pole, with more posterior electrodes to delineate the posterior margin of the network. The posterior insula and the orbitofrontal cortex were also sampled (Figure 13.1E).

Outcome

Interictal spikes were seen maximally in the anterior hippocampal and amygdalar contacts (Figure 13.1F), in addition to the temporal pole and posterior hippocampus. Following seizures, interictal spiking was more widespread. Ictal onset was simultaneous by visual inspection over anterior hippocampal and amygdalar contacts (Figure 13.1G). The patient underwent a conventional anterior temporal lobectomy and has been seizure-free at 6-month follow-up. Pathology was nonspecific (Chaslin’s gliosis and rare white-matter neurons).

Comment

Though the classic aura of MTLE is an epigastric rising sensation and seizures only rarely generalize, it is clear that MTLE may present somewhat differently. This case suggested that one of these situations may be when interictal epileptiform activity and seizures also prominently involve structures outside the hippocampus *per se*. A different point is whether all patients with nonlesional MRI exhibiting a classic MTLE phenotype in other respects should

still proceed to SEEG. Given the relatively nontraumatic nature of SEEG, and the authority that a successful intracranial investigation brings to a diagnosis, our bias is to recommend SEEG in such patients. An important advantage of doing so is clarifying the choice between a more selective procedure (e.g., laser ablation of the hippocampus in confirmed hippocampal onset syndromes) and conventional anterior temporal lobectomy.

Lateral and Hybrid Temporal Epilepsy

Data

A 21-year-old right-handed female was evaluated for seizures starting at age 14. A seizure would be heralded by auditory hallucination of (described as “buzzing” when she was younger, but changing to repetitive formed sentences that she would recognize, but not be able to exactly recollect in retrospect), followed by staring and speechlessness. During the auditory aura, she was deaf to external sounds. Occasionally she would progress to a convulsive phase. Interictal EEG showed profuse left hemispheric single spikes with temporal maximum, occasionally with an overriding polyspike that was posterior temporal maximum (Figure 13.2A).

During evaluation, multiple episodes of deafness were recorded with repetitive spike activity of a similar nature to her interictal discharges (not shown). She also had an episode that progressed to behavioral arrest accompanying EEG paroxysmal fast activity, maximum mid- and posterior temporal (Figure 13.2B).

MRI brain was reported normal; cranial PET showed left temporal hypometabolism (Figure 13.2C). Source localization of interictal MEG spikes was distributed along the lateral temporal and opercular regions in addition to the mesial temporal lobe (Figure 13.2D). EEG-functional MRI of her most frequent spike subpopulation showed maximum activation along the mid-portion of the left middle temporal gyrus (Figure 13.2E).

Neuropsychology showed IQ in the average range with significant weaknesses in tests of semantic fluency with intact verbal and nonverbal memory, indicating a dominant hemisphere temporal lobe neocortical process.

Analysis

The diagnosis of an NTLE was straightforward, with the auditory aura suggesting early involvement of the posterior sylvian temporal lobe; subsequent behavioral arrest suggested propagation into the hippocampus. The EEG findings were overwhelmingly left-sided and supported by the unilateral left temporal PET hypometabolism. Following discussion, a closely spaced SEEG evaluation of the posterior left temporal neocortex and the ipsilateral limbic structures was agreed on.

Implant

The left posterior perisylvian area was sampled orthogonally. Additional electrodes were placed more anteriorly into the left superior temporal gyrus. The left amygdala and hippocampus were sampled orthogonally; the posterior inferior temporal cortex was sampled with two more electrodes that targeted the lingual and occipital cortex medially (Figure 13.2F).

Outcome

Profuse spiking was seen in the juxta-sylvian lateral contacts involving electrodes labeled left retrosplenial (LRS), left posterior superior temporal, left occipital and left middle cingulate in addition to hippocampal contacts (Figure 13.2G). Seizures all involved a nonconvulsive phase followed by generalization—different from, but consistent with, the history and scalp evaluation—with onsets of direct current shift with superimposed low-voltage fast activity best seen in the posterior infrasylvian temporal cortex (electrode LRS; Figure 13.2H). Stimulation mapping confirmed language function in multiple lateral posterior perisylvian contacts. The patient accepted responsive neurostimulation (RNS) of the left infrasylvian temporal neocortex (two

