

Review Article

Stereoelectroencephalography-Guided Radiofrequency Thermocoagulation in Drug-Resistant Focal Epilepsy

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Abstract

Background: Stereoelectroencephalography (SEEG)-guided radiofrequency thermocoagulation (RF-TC) turns diagnostic depth electrodes into a therapeutic tool, delivering small lesions along the epileptogenic zone without further craniotomy.

Objective: To synthesise evidence on SEEG-guided RF-TC across epileptogenic-zone locations, safety, and its relationship to resective surgery.

Methods: Narrative review of case series, cohort studies, a systematic review and meta-analysis, and technique papers on SEEG methodology and RF-TC mechanism.

Findings: Pooled seizure freedom after RF-TC is modest, roughly 20-25%, with low complication rates, generally under 3%. Outcomes vary by target: hypothalamic hamartoma series report long-term freedom of 50-70%, approaching curative results, while insular and temporal targets fare less well than resection. Repeat thermocoagulation recovers seizure control in a meaningful subset after initial failure.

Conclusions: RF-TC fills a niche between medical therapy and resection: modest but real efficacy, low morbidity, and repeatability, best framed as palliative for most cortical epilepsies and potentially curative for hypothalamic hamartoma.

Keywords: Stereoelectroencephalography; Radiofrequency thermocoagulation; Drug-resistant epilepsy; Hypothalamic hamartoma; Epilepsy surgery

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Introduction

Roughly one in three patients with epilepsy continues to have seizures despite adequate trials of antiseizure medications, and for many of these patients with a focal onset, resective surgery offers the best chance of seizure freedom. Before resection can be offered, however, the epileptogenic zone must often be defined invasively, particularly when scalp electroencephalography and imaging disagree, when no structural lesion is visible, or when the presumed onset zone lies close to eloquent

cortex. Stereoelectroencephalography (SEEG), introduced by Talairach and Bancaud and refined over decades into a robot-assisted, multi-trajectory technique, implants multiple depth electrodes to sample cortical and subcortical structures in three dimensions, allowing seizure onset and propagation to be mapped with a spatial and temporal precision that scalp recording cannot match [1,2,3].

This invasiveness is not without cost, and it is only justified when the information gained meaningfully changes the surgical plan. Any technique that extracts additional therapeutic value from electrodes already implanted for diagnosis therefore carries obvious appeal, both clinically and in terms of resource use, since it requires no further anaesthesia, hospitalisation, or hardware beyond what the diagnostic evaluation already entails.

A key practical insight, first exploited systematically by the Lyon group, was that the same depth electrode contacts used to record seizures could, without further implantation, be used to deliver small radiofrequency lesions along presumed epileptogenic structures [4]. This SEEG-guided radiofrequency thermocoagulation (RF-TC) began as a way to test the functional and epileptogenic relevance of a contact before considering resection, but was soon recognised to sometimes produce lasting seizure control on its own, particularly in patients considered poor candidates for open surgery [5,6].

Two decades on, RF-TC has been applied across essentially every epilepsy substrate reached by SEEG: mesial and neocortical temporal epilepsy, insular epilepsy, focal cortical dysplasia, grey-matter heterotopy, and, most extensively, hypothalamic hamartoma [7,8,9]. The literature has grown from single-centre feasibility reports to multi-centre cohorts and, more recently, a pooled systematic review and meta-analysis, allowing

more confident statements about typical seizure-freedom rates and complication risk than were possible a decade ago.

This review synthesises the published case series, cohort studies, and the available systematic review and meta-analysis, organising the evidence by epileptogenic-zone location, safety profile, and the procedure's relationship to conventional resective surgery, and considers where the literature supports a palliative versus a genuinely curative framing. This is a narrative synthesis of the published record rather than a report of the authors' own operative series, and it does not attempt a formal quantitative meta-analysis beyond citing the one already published.

