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**MRI-GUIDED LASER INTERSTITIAL THERMAL THERAPY IN MODERN
NEUROSURGERY: THERMAL DOSIMETRY, PATIENT SELECTION, NEURO-
ONCOLOGICAL APPLICATIONS, AND PRECISION ABLATION FOR DRUG-
RESISTANT EPILEPSY**

Abstract

Background. Magnetic resonance-guided laser interstitial thermal therapy (MRgLITT) has evolved from an experimental stereotactic technique into a clinically relevant minimally invasive neurosurgical platform. Its principal advantage is the combination of stereotactic targeting, controlled thermal ablation, and real-time magnetic resonance thermometry. Contemporary indications include deep or surgically difficult gliomas, recurrent glioblastoma, progressive brain metastases after stereotactic radiosurgery, radiation necrosis, mesial temporal lobe epilepsy, hypothalamic hamartoma, and selected pediatric epileptogenic or neoplastic lesions.

Materials and Methods. A structured narrative review was performed using clinical trials, prospective multicenter registries, institutional cohorts, and translational studies addressing MRgLITT in neuro-oncology and epilepsy surgery. Evidence available through August 2026 was analyzed. Particular attention was directed toward patient selection, stereotactic trajectory planning, thermal dose coverage, lesion geometry, seizure outcome, tumor control, steroid dependency, neurological morbidity, quality of life, and the emerging biological effects of thermal ablation.

Results. The clinical effectiveness of MRgLITT is highly dependent on lesion geometry, anatomical location, thermal coverage, and disease phenotype. In recurrent and difficult-to-access high-grade gliomas, LITT provides cytoreduction with relatively short hospitalization and may facilitate rapid transition to adjuvant treatment. In biopsy-proven radiation necrosis, LITT can simultaneously establish tissue diagnosis and treat the responsible lesion while permitting corticosteroid reduction. For mesial temporal lobe epilepsy, prospective contemporary data indicate approximately 58% Engel class I seizure freedom at two years, although open anterior temporal resection retains higher average long-term seizure-freedom rates. Ablation of the amygdala, hippocampal head, parahippocampal region, and rhinal cortices is associated with better seizure outcomes than indiscriminate posterior extension. Hypothalamic hamartoma represents another particularly suitable indication because stereotactic disconnection can be achieved with limited surgical exposure.

Conclusion. MRgLITT should not be viewed as a smaller version of open resection. It represents a distinct stereotactic therapeutic paradigm in which treatment success depends on precise target selection, three-dimensional thermal coverage, avoidance of critical neurovascular structures, and disease-specific endpoint definition. Future development will likely integrate robotic trajectory planning, connectome-informed targeting, quantitative thermal modeling, and biologically rational combinations with systemic therapy.

Keywords: laser interstitial thermal therapy; MRgLITT; laser ablation; glioblastoma; radiation necrosis; brain metastasis; mesial temporal lobe epilepsy; hypothalamic hamartoma; MR thermometry; stereotactic neurosurgery.

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МРТ-КОНТРОЛИРУЕМАЯ ЛАЗЕРНАЯ ИНТЕРСТИЦИАЛЬНАЯ ТЕРМОТЕРАПИЯ В СОВРЕМЕННОЙ НЕЙРОХИРУРГИИ: ТЕРМИЧЕСКАЯ ДОЗИМЕТРИЯ, ОТБОР ПАЦИЕНТОВ, НЕЙРООНКОЛОГИЧЕСКИЕ ПРИМЕНЕНИЯ И ПРЕЦИЗИОННАЯ АБЛЯЦИЯ ПРИ ФАРМАКОРЕЗИСТЕНТНОЙ ЭПИЛЕПСИИ

Аннотация

Актуальность. Магнитно-резонансно-контролируемая лазерная интерстициальная термотерапия превратилась из экспериментальной стереотаксической технологии в клинически значимый минимально инвазивный метод нейрохирургического лечения. Основным преимуществом технологии является сочетание стереотаксического наведения, управляемой термической абляции и МР-термометрии в реальном времени. Современные показания включают глубоко расположенные глиомы, рецидивирующую глиобластому, прогрессирующие метастазы после стереотаксической радиохирургии, лучевой некроз, мезиальную височную эпилепсию и гипоталамические гамартомы.

Материалы и методы. Проведен структурированный нарративный обзор клинических исследований, проспективных многоцентровых регистров и клинических серий, посвященных применению MRgLITT в нейроонкологии и хирургии эпилепсии. Проанализированы данные, доступные до августа 2026 года. Особое внимание уделено отбору пациентов, планированию траектории, термической дозиметрии, геометрии абляции, контролю опухоли, исходам эпилепсии, неврологическим осложнениям и качеству жизни.

Результаты. Эффективность MRgLITT существенно зависит от геометрии патологического очага, его локализации, полноты термического покрытия и биологического характера заболевания. При рецидивирующих и труднодоступных глиомах технология обеспечивает минимально инвазивную циторедукцию. При лучевом некрозе процедура позволяет одновременно получить гистологическую верификацию и выполнить лечебную абляцию. При мезиальной височной эпилепсии современные проспективные данные демонстрируют приблизительно 58% Engel I через два года. Результат зависит не только от общего объема абляции, но и от точного включения ключевых структур мезиальной височной сети.