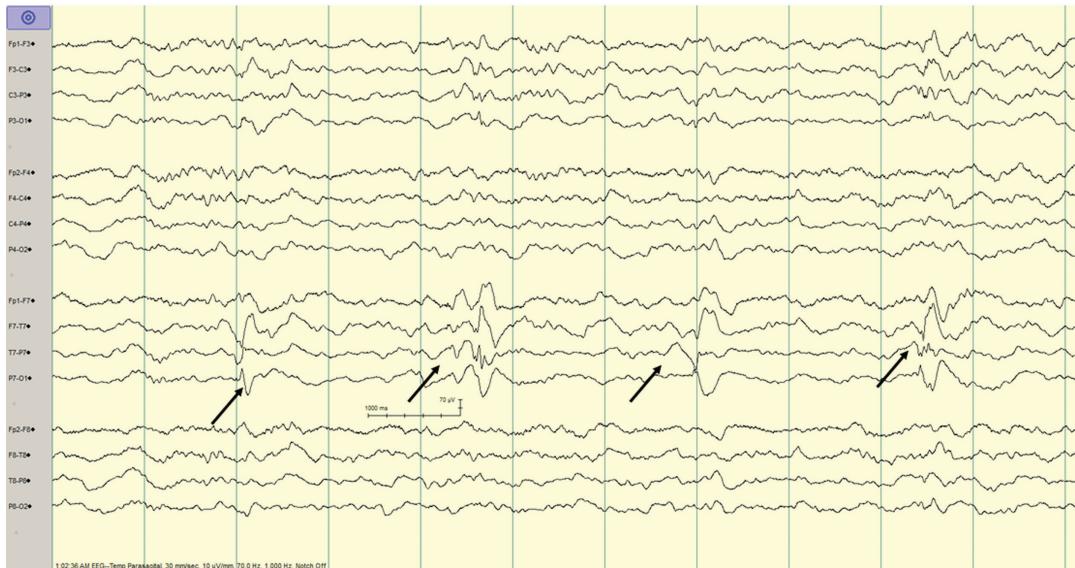
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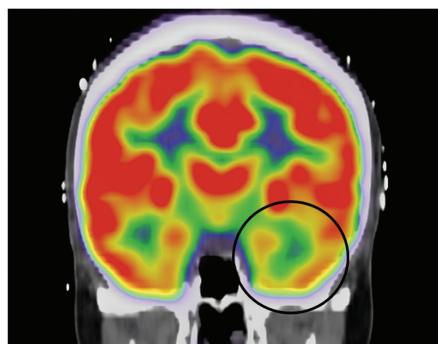
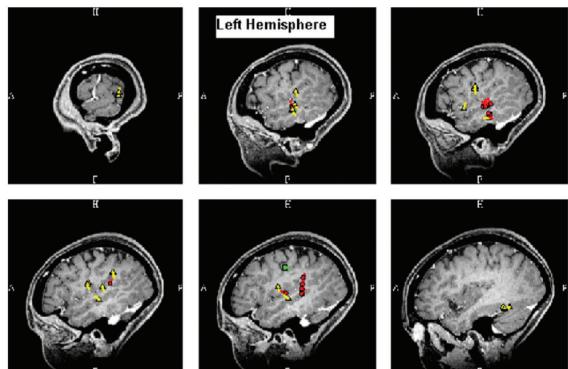
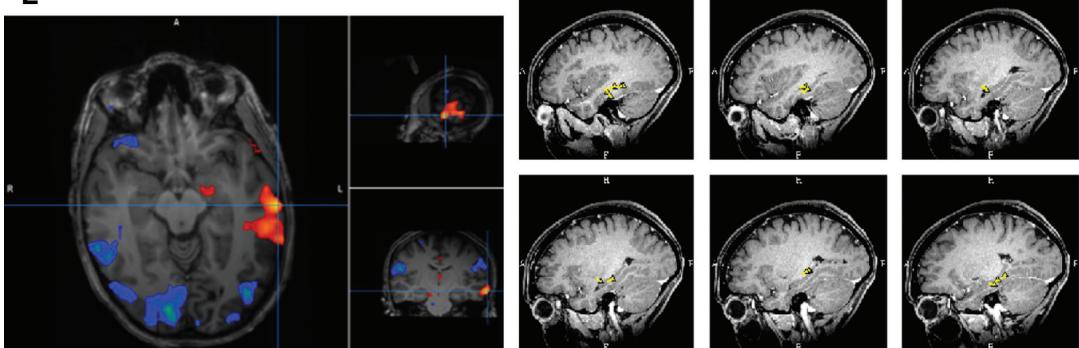
FIGURE 13.2 (A) 10 sec EEG page, longitudinal bipolar montage, passband 1–70 Hz, 10 μ V/mm gain. A run of left hemispheric spike-polyspike discharges in sleep, maximum posterior temporal. **(B)** EEG onset of a seizure beginning with an auditory hallucination progressing to brief behavioral arrest. Left hemispheric paroxysmal fast activity is seen maximally in the posterior temporal region (parenthesis). **(C)** Fluorodeoxyglucose-PET, coronal view, showing left anterior temporal hypometabolism (circled). **(D)** Magnetoencephalography source localization of left temporal interictal discharges, sagittal view, showing sources corresponding to interictal discharges (yellow), somatosensory (green), and receptive language (red; recording and analysis due to Dr Eduardo Castillo, AdventHealth Orlando). **(E)** EEG-functional MRI heat map of the most frequent left temporal spike subpopulation, showing high left middle temporal activation (recording and analysis due to Dr. Jean Gotman, Montreal Neurological Institute). **(F)** The left hippocampus sampled with orthogonally placed electrodes (LAH, LPH), with additional superior temporal and perisylvian sampling (left anterior superior temporal, left middle superior temporal, left posterior superior temporal, left lingula, left occipital, LRS, left posterior cingulate, left middle cingulate) and one additional electrode in the posterior insula. Other electrode names per scheme in Figure 13.1(E). **(G)** 10 sec intracranial EEG pages, showing all channels in bipolar montage (passband 3–70 Hz, gain 50 μ V/mm). Multi-focal spiking seen in neocortical lateral contacts (red arrows) as well as the anterior and posterior hippocampus (black arrows). **(H)** Ictal onset with direct current shift underlying a tonic discharge in multiple adjacent neocortical contacts, maximum in the lateral channels of LRS (bottom red arrow) corresponding to the posterior infrasylvian region.

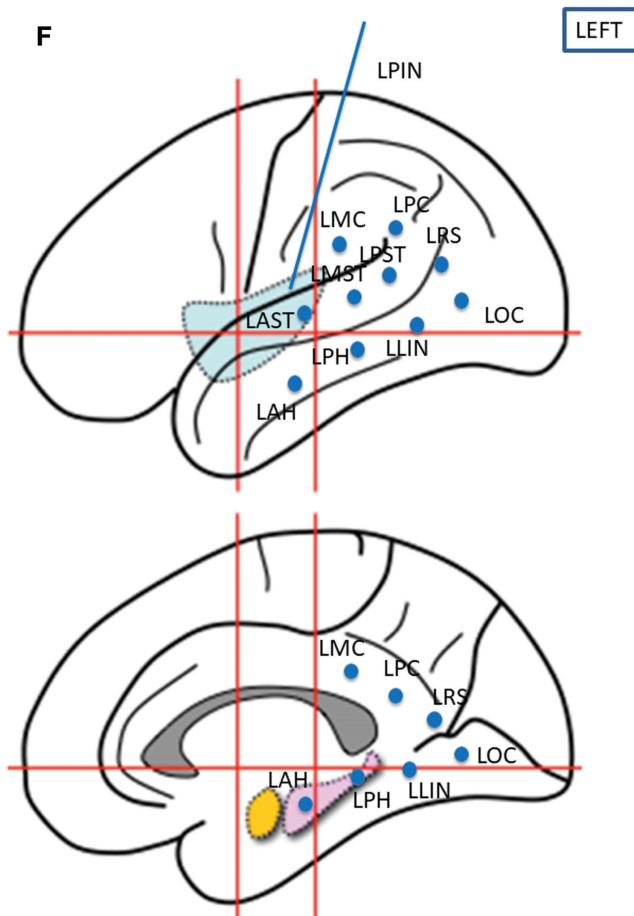
LAH, left anterior hippocampus; LAST, left anterior superior temporal; LLIN, left lingula; LMC, left middle cingulate; LMST, left middle superior temporal; LOC, left occipital; LPC, left posterior cingulate; LPH, left posterior hippocampus; LPIN, left posterior insula; LPST, left posterior superior temporal; LRS, left retrosplenial.

four-contact strips) and ipsilateral hippocampus (four-contact depth electrode). At 1-year follow-up, auditory auras continue but there has been a significant improvement in confusional and convulsive seizures.

Comment

The preimplant hypothesis of lateral TLE did not present a challenge in this case. The debate instead was whether it was possible with SEEG to cover the perisylvian area adequately to pick up focal ictal onsets separate from language-eloquent sites that would permit limited neocortical resection, in addition to defining the wider network and the role of the mesial structures. As alluded to previously, disentangling of lateral versus mesial contribution is a common indication for SEEG in TLE patients. Due to the high intrinsic epileptogenicity of the

B**C****D****E****FIGURE 13.2** Continued

**FIGURE 13.2** Continued

hippocampus, some mesial involvement in epilepsy of lateral temporal origin is virtually the rule. A practical decision in these circumstances is determining a threshold for including the hippocampus in resective procedures of the temporal lobe. A suggested practical strategy is to err on the side of preserving the hippocampus, the possibility of an interval hippocampectomy at a later stage (e.g., by thermal ablation) left open. In this patient, the close proximity of ictal onsets to perisylvian language sites precluded a resection option altogether.

Temporal Pole Epilepsy

Data

A 24-year-old right-handed male was evaluated for a 4-year history of seizures. There was a history of seizures at age of 1 year in the context of pneumococcal meningitis, but none in the intervening period until recurrence in adulthood. Neurological examination was normal apart from right-sided sensorineuronal hearing loss. Seizures were characterized by sudden onset of agitation with vigorous proximal and distal movements and intelligible repetitive vocalizations. Interictal EEG showed right temporal spikes with temporal intermittent rhythmic delta (Figure 13.3A). Ictal EEG was artifactual at onset and showed a late right temporal pattern (Figure 13.3B).

