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LITERATURE REVIEW

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Functional outcomes in MRI-guided laser interstitial therapy for temporal lobe epilepsy: a systematic review and meta-analysis

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OBJECTIVE The use of MRI-guided laser interstitial thermal therapy (MRgLITT) has emerged as a promising treatment option for patients with drug-resistant temporal lobe epilepsy (TLE). Although the minimally invasive approach holds promise as an effective treatment for achieving seizure freedom, a comprehensive review of its impact on functional outcomes is still warranted. To address this need, this review aims to summarize data pertaining to the functional and neurocognitive outcomes following MRgLITT for TLE.

METHODS Four primary electronic databases were screened following PRISMA guidelines by two independent reviewers. All functional data related to cognitive, behavioral, and emotional outcomes were gathered and analyzed as well as the neuropsychological tests issued to assess pre- and postoperative outcomes. The functional outcomes assessed were grouped into the 5 most common categories: verbal cognition, visual cognition, cognitive emotion, visual deficits, and other higher-order cognitive functioning.

RESULTS A total of 4184 studies were screened and ultimately 408 patients from 14 studies were included for analysis. Changes in functional areas were assessed by comparing pre- and postoperative scores across a comprehensive set of 31 different functional and cognitive assessments, and were tabulated as the percentage of patients whose status improved, declined, or was maintained, where possible. In verbal (n = 112) and visual (n = 42) cognition, the rates of patients experiencing a decline were 20.4% and 13.5%, respectively, and the rates of improvement were 24.9% and 16.7%, respectively. Other functional outcomes assessed, including cognitive emotion (n = 150), visual deficits (n = 325), and higher-order cognitive processes like attention/processing (n = 19), motor cognition (n = 18), and general executive function (n = 4), exhibited varying rates of decline, ranging from 10.5% to 25%.

CONCLUSIONS MRgLITT is an effective and minimally invasive surgical alternative treatment for TLE, but there is an observable impact on patient functioning and cognitive status. This review demonstrates the need for standardized methods that can accurately capture and quantify the associated risk of MRgLITT to optimize its effect on patient quality of life moving forward.

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KEYWORDS functional outcomes; MRI-guided laser interstitial thermal therapy; temporal lobe epilepsy; functional neurosurgery

The use of MRI-guided laser interstitial thermal therapy (MRgLITT) has emerged as a promising treatment option for patients with temporal lobe epilepsy (TLE) that is resistant to medication. MRgLITT is an ablative stereotactic procedure that uses thermal ablation to target epileptogenic foci, with the advantage of real-time tissue monitoring by MR thermography. This minimally invasive approach offers an alternative to traditional open resection and has been associated with lower morbidity rates, shorter hospital stays, and reduced hospital costs.[1,2] Furthermore, it has been shown that following open resection, up to 50%–60% of patients may experience deficits

ABBREVIATIONS BVMT-R = Brief Visual Memory Test–Revised; CVLT = California Verbal Learning Test; JLO = Judgment of Line Orientation; MRgLITT = MRI-guided laser interstitial thermal therapy; ROCF = Rey-Osterrieth Complex Figure Test; TLE = temporal lobe epilepsy; WAIS-IV = Wechsler Adult Intelligence Scale–Fourth Edition; WMS-IV LM II = Wechsler Verbal Memory Scale Logical Memory II; WMS-VR = Wechsler Memory Scale IV–Visual Reproduction.

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in both verbal and visual memory, with only 15% showing long-term memory improvements.[3]

Despite the growing interest in MRgLITT in the neurosurgical community, there remains a lack of consensus regarding the long-term functional and neurocognitive outcomes of MRgLITT treatment. Some studies indicate significant declines in verbal learning and memory, along with a higher risk of postoperative functional decline in patients who had higher preoperative functioning.[4–7] Previous studies have made efforts to explore this topic; however, they have fallen short of conducting a thorough assessment of the neurocognitive measures that are used to evaluate patients' function before and after surgery. Additionally, previous research has overlooked the analysis of cognitive domains that are commonly and infrequently assessed, resulting in a lack of clarity regarding what cognitive functions are being affected and a lack of uniformity in the neurocognitive testing protocols that are used.

To address these gaps in our understanding of outcomes and testing protocols in MRgLITT, we conducted an exhaustive review of all relevant literature pertaining to neurocognitive and functional outcomes in patients with TLE who underwent MRgLITT. Specifically, we provide a comprehensive analysis of various higher-order complex functions in cognition, behavior, and emotions following MRgLITT treatment. Furthermore, we evaluated the various tests used to assess these outcomes, with the aim of identifying a standardized battery of tests that could be used to facilitate comparisons across studies and improve the homogeneity of pre- and posttreatment testing.