Заключение. MRgLITT представляет самостоятельную стереотаксическую терапевтическую концепцию, эффективность которой определяется правильным выбором показаний, точностью траектории, адекватностью термического покрытия и защитой функционально значимых структур.

Ключевые слова: лазерная интерстициальная термотерапия; MRgLITT; глиобластома; лучевой некроз; метастазы головного мозга; эпилепсия; гипоталамическая гамартома; МР-термометрия.

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ZAMONAVIY NEYROXIRURGIYADA MRT NAZORATIDAGI LAZER INTERSTITIAL TERMOTERAPIYASI: TERMIK DOZIMETRIYA, BEMORLARNI TANLASH, NEYROONKOLOGIK QO‘LLANILISH VA FARMAKOREZISTENT EPILEPSIYADA PRETSIZION ABLATSIYA

Annotatsiya

Dolzarblik. Magnit-rezonans nazoratidagi lazer interstitsial termoterapiyasi eksperimental stereotaktik usuldan klinik jihatdan muhim minimal invaziv neyroxirurgik texnologiyaga aylandi. Ushbu usul stereotaktik nishonlash, boshqariladigan termik ablatsiya va real vaqt rejimidagi MRT-termometriyani birlashtiradi. Zamonaviy ko‘rsatmalar chuqur joylashgan gliomalar, qaytalangan glioblastoma, stereotaktik radiojarrohlikdan keyingi progressiv miya metastazlari, radiatsion nekroz, mezial temporal epilepsiya va gipotalamik gamartomalarni o‘z ichiga oladi.

Material va usullar. Neyroonkologiya va epilepsiya jarrohligida MRgLITT qo‘llanilishiga bag‘ishlangan klinik tadqiqotlar, prospektiv ko‘p markazli registrlar va klinik seriyalar strukturaviy narrativ tahlil qilindi. 2026-yil avgustigacha mavjud bo‘lgan ma’lumotlar baholandi. Bemorlarni tanlash, stereotaktik trayektoriya, termik qamrov, ablatsiya geometriyasi, o‘sma nazorati, tutqanoq natijalari va asoratlar asosiy tahlil yo‘nalishlari bo‘ldi.

Natijalar. MRgLITT samaradorligi patologik o‘choq geometriyasi, anatomik joylashuvi, termik qamrov va kasallik fenotipiga bog‘liq. Qaytalangan yoki jarrohlik yo‘li bilan yetib borish qiyin gliomalarda minimal invaziv sitoreduksiya amalga oshirilishi mumkin. Radiatsion nekrozda biopsiya va davolovchi ablatsiyani bir muolajada bajarish imkoniyati mavjud. Mezial temporal epilepsiyada zamonaviy prospektiv ma’lumotlarga ko‘ra, ikki yillik Engel I natija taxminan 58% ni tashkil etadi. Natija ablatsiya hajmidan tashqari, mezial temporal epileptogen tarmoqning muhim qismlarini aniq qamrab olishga bog‘liq.

Xulosa. MRgLITT ochiq jarrohlikning shunchaki kichikroq varianti emas, balki bemorni to‘g‘ri tanlash, aniq stereotaktik nishonlash va uch o‘lchamli termik nazoratga asoslangan mustaqil neyroxirurgik paradigma hisoblanadi.

Kalit so‘zlar: lazer interstitsial termoterapiya; MRgLITT; glioblastoma; radiatsion nekroz; miya metastazi; mezial temporal epilepsiya; gipotalamik gamartoma; MRT-termometriya.

Introduction. Magnetic resonance-guided laser interstitial thermal therapy represents one of the most important technological convergences between stereotactic neurosurgery, interventional MRI, thermal physics, neuro-oncology, and epilepsy surgery. Earlier attempts at intracranial laser ablation were constrained by inadequate thermal monitoring, difficulty controlling the spatial distribution of heat, and limited ability to protect adjacent eloquent structures. Modern MRgLITT

systems changed this paradigm by combining stereotactic catheter placement with real-time proton resonance frequency–based MR thermometry and software-generated thermal damage estimates. Early first-in-human experience in recurrent glioblastoma demonstrated the feasibility of controlled intracranial thermal ablation, while subsequent multicenter and large institutional cohorts expanded clinical use across primary tumors, metastases, radiation necrosis, and epileptogenic lesions [1, 2, 3, 4]. The LAANTERN prospective registry subsequently demonstrated that stereotactic laser ablation could be incorporated into routine neurosurgical practice with relatively short hospitalization and acceptable procedural morbidity, while longitudinal registry data provided additional information regarding functional status and patient-reported quality of life [5, 6]. The neuro-oncological rationale for LITT differs fundamentally from conventional microsurgical resection. Open surgery physically removes tumor and immediately reduces intracranial mass, whereas LITT produces coagulative necrosis in situ. The treated tissue subsequently undergoes inflammatory remodeling, edema, progressive involution, and eventual volume reduction. Therefore, postoperative imaging cannot be interpreted according to the same assumptions used after craniotomy. Initial enlargement of the ablated zone does not necessarily indicate tumor progression, and steroid requirements may temporarily increase as a consequence of thermal edema [1, 3, 11]. Early multicenter experience demonstrated that LITT may be especially attractive for difficult-to-access high-grade gliomas where open resection would require substantial transgression of normal brain [2, 9]. Prospective and registry-based investigations subsequently extended the approach to newly diagnosed and recurrent IDH-wild-type glioblastoma, recurrent metastatic lesions after radiosurgery, and treatment-related radiation necrosis [7, 10, 12]. Recent European experience continues to support feasibility in carefully selected recurrent IDH-wild-type glioblastoma, although the evidence remains predominantly observational rather than randomized [8].