MRI showed minor enlargement of the right hippocampus that was considered nondiagnostic (not shown) and PET, right temporal hypometabolism (Figure 13.3C). Neuropsychology

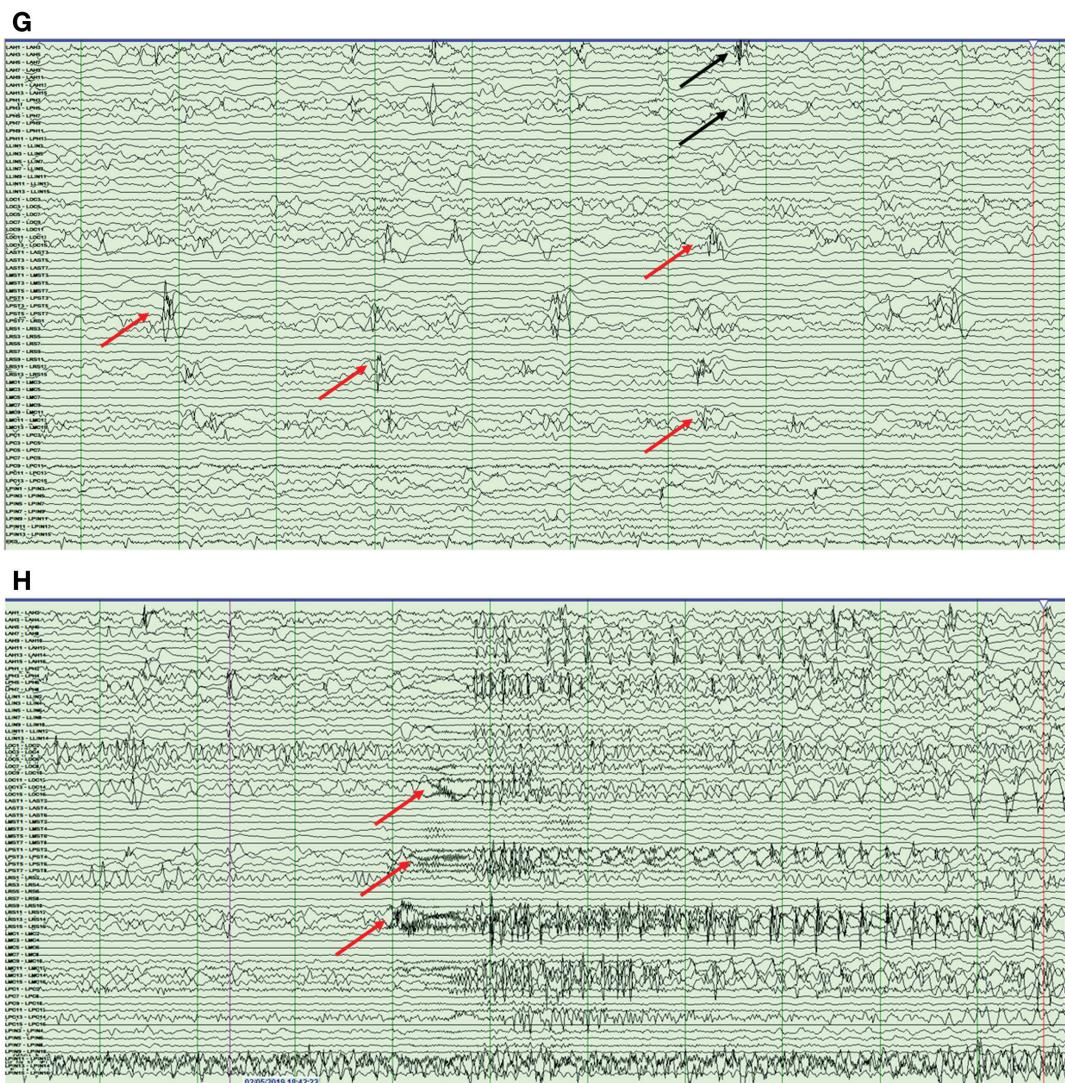


FIGURE 13.2 Continued

showed relative weaknesses and frank impairment in semantic fluency and confrontation naming. On memory, recognition was relatively better than free recall but with notably frequent false positive responses for information presented both verbally (word list learning, story memory) and visually (geometric shapes and complex figures). Intracarotid amobarbital (Wada) testing showed left language dominance, with poor spontaneous recall but perfect recognition of items presented to the isolated left hemisphere, and a zero score for both spontaneous recall and recognition in the isolated right hemisphere.

Analysis

Seizure semiology suggested involvement of the prefrontal region. The right temporal hypometabolism on PET, concordant interictal EEG and presence of verbal and nonverbal memory impairment, however, suggested temporal lobe involvement. Intracarotid amobarbital testing confirmed bilateral though highly asymmetric memory impairment, worse on the right side. Taken together, the data suggested TLE with frontal lobe features; that is, a “pseudo-frontal” presentation of TLE.

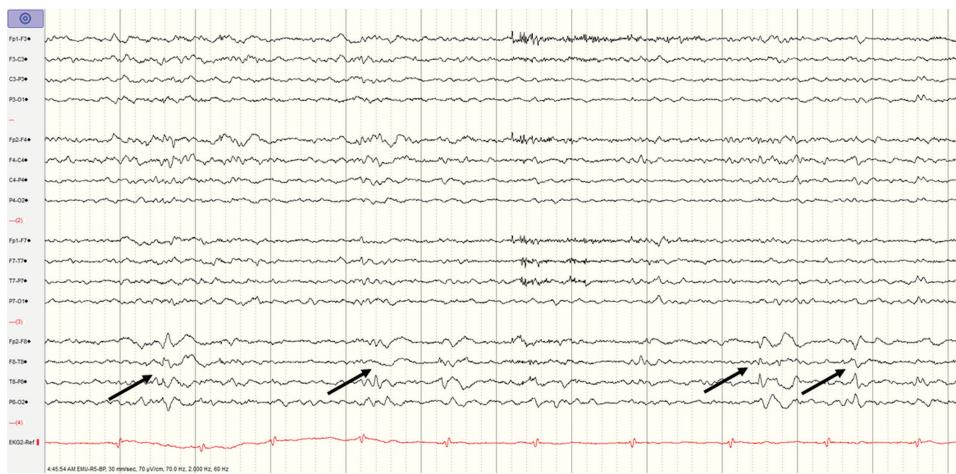
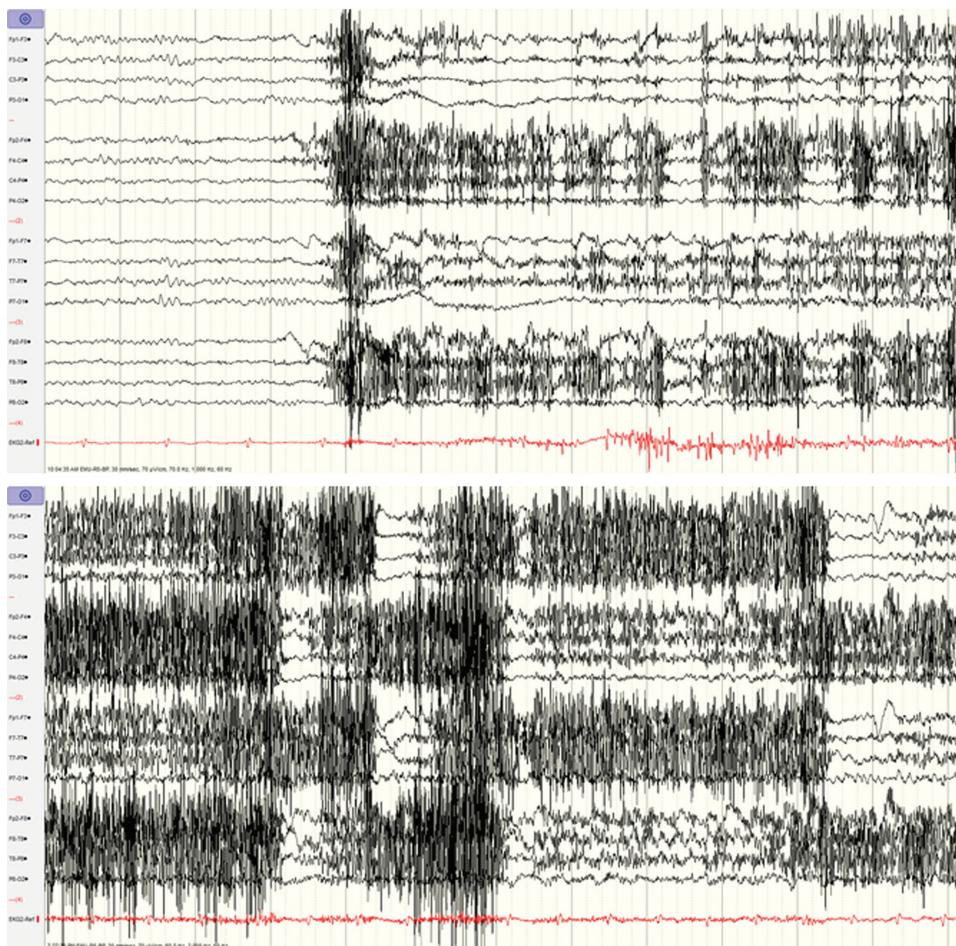
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FIGURE 13.3 (A) 10 sec EEG pages, longitudinal bipolar montage, passband 1-70 Hz, 7 μ V/mm gain. Run of polymorphic right temporal maximum spikes in light sleep (arrows). (B) Nonlocalizable ictal onset with superimposed widespread electromyogram artifact corresponding to clinical seizure onset with agitated movements (top panel) that evolves 30 sec later to a well-defined right