Methods

Literature Search

We followed the PRISMA guidelines in conducting and reporting this literature review. We conducted an exhaustive systematic literature search in PubMed, EMBASE, Web of Science, and Cochrane to collect and analyze all studies that investigated neurocognitive and functional outcomes of MRgLITT in TLE. We searched for all studies published from database inception to October 15, 2022, in the PubMed, EMBASE, Web of Science, and Cochrane databases using the following terms: "Epilepsy," "Epilepsies," "seizure," "seizure disorder," "seizures," "Epileptogenic," "laser induced thermal therapy," "laser-induced thermal therapy," "laser induced thermotherapy," "laser-induced thermotherapy," "laser interstitial thermal therapy," "laser-interstitial thermal therapy," "laser interstitial thermotherapy," "laser-interstitial thermotherapy," "laser interstitial thermal ablation," "laser-interstitial thermal ablation," "laser induced thermal ablation," "laser-induced thermal ablation," "LITT Thermal Ablation," "MRgLITT," and "Laser Thermal Ablation."

Study Selection

Studies were included if they 1) involved 1 or more patients with a clinically confirmed diagnosis of TLE who underwent MRgLITT; 2) reported pre- and postoperative neurocognitive or functional data on a patient-specific level; and 3) were written in English. Studies were excluded if they 1) only included patients within the pediatric population; 2) reported cases of epilepsy originating outside of the temporal lobe; and 3) did not define how postoperative changes in function were measured. For all included studies reporting cases of MRgLITT in patients with TLE, the diagnosis of TLE was confirmed using standard protocols such as video-EEG or MRI.

Our initial literature search yielded 4184 articles, which were imported into and analyzed using a publicly available systematic review software (https://www.rayyan.ai/). After duplicates were removed (n = 619), a total of 3565 article titles and abstracts were screened independently for the study's inclusion and exclusion criteria by two blinded reviewers (D.A.B. and D.J.V.), with any disagreements resolved by a third reviewer (N.B.D.). From this screening process, 34 articles were identified for full-text review. Furthermore, both the references cited in these articles and the references contained within previous systematic reviews on MRgLITT were screened, but no additional relevant studies were identified. After conducting a full-text review, we identified and included 14 papers in our study (Fig. 1).

During the full-text screening for data, we conducted an analysis of the authors and hospital systems associated with each included study, with the aim of avoiding the duplication of neurocognitive data from the same patients across multiple studies, thereby ensuring the integrity of our study and minimizing bias. In instances in which 2 studies may have recruited patients from the same hospital system, we gave priority to the most recently published study.[5,6,8]

Furthermore, if 2 studies containing patients from the same hospital system contained different cognitive measures, then both data points were included in our study. However, if 2 studies used the same neurocognitive tests, then the data from the article published most recently were used and incorporated in our analysis.[7,9–11] For example, one instance in which we implemented our data selection protocol included when we encountered the verbal cognitive outcomes described in both Grewal et al. (Mayo Clinic, 2018)[16] and Dredla et al. (Mayo Clinic, 2016).[15] Since both studies included patients from the same hospital system, the results from Grewal et al. were tabulated into the analysis, whereas the verbal cognitive results of Dredla et al. were excluded because it was the older study.

Data Extraction and Analysis

The neurocognitive outcomes and tests used in each study were extracted and incorporated in an Excel (Microsoft Corporation) document for data analysis. To streamline data analysis and enhance the overall interpretation of neurocognitive outcomes determined by the neurocognitive tests, we classified postoperative cognitive outcomes into 5 domains (verbal, visual, executive functioning, attention and processing, and motor), categorizing each neurocognitive test according to the domain with which it best aligned. To determine the frequency of usage for each neurocognitive test, we computed the utilization rates by analyzing the prevalence of these tests across the studies included in our review. The results of this analysis are included in Table 1, and a comprehensive list of cognitive tests used in each study is included in Supplementary Table 1.