Radiographically progressive enhancement after stereotactic radiosurgery represents a particularly important clinical indication because conventional MRI often cannot reliably distinguish viable metastatic tumor from radiation necrosis. Both entities may produce contrast enhancement, vasogenic edema, neurological deterioration, and corticosteroid dependence. Stereotactic biopsy followed immediately by LITT can transform this diagnostic uncertainty into a combined diagnostic–therapeutic procedure [10, 11, 12, 13]. The prospective LAASR study established multicenter feasibility of laser ablation in patients with metastatic tumors showing progression after stereotactic radiosurgery, including patients with recurrent tumor and biopsy-proven radiation necrosis [10]. Later studies demonstrated that biopsy-proven radiation necrosis treated with LITT can exhibit durable lesion control and permit reduction of corticosteroid dependence [12]. The functional-neurosurgical application of MRgLITT has developed in parallel. Mesial temporal lobe epilepsy is the most intensively investigated epileptic indication. Traditional anterior temporal lobectomy and selective amygdalohippocampectomy remain highly effective interventions, but concerns regarding memory, language, visual field injury, cosmetic consequences, hospitalization, and patient acceptance have driven interest in stereotactic laser amygdalohippocampotomy. Early prospective and institutional studies demonstrated the feasibility of MRI-guided ablation of the amygdalohippocampal complex [15, 16]. Subsequent work showed that seizure outcome depends not merely on total thermal volume but on the anatomical distribution of ablation across the amygdala, hippocampal head,

parahippocampal gyrus, and rhinal cortices [17, 18, 19]. This anatomical principle has been reproduced across different cohorts. Stereoelectroencephalography-guided LITT can refine candidate selection when the epileptogenic network is not fully established by noninvasive evaluation [20, 21]. Other institutional experiences have demonstrated meaningful seizure reduction with variable preservation of neuropsychological function [22, 23]. A multicenter analysis of 234 patients showed that anterior, medial, and inferior mesial temporal ablation, particularly greater amygdalar coverage, was associated with a higher probability of Engel class I outcome, whereas indiscriminate posterior extension produced diminishing benefit [24]. Clinically significant visual deficits have nevertheless been reported when thermal spread or trajectory positioning compromises the optic radiations or related visual pathways [25]. Prospective registry evidence has progressively strengthened the literature. The 2020 multicenter study by Landazuri and colleagues reported Engel I outcomes in approximately 64% of patients at one year across a heterogeneous drug-resistant epilepsy cohort [26]. More detailed three-dimensional analyses have linked parahippocampal ablation with improved seizure control [27]. Longer-term multicenter experience confirms that seizure outcomes can remain durable, but some patients experience recurrence and subsequently undergo open temporal surgery [28]. In the prospective LAANTERN MTLE cohort published in 2025, 58.4% of evaluable patients achieved Engel class I outcome at two years, with parallel improvement in quality-of-life measures and generally low procedural morbidity [29]. Hypothalamic hamartoma represents another disease in which the geometry of the pathological network makes minimally invasive stereotactic ablation conceptually attractive. The therapeutic target is often functional disconnection of the hamartoma from hypothalamic and limbic circuits rather than large-volume tissue destruction. Pediatric series have demonstrated high rates of gelastic seizure control with MR-guided laser ablation, sometimes requiring staged or repeated treatment for complex lesions [30, 31]. Early pediatric experience also established the feasibility of MR-guided laser ablation for other discrete epileptogenic foci [32]. More recently, pediatric low-grade gliomas located in deep or surgically difficult regions have also been treated using LITT, illustrating the expanding role of stereotactic thermal ablation beyond adult neuro-oncology and temporal epilepsy [33].

Taken together, these studies [1, 5, 10, 15, 24, 29, 30] demonstrate that LITT is not defined by a single disease indication. Rather, it is a technical platform whose effectiveness is determined by the relationship among pathological target geometry, thermal dose, access corridor, neurological function, and disease-specific therapeutic objective. The same physical device may be used to cytoreduce a recurrent glioblastoma, destroy radiation necrosis, interrupt an epileptogenic mesial temporal network, or disconnect a hypothalamic hamartoma; however, the definition of successful treatment is fundamentally different in each scenario [2, 7, 12, 19, 27, 31].

Materials and Methods. A structured narrative review was conducted using peer-reviewed clinical studies addressing intracranial MR-guided laser interstitial thermal therapy. Literature available through August 2026 was considered. Priority was assigned to prospective multicenter registries, multicenter cohort studies, major institutional series, prospective trials, and studies investigating the relationship between ablation geometry and clinical outcome. Neuro-oncological studies were evaluated separately for high-grade glioma, recurrent glioblastoma, brain metastasis, and radiation necrosis. Functional-neurosurgical evidence was analyzed for mesial temporal lobe epilepsy,

other focal drug-resistant epilepsies, and hypothalamic hamartoma. The principal clinical outcomes included overall survival, progression-free survival, local control, neurological complications, hospitalization duration, corticosteroid discontinuation, seizure freedom, quality of life, and neuropsychological outcome. Technical variables included catheter trajectory, target volume, lesion diameter, relationship to heat sinks and vascular structures, thermal damage coverage, overlap of the ablation volume with the intended anatomical target, and proximity to critical functional structures. Because study populations and outcome definitions were highly heterogeneous, quantitative pooling was not attempted. Instead, findings were synthesized into a disease-specific precision-ablation framework.