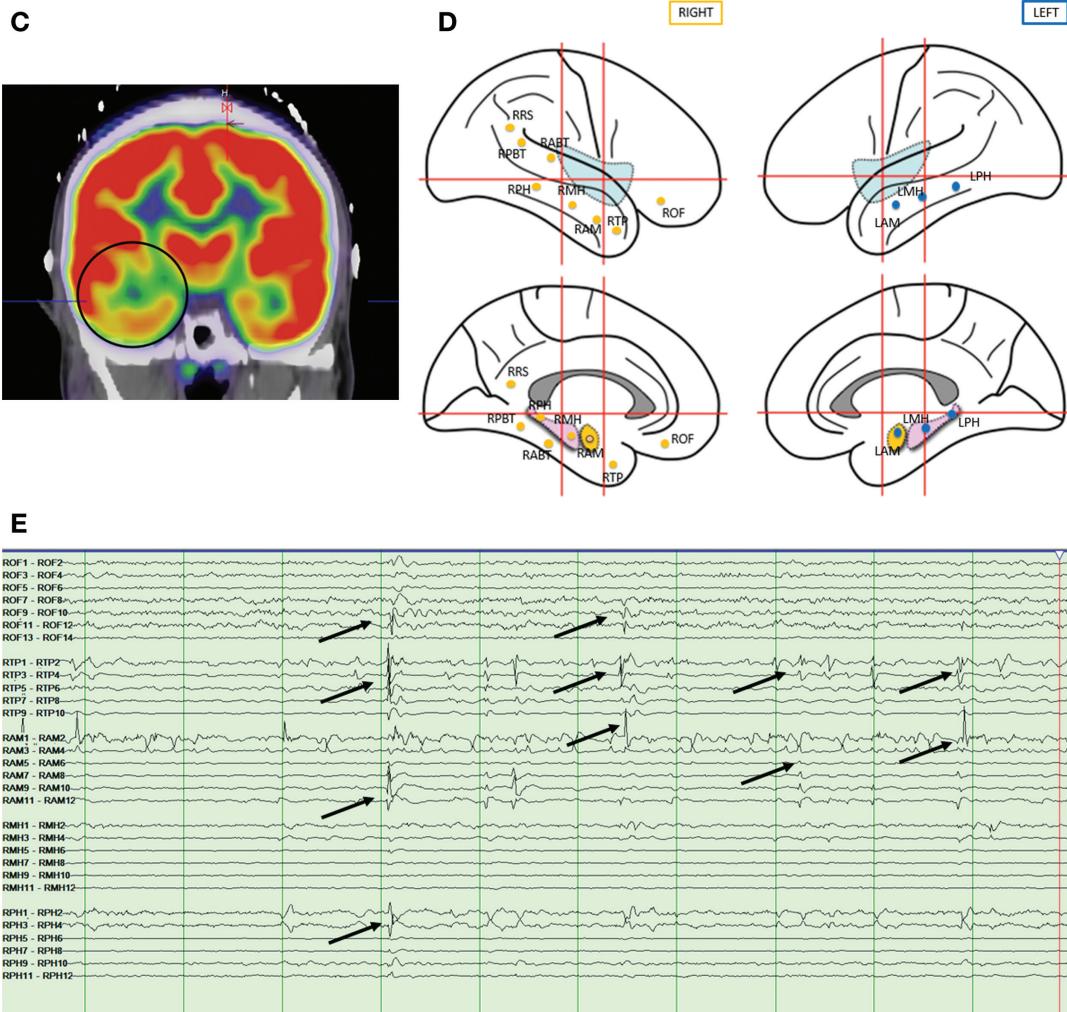
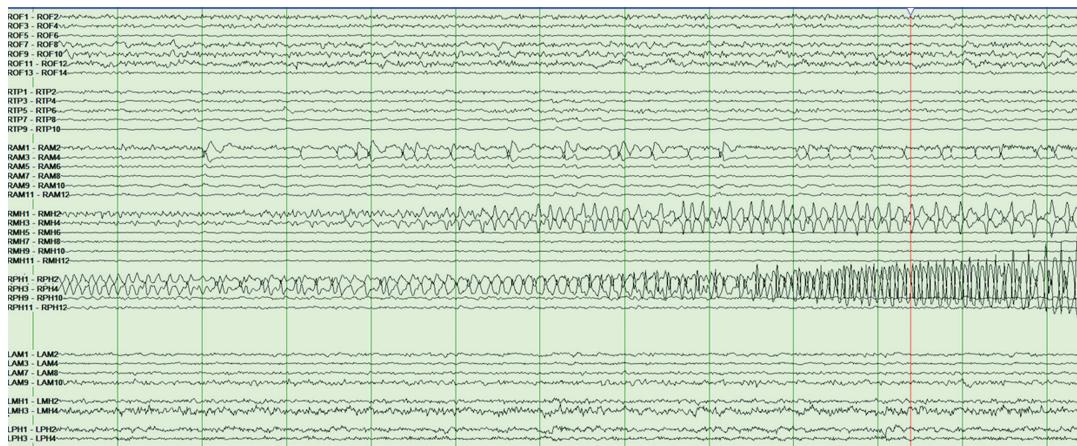
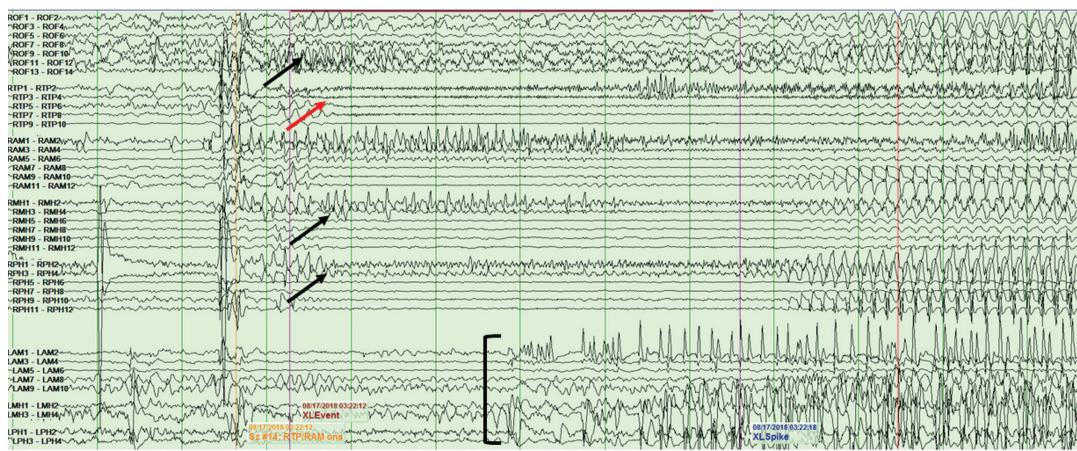