SEEG Methodology and the Rationale for RF-TC

SEEG implantation follows an individualised, hypothesis-driven trajectory plan built from non-invasive data (scalp EEG semiology, MRI, PET, and increasingly connectivity modelling), placing 10-18 multicontact electrodes stereotactically, historically with a frame and increasingly with robotic assistance [2]. Across large single-centre series of several hundred procedures, implantation-related complication rates are low, with symptomatic haemorrhage in roughly 1-2% of patients [2,3].

Because the electrodes already traverse the tissue under investigation, RF-TC exploits the existing hardware: a radiofrequency generator delivers current between adjacent contacts, or between a contact and a reference, heating tissue to coagulation temperature and producing a small, roughly spherical lesion a few millimetres in diameter [4]. No additional craniotomy, anaesthesia escalation, or hardware is required beyond what the diagnostic work-up already used, which is the central practical appeal of the technique relative to open resection or to purpose-built ablative technologies such as

laser interstitial thermal therapy [10].

Selection of contacts for thermocoagulation is guided directly by the SEEG recording itself: contacts implicated in the earliest ictal changes, in interictal spiking, or in stimulation-evoked habitual seizures are prioritised, so the therapeutic lesion is placed exactly where the diagnostic data point rather than at a location chosen from imaging alone. This tight coupling between diagnosis and treatment is unique among epilepsy surgical techniques and is a large part of why RF-TC can be offered even to patients whose epileptogenic zone is considered too small, too deep, or too close to eloquent cortex to resect safely.

Mechanism of Thermocoagulation Lesioning

RF-TC lesions are created by resistive heating as alternating current passes between electrode contacts, with lesion size determined by contact spacing, power, and duration rather than by a single fixed protocol. Early series used single-contact pairs and modest lesion numbers; later "optimised" and three-dimensional protocols apply multiple overlapping lesions along a trajectory or across several electrodes to approximate the shape of the presumed epileptogenic structure more closely, an approach explicitly developed for mesial temporal and hypothalamic targets [8,11].

Unlike resection, RF-TC does not remove tissue; it destroys a limited volume in place, which likely explains why its efficacy, while real, generally falls short of resection when the epileptogenic zone is large or poorly localised. This also explains its repeatability: because RF-TC does not consume anatomical territory the way resection does, additional lesions can be placed in the same or adjacent structures if seizures recur, an option unavailable to most patients after failed resection [12].

Outcomes by Epileptogenic Zone

Temporal and mesial temporal epilepsy

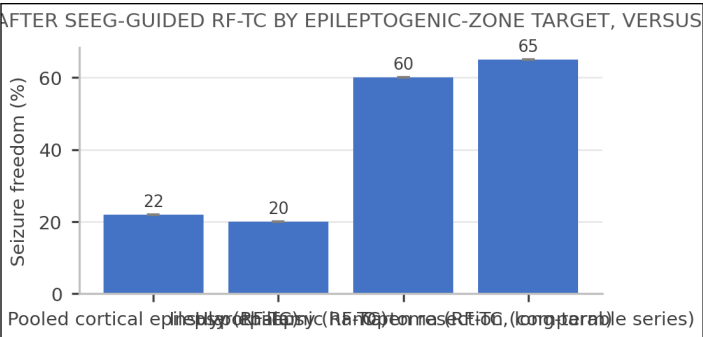


Figure 1: Seizure freedom after SEEG-guided RF-TC varies by epileptogenic-zone target: roughly 20-25% pooled across cortical epilepsy series [25], lower for insular targets [14], but 50-70% long-term for hypothalamic hamartoma [16], approaching rates reported after open resection [27].

RF-TC targeting the amygdala-hippocampal complex, applied through electrodes already sampling mesial temporal structures, produces seizure reduction in a majority of patients but sustained seizure freedom in a minority, with optimised three-dimensional lesioning protocols reporting improved rates compared with earlier single-lesion approaches [8]. RF-TC in this setting has also been proposed as a prognostic test: response to thermocoagulation may predict outcome from subsequent anterior temporal lobectomy in patients who do not achieve durable freedom from RF-TC alone [13].