Results.

Biophysics of Thermal Ablation. LITT converts laser energy into thermal energy within tissue. When tissue temperature rises sufficiently, proteins denature, cellular membranes are disrupted, vascular thrombosis occurs, and irreversible coagulative necrosis develops. The biological response is simultaneously temperature- and time-dependent. Very high temperatures can produce irreversible injury rapidly, whereas lower temperatures require longer exposure to produce equivalent tissue destruction. Contemporary systems therefore do not simply report instantaneous temperature. Treatment software estimates cumulative thermal exposure and generates thermal-damage maps representing tissue predicted to have crossed a defined injury threshold. This is critical because the neurosurgeon is not attempting to maximize temperature. The objective is to create complete three-dimensional thermal coverage of the pathological target while keeping critical surrounding tissue below a damaging thermal dose. The physics of heat propagation also means that identical laser parameters can produce different ablation volumes in different tissues. Tissue water content, vascularity, blood flow, prior radiation, necrosis, cystic change, and proximity to cerebrospinal-fluid spaces can alter thermal behavior. Large vessels can function as heat sinks by dissipating thermal energy. This may protect nearby neural structures but may also prevent complete tumor ablation. Consequently, real-time thermometry is not merely a monitoring convenience; it is the principal feedback mechanism through which the procedure becomes dynamically controlled.

Trajectory Planning. Successful LITT begins before thermal energy is delivered. The ideal trajectory should traverse the longest useful axis of the target while minimizing entry through cortical vessels, sulci, ventricles, functionally critical cortex, and major white-matter pathways. A relatively spherical lesion may be covered by a single centrally positioned trajectory, whereas an elongated or irregular lesion may require catheter repositioning, multiple pullbacks, or more than one trajectory. Geometry becomes increasingly problematic as target diameter increases. A larger lesion requires prolonged heating and may generate substantial perilesional edema. Large targets can also contain regions that are incompletely covered because heat cannot be distributed uniformly without exceeding safe temperatures at the margins. This explains why tumor volume and diameter repeatedly appear as practical selection factors in clinical series [1, 2, 3]. The concept is different in epilepsy. For mesial temporal lobe epilepsy, the objective is not simply maximal tissue volume. The catheter should follow a trajectory that provides high-quality coverage of the amygdala and hippocampal head and extends along the mesial temporal network without unnecessary posterior or lateral thermal injury [17, 19, 24].

MR Thermometry. MR thermometry provides repeated spatial maps of temperature change during energy deposition. Temperature-sensitive MR phase information is processed to estimate heating within and around the target. Software-defined safety points are typically positioned near structures such as the internal capsule, optic pathways, brainstem, hypothalamus, ventricular margins, or cortex. Energy delivery can be interrupted when temperatures at safety boundaries approach predefined thresholds. This closed feedback loop represents a major conceptual advantage over ablative technologies in which tissue injury is inferred primarily from delivered power, impedance, or postoperative imaging. However, MR thermometry has limitations. Motion, susceptibility artifacts, blood products, air, previous surgical material, and tissue interfaces may impair accuracy. Therefore, predicted thermal damage should always be interpreted within the complete anatomical and procedural context.

LITT for High-Grade Glioma. High-grade glioma represents one of the earliest modern indications for intracranial LITT. The first-in-human NeuroBlate trial demonstrated that stereotactic thermal treatment could be safely applied to recurrent glioblastoma and introduced the concept of thermal-dose-controlled cytoreduction [1]. Mohammadi and colleagues subsequently evaluated difficult-to-access high-grade gliomas across multiple centers and showed that LITT could provide cytoreduction in patients for whom conventional surgery carried substantial anatomical risk [2]. Large institutional and registry cohorts confirmed that the technique could be applied to a heterogeneous spectrum of intracranial lesions with relatively short postoperative hospitalization [3, 4, 5]. LAANTERN registry data involving 223 patients with primary and metastatic intracranial tumors reported a median postoperative hospital stay of approximately 33 hours. Quality-of-life measurements were generally stabilized over follow-up, although interpretation is limited by heterogeneity of tumor biology and indication [6]. The main oncological limitation is that LITT is a local cytoreductive treatment applied to an infiltrative disease. Even complete thermal coverage of the radiographically defined glioblastoma does not eradicate diffusely infiltrating tumor beyond the ablation field. Accordingly, LITT should not be interpreted as a substitute for radiotherapy, temozolomide, tumor-treating fields, or appropriate molecularly directed treatment. Its most rational role is in selected patients in whom conventional cytoreduction is desirable but open surgery presents excessive morbidity or has already been performed.