FIGURE 13.3 Continued

temporal theta rhythm (bottom panel). **(C)** Fluorodeoxyglucose-PET, coronal view, showing right anterior temporal hypometabolism (circled). **(D)** The right temporal lobe and paralimbic regions sampled similar to previous examples; limited sampling of the left temporal lobe targeting the amygdala and hippocampus. Other electrode names per previously. **(E)** 10 sec intracranial EEG pages, showing only a selection of right orbitofrontal, temporal pole, amygdalo-hippocampal, and left amygdalo-hippocampal electrodes for clarity, with noisy channels removed. Bipolar montage (passband 5-70 Hz, gain 30-70 μ V/mm). Variably synchronous spiking involving the lateral orbitofrontal, temporo-polar, amygdalar and hippocampal contacts (arrows). **(F)** Ictal onset type 1: evolving rhythmic change from right hippocampus. The left hippocampus is quiet. **(G)** Ictal onset type 2: tonic discharge involving the deep temporal-polar contacts (red arrow) with simultaneous involvement of the lateral orbitofrontal and hippocampal contacts (black arrows), with early spread to the left amygdalo-hippocampus (parenthesis). **(H)** Ictal onset type 3: evolving rhythmic change from the left hippocampus; the right hippocampus is quiet.

ABT, anterior basal temporal; LAM, left amygdala; LPH, left posterior hippocampus; LMH, left mid-hippocampus; PBT, posterior basal temporal; RAM, right amygdala; RMH, right mid-hippocampus; ROF, right orbitofrontal; RPBT, right posterior basal temporal; RPH, right posterior hippocampus; RRS, right retrosplenium; RTP, right temporal pole.

F**G****H****FIGURE 13.3** Continued

Implant

The right temporal lobe was sampled orthogonally to target the amygdala, hippocampus, and temporal pole. A single orbitofrontal electrode was placed orthogonally traversing the inferior frontal gyrus. Additional right temporal electrodes were placed to delineate the posterior margin of the network and the left temporal lobe was sampled orthogonally to target the amygdala and hippocampus (Figure 13.3D).

Outcome

Interictal spikes originated in the right amygdala and hippocampus independently. In addition prominent spiking was seen from the right temporal pole, lateral contacts of the right amygdalar electrode, and the right lateral orbitofrontal electrode (Figure 13.3E).

Scattered spikes were seen in the left amygdalo-hippocampal contacts as well (not shown). Multiple seizure types were recorded. Subclinical seizures arose from the right hippocampus (the majority; Figure 13.3F). Seizures reminiscent of his scalp evaluation with vigorous sudden agitated movements (one of which proceeded to generalization), arose simultaneously from right temporal pole, amygdala-hippocampus, and right orbitofrontal cortex, with the former structure showing the maximal early change (Figure 13.3G). Finally, seizures with staring and loss of contact of left hippocampal origin (Figure 13.3H) were also recorded.

The patient proceeded to a conventional right anterior temporal lobectomy and been free of clinical seizures for more than 1 year. Pathology showed Type I dysplasia in the neocortical specimens and early hippocampal sclerosis.

Comment

Seizure semiology of hyperkinetic behavior is the classic hallmark of anterior frontal epilepsies, but may also occur in extrahippocampal TLE,¹⁷ usually in epilepsies arising from the temporal pole.¹⁸ The frontal lobe semiology of these epilepsies arises from early seizure propagation into the polar and orbital frontal cortex, as in this patient.

Bi-Temporal Epilepsy

Data

A 39-year-old left-handed male with a positive family history of sinistrality was evaluated for seizures starting in childhood during a febrile illness thought to be meningitis. Phenobarbital was started and weaned at teenage without apparent seizure recurrence until age 36, when he had a motor vehicle accident due to “blanking out” at the wheel. Habitual seizures from then on were characterized by staring, wandering, or stomping his feet if he was stood up. There was no warning. Convulsive seizures were rarer, and arose from sleep. Interictal EEG showed independent left and right temporal spikes in an approximately 60:40 ratio in addition to spikes that had a wider bihemispheric distribution (Figure 13.4A and 13.4B).

Ictal EEG was nonlocalizing at onset and showed a later diffuse pattern that was maximum right temporal (Figure 13.4C). MRI showed left hippocampal sclerosis in addition to a left middle cranial fossa meningoencephalocele (Figure 13.4D). Neuropsychology showed broad impairment across both verbal and perceptual domains.

Analysis

The presence of two epileptogenic brain lesions in close proximity in the same temporal lobe suggested the reasonable strategy of left temporal lobectomy without further investigations. Indeed, the only allowable resective procedure in this patient would have been left-sided. Yet, the exclusively right-sided appearance of ictal EEG changes gave pause. If in fact all seizures originated on the right, a left-sided procedure would constitute a significant intervention with small—though potentially serious—operative risks, for little or no benefit. If, on the