Insular epilepsy

Insular targets are anatomically difficult to resect safely given the proximity of vascular and eloquent structures, making RF-TC an attractive alternative, but published outcomes are more modest than for mesial temporal targets, reflecting both the difficulty of fully ablating a deep, functionally complex region and the frequent involvement of insular epilepsy in wider opercular-insular networks [14].

Hypothalamic hamartoma

Hypothalamic hamartoma is the indication with the most mature RF-TC literature and the best outcomes. Because open resection carries substantial risk to hypothalamic and visual structures, RF-TC has become a preferred

first-line surgical option in several centres, with long-term seizure freedom reported in roughly half to two-thirds of patients in dedicated series, and gelastic seizure control often exceeding freedom from other seizure types [15,16,17]. Electroclinical pattern and hamartoma attachment type predict surgical prognosis [18], optimised stereo-array protocols and giant hamartomas have been specifically addressed [11,19], early MRI-guided stereotactic approaches established feasibility [20], and repeat thermocoagulation after recurrence recovers seizure control in a substantial proportion of initial non-responders [12].

Table 1: Representative published series of SEEG-guided radiofrequency thermocoagulation by epileptogenic-zone target reviewed here [4,24,8,14,15,16,7,23]; N = 8 series.

Series	Target	Design	Key seizure outcome	Notes
Guenot 2004	Mixed cortical	Feasibility series	Partial improvement in majority	First systematic feasibility report
Bourdillon 2017	Mixed cortical	10-year single-centre cohort	~20-25% Engel I at last follow-up	Largest single-centre series
Fan 2019	Mesial temporal, hippocampal sclerosis	Optimized 3D lesioning	Improved freedom vs single-lesion protocol	Also used as pre-resection test
Rucar 2022	Insular	Review chapter	More modest than temporal targets	Reflects network complexity
Shirozu 2016	Hypothalamic hamartoma (giant)	Single-centre cohort	Majority gelastic seizure control	Stereotactic RF-TC
Shirozu 2021	Hypothalamic hamartoma	Long-term follow-up cohort	50-70% long-term freedom	Approaches curative outcomes
Cossu 2013	Grey-matter nodular heterotopy	Case series	Seizure reduction in most	Extends RF-TC beyond cortex
Chipaux 2019	Mixed, paediatric	Multicentre paediatric series	Feasible, acceptable safety	Confirms use in children

Other targets: heterotopy, MRI-negative and eloquent cortex

RF-TC has been extended to grey-matter nodular heterotopy, where surgical access is otherwise difficult and where heterotopic nodules are frequently multiple and deep, making resection disproportionately morbid relative to the tissue volume actually driving seizures [7]. It has similarly been applied to MRI-negative epilepsy, where no structural target exists to guide a resection at all, and where predictors of response instead rely on concordance of SEEG and network-level electrophysiological markers rather than a visible lesion [21]. Network-based analyses suggest that disrupting key hub structures within the epileptogenic network, rather than only the presumed seizure-onset zone itself, may explain some otherwise unexpected favourable outcomes [22]. Paediatric series across multiple substrates confirm feasibility and an acceptable safety profile in children, an important population given the frequency of non-lesional and multifocal epilepsy in this age group [23].

Safety and Complications

Across single-centre and pooled series, RF-TC carries a low complication rate compared with open resection. Bourdillon's 10-year experience and subsequent systematic review report permanent neurological deficits in a small minority of patients, generally under 3%, most transient and related to the specific structure lesioned rather than to the thermocoagulation procedure itself [24,25]. Patient-level meta-analysis of radiofrequency ablation across refractory epilepsy substrates confirms a favourable morbidity profile relative to reported resective series, though direct head-to-head comparative data remain limited [26]. Paediatric and hypothalamic hamartoma series similarly report low rates of permanent morbidity even with repeat procedures [23,12].