Newly Diagnosed and Recurrent Glioblastoma. The indication for newly diagnosed deep glioblastoma differs from that for recurrent disease. In newly diagnosed lesions, tissue acquisition is essential. A stereotactic biopsy can be obtained along the planned trajectory before thermal ablation. This allows histological and molecular diagnosis while avoiding a second procedure. In recurrent glioblastoma, patient selection must account for performance status, disease distribution, recurrence volume, interval from initial treatment, extracranial disease, prior radiation, corticosteroid dependence, and the feasibility of subsequent systemic treatment. Recent real-world data continue to emphasize selection. A Scandinavian two-center cohort published in 2026 examined LITT specifically for IDH-wild-type recurrent glioblastoma in a publicly funded European healthcare setting, demonstrating feasibility but also reinforcing that the technique remains supported mainly by nonrandomized cohort evidence. A favorable LITT candidate generally has a relatively circumscribed recurrence that is deep, surgically inaccessible, or located in a region where conventional cortical exposure would cause

disproportionate morbidity. Diffuse multifocal recurrence is a fundamentally different biological problem and is unlikely to benefit substantially from focal thermal cytoreduction.

Brain Metastasis and Radiation Necrosis. The post-SRS enhancing lesion presents one of the strongest conceptual indications for LITT. The surgeon can obtain stereotactic tissue for diagnosis and then ablate the lesion during the same intervention. If biopsy demonstrates viable metastatic tumor, thermal therapy provides immediate local cytoreduction. If biopsy demonstrates radiation necrosis, the procedure destroys the inflammatory necrotic core and can facilitate resolution of surrounding edema. The multicenter prospective LAASR study evaluated patients with progressive metastatic lesions after stereotactic radiosurgery and included both recurrent tumor and radiation necrosis [10]. Radiation necrosis is particularly important because chronic high-dose corticosteroid exposure has substantial metabolic, infectious, psychiatric, and myopathic consequences. Initial clinical experience demonstrated that LITT could be applied to medically refractory radiation necrosis, although substantial transient post-ablation enlargement and edema may occur [11]. More robust multicenter data subsequently evaluated biopsy-proven radiation necrosis in radiographically recurrent brain metastases. In the 2023 study by Chan and colleagues, LITT provided durable control of the treated radiation-necrosis lesion and enabled corticosteroid tapering in many patients [12]. Comparative studies have also examined LITT against bevacizumab for previously irradiated metastatic lesions [13]. These studies remain nonrandomized and are vulnerable to differences in lesion size, symptom severity, performance status, and diagnostic certainty.

Table 1. Disease-specific rationale for MRgLITT

Clinical indication	Primary therapeutic objective	Why LITT may be attractive	Major limitation
Deep newly diagnosed glioma	Biopsy + cytoreduction	Avoids major cortical transgression	Does not address diffuse infiltration
Recurrent glioblastoma	Local salvage cytoreduction	Short recovery and limited exposure	Strong selection bias in available studies
Progressive brain metastasis after SRS	Diagnosis + local treatment	Biopsy distinguishes recurrence from RN	Limited utility for widespread intracranial disease
Radiation necrosis	Reduce necrotic inflammatory core and edema	Potential steroid reduction	Early postoperative edema can worsen
Mesial temporal lobe epilepsy	Disconnect mesial epileptogenic network	Minimally invasive; shorter recovery	Lower average seizure freedom than ATL
Hypothalamic hamartoma	Disconnect epileptogenic attachment	Excellent access to deep target	Complex anatomy may require repeat ablation
Selected pediatric lesions	Focal ablation with limited surgical exposure	Avoids open corridor through developing brain	Long-term evidence remains limited

Mesial Temporal Lobe Epilepsy. MRgLITT has arguably generated its most sophisticated targeting literature in mesial temporal lobe epilepsy. Early work demonstrated the feasibility of real-time MRI-guided stereotactic laser amygdalohippocampotomy [15]. Subsequent studies found meaningful seizure control while raising questions regarding the optimal ablation volume and anatomical structures responsible for seizure freedom [16–19]. The assumption that a larger ablation is necessarily superior has not been supported. Multicenter spatial analyses indicate that seizure control is most strongly associated with treatment of specific anterior and medial mesial temporal structures. Wu et al. evaluated 234 patients treated at 11 centers. Engel I outcomes were obtained in approximately 58% at one and two years. Better outcomes were associated with ablation that included greater portions of the amygdala and anterior mesial structures, while additional posterior extension produced diminishing returns [24]. This represents an important general principle of precision ablation: location can be more important than volume. Thermal destruction of additional tissue that does not belong to the critical epileptogenic network may increase complication risk without improving seizure control.

Long-Term Seizure Outcomes. Long-term data are essential because early seizure freedom after epilepsy surgery can deteriorate with time. Youngerman and colleagues reported multicenter long-term outcomes after mesial temporal LITT and examined subsequent surgery in patients with seizure recurrence. Engel I or II outcomes were observed in approximately three-quarters of evaluable patients at one and two years, while outcomes declined with longer follow-up [28]. The prospective LAANTERN cohort reported in 2025 provides an important contemporary benchmark. Among patients with evaluable two-year data, Engel class I outcome was achieved in 58.4%, while ILAE class 1/2 outcome was achieved in 57.2%. Adverse events occurred in 16.5% of patients and were predominantly mild and transient. Quality-of-life measures improved at most evaluated time points. These results are clinically meaningful but should not be interpreted as equivalence to anterior temporal lobectomy. Open temporal surgery generally achieves higher long-term seizure-freedom rates in appropriately selected patients. The trade-off is therefore not simply “old surgery versus new technology.” It involves seizure-control probability, neurocognitive risk, visual-field risk, recovery time, patient preference, and willingness to undergo a potentially staged therapeutic pathway.