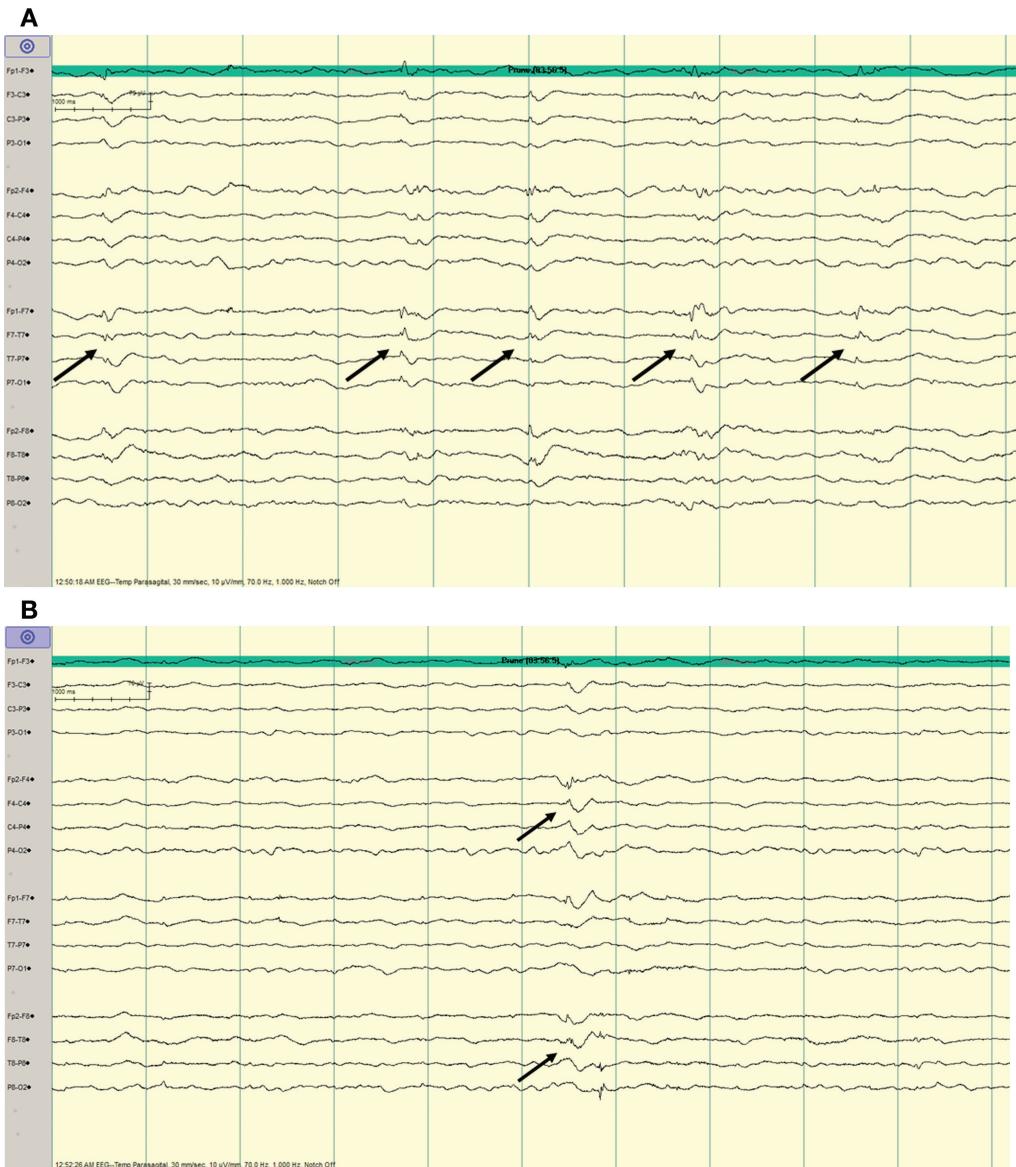


FIGURE 13.4 (A) 10 sec EEG pages, longitudinal bipolar montage, passband 1-70 Hz, 7 μ V/mm gain. A train of left temporal spikes (arrows) are seen. **(B)** A single, widely distributed small-amplitude right hemispheric interictal spike. **(C)** Nonlocalizable ictal onset that is swamped by diffuse electromyogram towards the end of the page (top panel) that evolves 30 sec later to a well-defined theta-delta rhythm, maximum right temporal (bottom panel). **(D)** Left: T2-weighted MRI, coronal view through anterior temporal region showing left hippocampal volume loss and high signal (circled). Right: base of skull CT showing a small bony defect of the left middle cranial fossa with herniating intracranial contents (circled). **(E)** The left temporal lobe sampled similar to previous examples with the temporo-polar electrode in close proximity to the encephalocele; limited sampling of the right temporal lobe targeting the amygdala and hippocampus. Electrode names per previously. **(F)** 10 sec intracranial EEG pages, showing the entire implant, with noisy channels removed. Bipolar montage (passband 5-70 Hz, gain 50-70 μ V/mm). Profuse left (red arrows) and right (black arrows) amygdalo-hippocampal spiking. **(G)** Ictal onset with DC shift and paroxysmal fast activity in the left amygdalo-hippocampus (arrows), with semiperiodic spiking in parallel in the right amygdalo-hippocampus. **(H)** Ictal onset with paroxysmal fast activity in the right amygdalo-hippocampus (arrows), appearing to silence spiking in the left amygdalo-hippocampus.

LAH, left anterior hippocampus; LAMY, left amygdala; LBT, left basal temporal; LPH, left posterior hippocampus; LRS, left retrosplenial; LTP, left temporal pole; RAH, right anterior hippocampus; RAMY, right amygdala; RPH, right posterior hippocampus.