Comparison with Open Resective Surgery and Palliative versus Curative Intent

Table 2: Safety and intent summary across major reference points discussed in this review [2,25,26,28,16].

Reference point	Permanent complication rate	Typical intent	Source
SEEG implantation	~1-2%	Diagnostic	cardinale2013
RF-TC, cortical epilepsy	Generally <3%	Mostly palliative	bourdillon2018
Radiofrequency ablation, pooled	Low vs resection	Palliative/bridging	kerezoudis2022
RF-TC, selected lesions	Low	Palliative, selected cases curative	wellmer2016
RF-TC, hypothalamic hamartoma	Low	First-line, often curative	shirozu2021

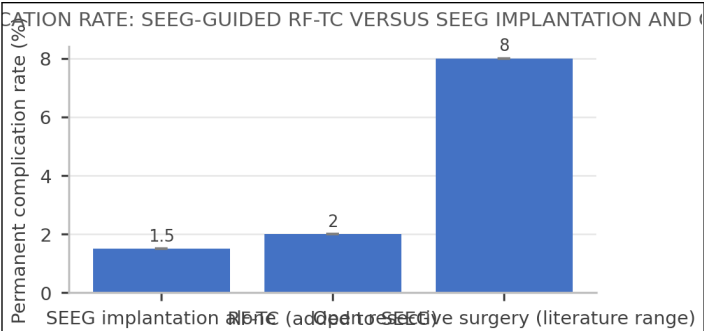


Figure 2: Permanent complication rates are low for SEEG implantation alone [2] and remain low with added RF-TC [24,25], generally well below rates reported for open resective surgery [26].

The central trade-off running through this literature is efficacy versus morbidity. Pooled seizure freedom after RF-TC across cortical epilepsies, on the order of 20-25% in the Bourdillon meta-analysis, is substantially lower than the roughly 60-70% typically achieved by resection in comparable populations, a gap corroborated by single-centre North American experience [25,27]. This has led most authors to frame RF-TC explicitly as palliative for the majority of cortical indications: a lower-risk option for patients who decline, or are poor candidates for, resection, or as a bridge providing localising information before a subsequent resection [5,13].

Hypothalamic hamartoma is the clear exception. Because open resection of hypothalamic hamartoma carries meaningfully higher risk to endocrine, visual, and cognitive function, and because RF-TC series report

long-term seizure freedom rivalling resection, several groups now regard RF-TC as first-line and, in a substantial proportion of patients, curative rather than palliative for this lesion [15,16,28]. This location-dependent duality is captured well by Wellmer and colleagues' explicit description of lesion-guided stereotactic RF-TC as "palliative, in selected cases curative," a framing this review adopts as the most accurate overall characterisation of the technique [28]. Comparative work against other minimally invasive ablative modalities, such as laser interstitial thermal therapy for focal cortical dysplasia, suggests broadly similar efficacy and safety trade-offs, positioning RF-TC as one of several viable lower-morbidity alternatives to resection rather than a uniquely superior technique [10].

Conclusion

SEEG-guided radiofrequency thermocoagulation has matured from an incidental by-product of invasive monitoring into a defined therapeutic option across drug-resistant focal epilepsy. The published record supports a consistent picture: efficacy that is real but generally more modest than resection for most cortical epilepsies, a low and largely acceptable complication profile, and repeatability that makes RF-TC attractive even after an unsuccessful first attempt. Hypothalamic hamartoma stands apart, with outcomes that support first-line and often curative use given the disproportionate risk of open resection at that site. Future work should prioritise standardised outcome reporting, direct comparative trials against resection and competing ablative technologies, and refinement of network-based targeting to close the efficacy gap that currently separates thermocoagulation from resective surgery in most cortical epilepsies. Until such data mature, the most defensible use of RF-TC remains as a low-risk option offered alongside, not instead of, a well-planned resective strategy for most cortical substrates, reserving unqualified

first-line status for hypothalamic hamartoma.

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