Cognitive and Visual Outcomes. One reason patients and clinicians consider LITT is the potential to reduce neuropsychological morbidity associated with larger temporal resections. Because laser amygdalohippocampotomy preserves much of the lateral temporal neocortex, certain language and memory functions may be less disrupted than after standard temporal resection. Nevertheless, LITT is not neurocognitively neutral. Mesial structures themselves participate in episodic memory, and dominant-hemisphere ablation can still affect verbal memory. Visual pathways represent another major risk. The optic tract, lateral geniculate region, Meyer's loop, and optic radiations lie close to therapeutic trajectories and thermal fields. Clinically significant visual deficits after mesiotemporal LITT have been described and are linked to trajectory and thermal spread [25]. Therefore, postoperative visual field testing should be considered part of rigorous outcome assessment rather than relying only on subjective patient complaints.

Hypothalamic Hamartoma. Hypothalamic hamartoma is an archetypal disease for stereotactic thermal disconnection. Gelastic seizures arise from an intrinsically epileptogenic lesion deeply situated adjacent to critical hypothalamic and neurovascular structures. Open or transventricular

procedures historically carried substantial morbidity. Laser ablation allows treatment of the attachment zone through a stereotactically planned trajectory. Curry and colleagues reported 71 patients treated with MR-guided laser ablation, with 93% freedom from gelastic seizures at one year, although approximately 23% required more than one ablation [30].

This finding illustrates another crucial principle. In complex epileptogenic lesions, staged treatment is not necessarily treatment failure. A deliberate limited first ablation may provide a safer risk profile than attempting complete thermal disconnection in one session when critical structures are immediately adjacent to the target.

Pediatric Applications. Pediatric LITT requires additional consideration because lesion biology, skull dimensions, anesthetic requirements, and developmental vulnerability differ from adults. Early work established feasibility for stereotactic treatment of pediatric epileptogenic foci [32]. More recent experience has extended LITT to selected pediatric low-grade gliomas, particularly deep lesions in which conventional surgical access would be associated with substantial morbidity [33]. However, pediatric tumors may remain clinically relevant for decades.

Long-term endocrine, neurocognitive, epileptic, and oncological outcomes are therefore more important than short-term radiographic volume reduction alone.

Thermal Coverage Versus Thermal Injury. A technically successful trajectory can still produce an inadequate treatment if the thermal damage volume does not sufficiently cover the intended target. Conversely, aggressive pursuit of complete thermal coverage may injure adjacent white-matter tracts, visual pathways, cranial nerves, hypothalamus, or internal capsule. The most useful concept is therefore the therapeutic thermal window. Within this window, the target receives an irreversible thermal dose while the surrounding critical structures remain below injury thresholds. This relationship is inherently three-dimensional. Ablation should therefore be evaluated according to overlap between the predicted thermal damage volume and the biological or epileptogenic target, rather than by laser power or procedural duration alone.

Table 2. Variables influencing MRgLITT outcome

Variable	Potential effect on treatment
Target volume	Large lesions require longer heating and produce more edema
Target geometry	Irregular lesions are difficult to cover from one trajectory
Catheter orientation	Determines longitudinal distribution of thermal injury
Vascular heat sink	May limit ablation adjacent to vessels
CSF interface	Alters local thermal distribution
Previous radiation	May modify tissue properties and edema response
Target proximity to critical tract	Restricts acceptable thermal margin
Percentage thermal coverage	Inadequate coverage increases local failure risk
Disease biology	Determines whether focal ablation can meaningfully alter outcome
Postoperative systemic therapy	Strongly influences neuro-oncological survival

Complications. The major complications of LITT include intracranial hemorrhage, neurological deficit, cerebral edema, seizure, infection, catheter malposition, thermal injury to adjacent structures, and rarely death. Edema deserves particular attention. Unlike surgical resection, the ablated

tissue remains intracranial after treatment. The inflammatory response can initially enlarge the lesion and worsen mass effect. This is especially relevant for large tumors, lesions near the brainstem, and patients with limited intracranial compliance. Corticosteroids are therefore commonly required in the early postoperative period. Ablation volume can expand substantially during the first several weeks before subsequently involuting [11]. For this reason, a patient with a large lesion causing life-threatening mass effect may be better treated by open decompressive resection rather than LITT, even if stereotactic thermal treatment is technically possible.

Proposed Precision Selection Model. Patient selection should begin by defining the clinical objective. In neuro-oncology, the question is whether focal cytoreduction is likely to improve local disease control or facilitate further treatment. In radiation necrosis, the objective is to reduce inflammatory lesion burden and steroid dependence. In epilepsy, the objective is network disconnection sufficient to produce durable seizure freedom. Once the clinical objective is defined, the target must be evaluated for geometric suitability. A compact deep lesion aligned with a safe stereotactic corridor is a stronger candidate than a broad infiltrative lesion surrounding multiple eloquent structures. The final step is to determine whether the expected therapeutic gain justifies the thermal risk.