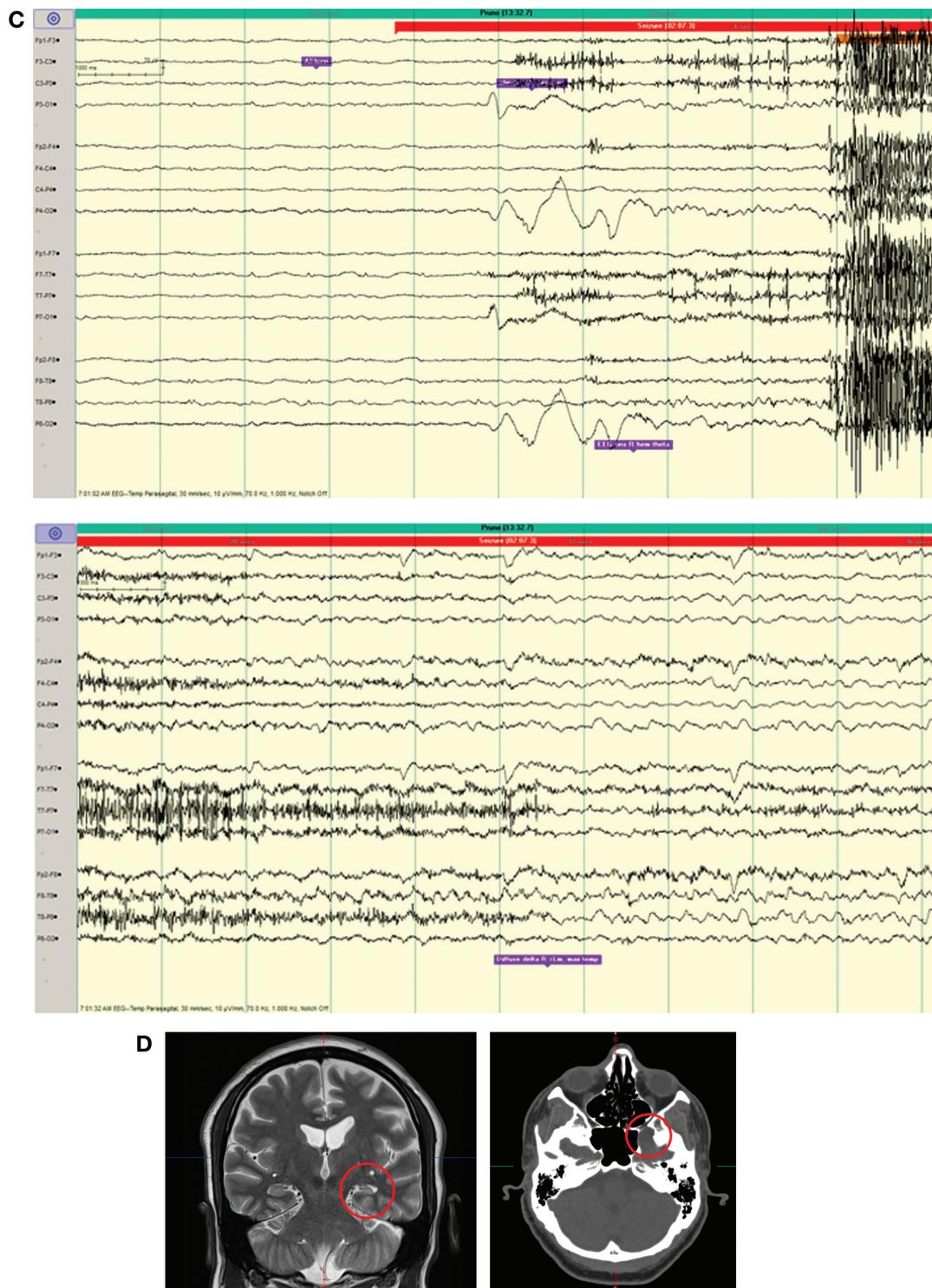
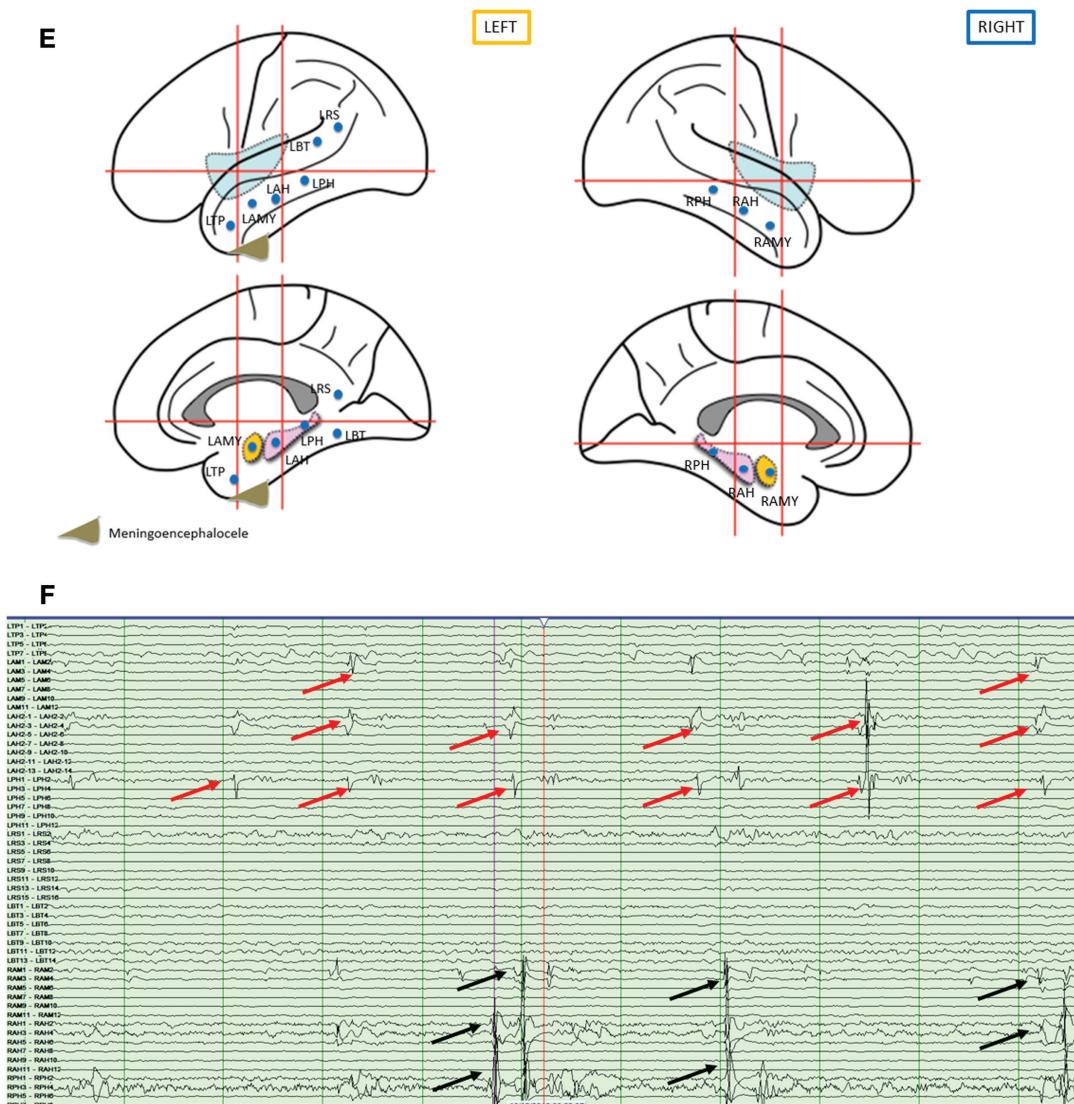


FIGURE 13.4 Continued

**FIGURE 13.4** Continued

other hand, SEEG demonstrated ictal onsets on the left that preferentially migrated to the right (yielding the right-sided scalp pattern), left temporal lobectomy would be beneficial.

Implant

The left temporal lobe was sampled orthogonally to target the amygdala and hippocampus. A temporal pole electrode was placed in close proximity to the meningoencephalocele. Additional electrodes were placed to delineate the posterior margin of the network and the posterior portion of the superior temporal gyrus to map language if necessary. The right temporal lobe was sampled orthogonally to target the amygdala and hippocampus (Figure 13.4E).

Outcome

There was profuse spiking at both left and right amygdalo-hippocampal contacts (Figure 13.4F). Seizures without clinical signs were recorded arising simultaneously from the left amygdala and left anterior and posterior hippocampus (Figure 13.4G). These seizures did not propagate