Table 3. Proposed MRgLITT precision-selection framework

Domain	Favorable characteristic	Unfavorable characteristic
Geometry	Compact, approximately spherical or elongated along safe axis	Highly irregular, multifocal, very large
Access	Direct stereotactic corridor	Multiple critical structures along corridor
Functional anatomy	Safe distance from eloquent tracts	Target embedded within indispensable tract
Neuro-oncology	Focal deep recurrence	Diffuse multifocal progression
Radiation necrosis	Symptomatic focal RN with steroid dependence	Diffuse treatment-related change
MTLE	Concordant unilateral mesial temporal network	Broad bilateral or neocortical epilepsy
HH	Clearly defined epileptogenic attachment	Complex broad attachment requiring staged treatment
Systemic status	Good performance status and further treatment options	Rapid systemic progression and poor functional reserve

Discussion. The literature reviewed here demonstrates that MRgLITT should not be evaluated as a single procedure with a universal outcome. Its value depends on the relationship between disease biology, stereotactic geometry, functional anatomy, and the specific therapeutic endpoint. The development of the field from early recurrent-glioblastoma trials through large institutional series and prospective registries illustrates a gradual transition from feasibility testing toward indication-specific treatment strategies [1, 2, 3, 4, 5, 6]. In neuro-oncology, the major advantage of LITT is not that thermal ablation is inherently superior to microsurgical cytoreduction. Rather, it provides access to lesions for

which the morbidity of open exposure may exceed the value of surgery. The original difficult-to-access glioma experience, subsequent LAANTERN data, studies of IDH-wild-type glioblastoma, and the recent Scandinavian experience all support this patient-selection principle [2, 5, 6, 7, 8, 9]. The evidence nevertheless remains vulnerable to selection bias. Patients referred for LITT are not interchangeable with patients undergoing craniotomy, and survival comparisons based on retrospective cohorts cannot establish therapeutic equivalence. A second distinction is that cytoreduction and biological disease control are not synonymous. Glioblastoma is an infiltrative systems-level disease. Thermal elimination of a 2-cm recurrence can provide meaningful local control, but malignant cells remain beyond the thermally treated volume. The procedure must therefore be understood within a multimodal treatment sequence rather than as an isolated definitive therapy [1, 2, 7, 8, 9]. The radiation-necrosis literature illustrates a more uniquely advantageous application. In the post-SRS patient, diagnosis and treatment are inseparable because progressive tumor and radiation injury can appear remarkably similar radiographically. The LAASR study, early radiation-necrosis experience, later biopsy-confirmed cohorts, and comparative work against bevacizumab collectively support the value of obtaining tissue immediately before ablation [10, 11, 12, 13]. This combination reduces a major weakness of empiric therapy: treating an imaging diagnosis without knowing whether viable tumor is present. The role of LITT in brain metastasis should nevertheless be separated from its role in radiation necrosis. A patient with isolated viable recurrence and controlled systemic disease may benefit from local salvage, whereas a patient with rapidly progressing extracranial cancer and multiple untreated brain metastases may derive little benefit from focal thermal ablation. The clinical value of technical local control is therefore conditional on global disease trajectory [10, 12, 13, 14]. The epilepsy literature provides perhaps the strongest evidence that three-dimensional targeting is more important than indiscriminate treatment volume. Initial feasibility studies of mesial temporal laser ablation established that the amygdalohippocampal complex could be treated through a stereotactic corridor [15, 16]. Subsequent anatomical and neuropsychological studies refined the relevant target [17, 18, 19, 20, 21, 22, 23]. The multicenter analysis by Wu et al. was particularly influential because it demonstrated that seizure outcome was associated with the spatial distribution of ablation across the anterior, medial, and inferior mesial temporal region rather than simple posterior extension [24]. This finding should influence how success is measured. An ablation covering 90% of a poorly selected anatomical volume may be inferior to a smaller ablation precisely intersecting the critical epileptogenic network. The visual complications described by Jermakowicz and colleagues further demonstrate the cost of unnecessary thermal extension [25]. Thus, precision epilepsy ablation is fundamentally a network-targeting procedure rather than a lesion-volume procedure. Prospective data have strengthened this interpretation. The 2020 multicenter cohort demonstrated clinically meaningful one-year seizure outcomes across drug-resistant epilepsies [26], and later work linked specific parahippocampal coverage to improved outcome [27]. Long-term multicenter follow-up subsequently showed that seizure recurrence remains clinically relevant and that open surgery after failed LITT can remain an effective salvage strategy [28]. The 2025 LAANTERN data now provide prospective two-year information, with Engel I seizure freedom in 58.4% of evaluable patients [29]. These figures create an important counseling issue. If only seizure freedom is considered, conventional anterior temporal surgery will often remain the more effective operation. LITT becomes attractive when the

patient values shorter hospitalization, limited tissue disruption, potentially different neuropsychological risk, and the possibility of preserving open resection as a subsequent option [15, 18, 19, 24, 28, 29]. A patient should therefore not be counseled that LITT and temporal lobectomy are simply equivalent alternatives with different incision sizes. Hypothalamic hamartoma illustrates another form of precision targeting. Here, the pathological objective is often disconnection of an epileptogenic interface. The high gelastic-seizure control rates reported in large laser series support the suitability of this disease for stereotactic thermal treatment [30, 31]. The fact that a proportion of patients require repeated procedures is not necessarily evidence of inadequate technology. A staged strategy may reflect appropriate respect for the hypothalamus, fornix, mammillary bodies, optic structures, and vascular anatomy. Pediatric applications further demonstrate the need to avoid extrapolating adult treatment assumptions. Early pediatric epilepsy experience and more recent use in deep low-grade glioma show that the platform can be technically adapted across ages [32, 33]. Yet a minimally invasive operation is not automatically developmentally benign. Cognitive, endocrine, visual, seizure, and oncological follow-up must extend over years.

Across all indications, thermal dosimetry remains the shared technical language. Clinical studies that focus only on lesion size without quantifying thermal coverage risk obscuring a central determinant of outcome [1, 17, 24, 27]. A meaningful future LITT dataset should report the proportion of target exposed to irreversible thermal dose, thermal exposure of critical structures, catheter trajectory, number of pullbacks, lesion geometry, and postoperative ablation volume. The next generation of stereotactic thermal therapy is likely to become increasingly computational. Robotic stereotaxy can improve trajectory reproducibility. Automated segmentation can quantify target coverage. Diffusion tractography can identify white-matter structures requiring thermal protection. Patient-specific finite-element modeling may eventually predict heat distribution before laser activation. In epilepsy, SEEG and connectomic information could help determine the most relevant portion of an epileptogenic network. In neuro-oncology, imaging and radiomic features may help distinguish regions of viable tumor from necrotic or treatment-related tissue. However, increased technological complexity should not obscure the clinical decision. The fundamental question remains whether destruction of the proposed target is likely to improve an outcome meaningful to the patient. For a patient with recurrent glioblastoma, that outcome may be local control sufficient to permit another systemic treatment [7, 8]. For a patient with radiation necrosis, the outcome may be corticosteroid independence [11, 12]. For a patient with MTLE, the outcome is durable seizure freedom with acceptable cognitive and visual function [24, 25, 26, 28, 29]. For a child with hypothalamic hamartoma, the objective may be termination of gelastic seizures and prevention of progressive epileptic encephalopathy [30, 31]. Accordingly, MRgLITT should be understood as a precision ablation platform rather than a diagnosis-specific operation. The same instrument generates heat, but the biological target, functional boundary, acceptable ablation volume, and definition of success differ radically among clinical indications. The current evidence base also highlights the need for better comparative research. Randomized trials comparing LITT with open resection will be difficult because treatment eligibility is strongly determined by lesion anatomy and patient preference. Nevertheless, prospective propensity-adjusted studies, standardized thermal-coverage metrics, disease-specific

functional outcomes, and long-term quality-of-life assessment can substantially improve comparative effectiveness research.

For glioblastoma, future studies should compare patients within the same molecular and anatomical risk strata rather than pooling newly diagnosed and recurrent tumors [2, 7, 8]. For radiation necrosis, studies should include histological confirmation whenever safely feasible [10, 12, 13]. For temporal epilepsy, standardized neuropsychological testing and formal perimetry should accompany Engel or ILAE classification [18, 25, 28, 29]. Finally, future research should investigate whether thermal injury produces therapeutically exploitable biological effects beyond local cytotoxicity. Thermal ablation alters vascular permeability, releases intracellular antigens, induces inflammation, and changes the local immune microenvironment. These phenomena create a biological rationale for combining LITT with systemic therapies in neuro-oncology, but mechanistic plausibility must not be mistaken for established clinical benefit. The strongest future role of LITT will therefore arise not from expanding its indication to every intracranial lesion but from increasingly precise selection of the lesions and networks for which controlled thermal destruction offers a superior risk–benefit relationship compared with open surgery, radiation, medication, or observation.

Conclusion. MRI-guided laser interstitial thermal therapy has matured into a versatile stereotactic neurosurgical platform with clinically relevant applications in neuro-oncology and epilepsy surgery. Its central technological advantage is the ability to combine stereotactic access with real-time thermal monitoring and controlled three-dimensional tissue ablation. In neuro-oncology, MRgLITT is particularly relevant for selected deep or difficult-to-access gliomas, focal recurrent glioblastoma, progressive metastatic lesions after stereotactic radiosurgery, and biopsy-proven radiation necrosis. The procedure can combine diagnostic tissue acquisition with immediate local treatment and generally permits relatively short hospitalization. In mesial temporal lobe epilepsy, LITT provides a minimally invasive alternative to open temporal surgery but produces lower average seizure-freedom rates than established resective procedures. Outcomes depend strongly on precise coverage of the epileptogenic mesial temporal network rather than on total ablation volume alone. Hypothalamic hamartoma represents a particularly suitable application because stereotactic thermal therapy can produce effective epileptogenic disconnection while avoiding extensive open surgical exposure. The principal determinant of successful MRgLITT is not maximum thermal destruction. It is the creation of adequate irreversible thermal coverage of the intended pathological target while maintaining a safe thermal boundary around critical neural and vascular structures. Future progress is expected to arise from robotic stereotaxy, connectome-guided target definition, automated three-dimensional thermal-damage analysis, computational heat modeling, and rational integration with systemic neuro-oncological therapy. MRgLITT should therefore be regarded neither as a replacement for microsurgery nor merely as a less invasive alternative. It represents a distinct precision-neurosurgical strategy whose value depends on selecting the correct patient, the correct target, the correct trajectory, and the correct disease-specific therapeutic endpoint.

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