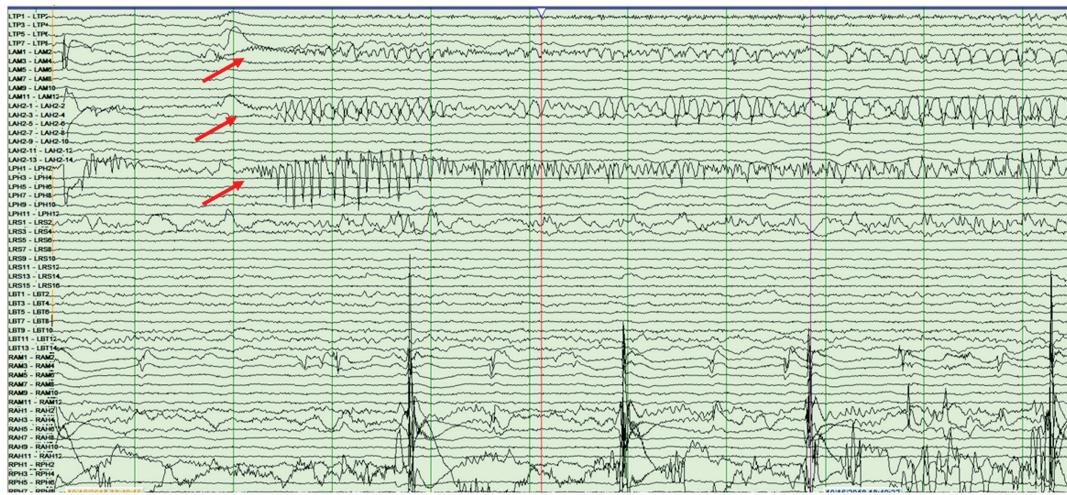
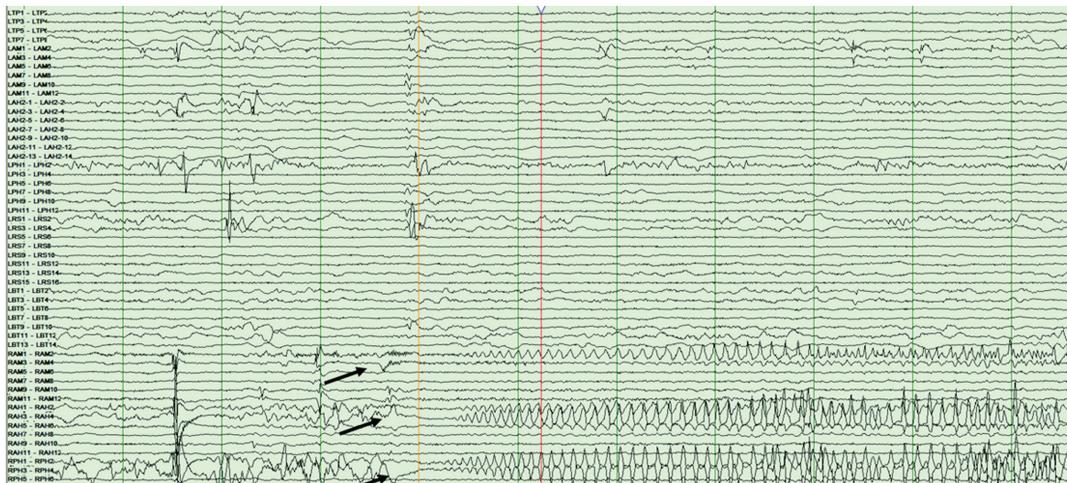
G**H**

FIGURE 13.4 Continued

to outside the structures of onset. All seizures reminiscent of those captured in the scalp evaluation—episodes of agitation and confusion without warning—were of right hippocampal origin (Figure 13.4H).

The patient was offered RNS of both mesial temporal regions. If over the longer term—due to neuromodulatory changes or otherwise—he should develop a significant left more than right asymmetry, formal left temporal lobectomy remains an option,¹⁹ leaving the right RNS in situ.

Comment

A major influence on the evaluation of all suspected TLE is the singular character of epileptiform activity arising from the hippocampus. Spikes restricted to the hippocampus are invisible on scalp EEG, the “closed field” geometry of the hippocampus creating large potential gradients within it, but essentially none outside. Recruitment of temporal neocortex is the reason why “hippocampal” spikes are seen on the surface at all. The closed-field nature of hippocampal EEG applies to seizures as well: purely hippocampal seizures are also not detected on the surface, but only declare themselves when extrahippocampal structures are involved. For these reasons, the final diagnosis in bitemporal epilepsy is challenging without the availability

of intracranial EEG from both hippocampi and a selection of bilateral extrahippocampal structures. In this case, the presence of two epileptogenic lesions in the same mesial temporal lobe suggested a left → right propagation network on noninvasive investigation, but SEEG proved otherwise.

SUMMARY

The widespread worldwide adoption of SEEG in the past decade, along with the emergence of minimally invasive (laser interstitial thermal therapy) and neuromodulatory (RNS) treatments for refractory focal epilepsy, is redefining surgical epileptology. In TLE, consideration of functional anatomy illuminates the behaviors of TLE subtypes and informs SEEG implant strategies. In turn, the impact of SEEG on surgical strategy in TLE can be profound. The classical mesial versus lateral temporal lobe syndromes, in addition to the temporo-polar and bitemporal variants, can be demonstrated with targeted sampling of the hippocampus and extrahippocampal structures. In our center, the temporal pole and the amygdalo–hippocampal complex are sampled orthogonally to also sample the lateral cortex. Posterior coverage both superiorly and inferiorly obtains sampling of the corresponding temporal lobe areas, with additional posterior temporal infrasylvian coverage in the language dominant hemisphere. A further posterior electrode targeted to the retrosplenial area serves to delimit the posterior and superior margin laterally and exclude posterior limbic lobe network involvement. Sampling of the paralimbic orbitofrontal cortex is recommended, and our practice is to use a single trajectory with lateral entry in the inferior frontal region that traverses the posterior orbitofrontal cortex in the coronal plane. Insular electrodes, due to their higher intrinsic surgical risk, are used sparingly. Contralateral electrodes—usually hippocampal targeted—are used only when there is definite evidence for contralateral involvement. Despite such SEEG implant “formulas” for TLE, there is little substitute for thorough review of the noninvasive data—history, semiology, imaging, and careful interpretation of scalp EEG with its caveats—to create a strong preimplant hypothesis; an electroclinical diagnosis needs to be considered before it can be recognized. Though such deliberation might be a novelty for some, a different viewpoint holds that the current global SEEG wave is merely a rediscovery of the systematic principles of “anatomo-clinical-electrical” correlation introduced by the founders of the discipline over 50 years ago.²⁰ On a different and more general point, the relatively nontraumatic nature of SEEG and the variety of surgical options—conventional and tailored lobar resections, lesionectomy, laser ablation, neuromodulation—opened up by a successful SEEG evaluation implies greater overall surgical success with SEEG compared to the subdural grid approach.²¹ Whether the historically static utilization of epilepsy surgery as a treatment for pharmacoresistant epilepsy^{22,23} will change because of these recent developments remains to be seen.²⁴

ACKNOWLEDGMENTS

GPK and SM acknowledge the neurosurgical expertise of Steven Roper, MD, and their mentors and colleagues, past and present, for their instruction and influence.

KEY REFERENCES

- ONLY KEY REFERENCES APPEAR IN THE PRINT EDITION. THE FULL REFERENCE LIST APPEARS IN THE DIGITAL PRODUCT FOUND ON [HTTP://CONNECT.SPRINGERPUB.COM/CONTENT/BOOK/978-0-8261-3693-0/PART/PART05/CHAPTER/CH13](http://CONNECT.SPRINGERPUB.COM/CONTENT/BOOK/978-0-8261-3693-0/PART/PART05/CHAPTER/CH13)
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ABSTRACT

Temporal lobe epilepsy (TLE) is a heterogeneous condition that can be classified as hippocampal, extra-hippocampal, bitemporal, or temporal-plus, depending on the degree of mesial, lateral, bilateral or extra-temporal involvement respectively. Stereo EEG (SEEG) evaluation of the temporal lobe is directed to identifying TLE subtypes, in addition to mapping language-eloquent cortex in the dominant hemisphere. Canonical placement schemes include the temporal pole and amygdala–hippocampal complex through a lateral approach, additional posterosuperior and posteroinferior coverage adjusted for hemispheric dominance, “sentinel” electrodes in the posterior limbic and orbitofrontal paralimbic regions, the insula if specifically indicated, and bilateral placements for suspected bilateral TLE. As with all SEEG, the yield of stereotaxic exploration of TLE is highly hypothesis dependent, demanding synthesis of the noninvasive data into a set of specific questions that the subsequent implant answers.

KEYWORDS

intractable focal epilepsy
network
hypothesis
stereotaxy
intracranial EEG
epilepsy surgery
SEEG

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B | SECTION V. PRACTICAL APPROACH

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