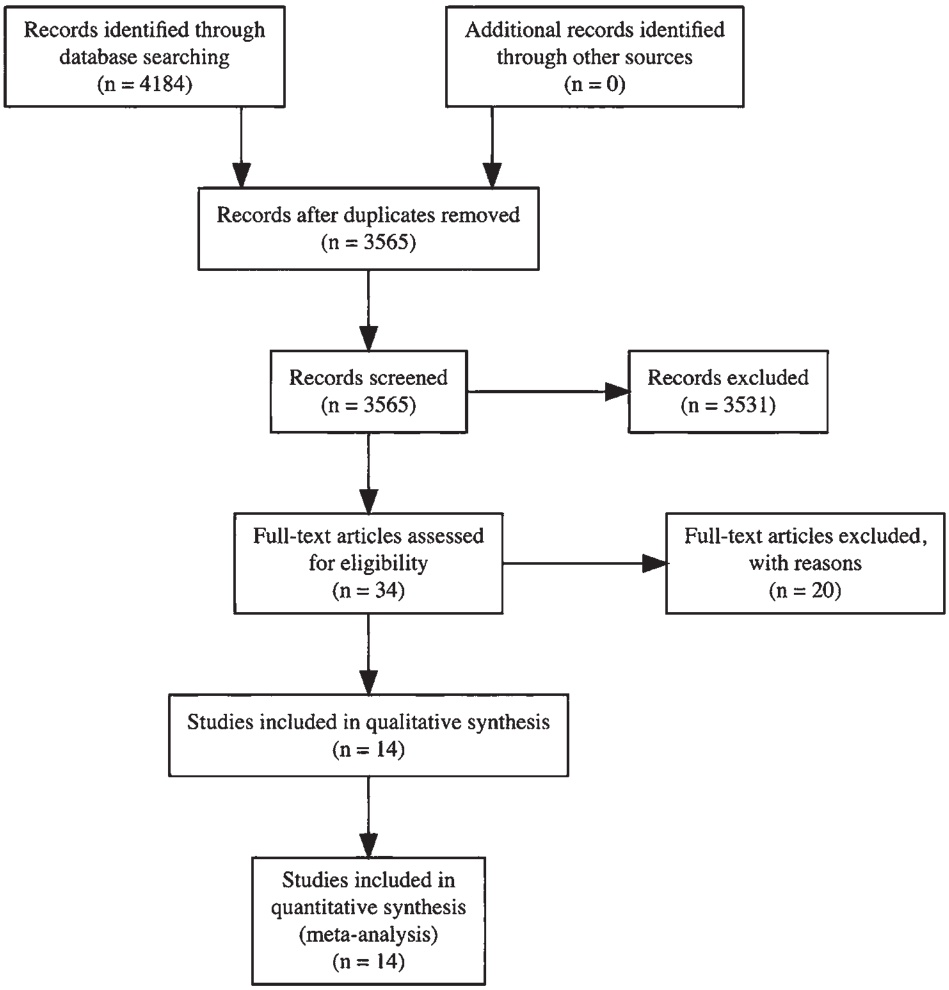

FIG. 1. PRISMA flowchart. Data added to the PRISMA template (from Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* 2009;6[7]:e1000097) under the terms of the Creative Commons Attribution (CC BY-NC 2.0) License (https://creativecommons.org/licenses/by/2.0).

After categorizing outcomes based on the 5 cognitive domains, patient outcomes were further grouped according to whether there was a decline, maintenance, or improvement in their domain-specific function. If not explicitly stated within the study, a decline or improvement of 1 SD between pre- and postprocedure cognitive assessment was interpreted as a significant change in cognitive function.

Subgroup analysis comparing outcomes of dominant and nondominant hemisphere approaches was conducted for the 5 studies that specified the hemisphere in which the surgery was performed. In this analysis, we reported outcomes only from papers that used functional MRI (fMRI) or both Wada testing and fMRI to assess language lateralization.[6,7,10,12,13]

Results

Study Selection

As outlined in Fig. 1, a broad literature search revealed 14 studies eligible to be included in our analysis.[6–21] The reported cognitive outcomes included in these studies varied. Verbal cognitive outcomes were reported in 8 studies, visual cognitive outcomes in 4 studies, cognitive emotion outcomes in 4 studies, and visual deficits in 10 studies. Additional cognitive outcomes were investigated and reported in 4 studies, encompassing 3 broad categories. Due to the examination of various cognitive functions and their reporting, these outcomes were classified into 3 distinct categories, each capturing specific aspects: general executive function (such as planning and organization), attention, and motor cognition (initiation).[22] The studies included in this analysis are summarized in Table 2, which provides an overview of the cognitive outcome categories reported in each study. As discussed previously, the categories of cognition were determined by the cognitive assessment used (Table 1).

Verbal Cognitive Outcomes

Verbal cognition was measured by a total of 16 differ-

TABLE 1. Cognitive assessments and utilization rates

Full Test Name	Abbreviation	Utilization
Verbal cognition		
Boston Naming Test	BNT	75%
Wechsler Verbal Memory Scale Logical Memory II–Delayed	WMS-IV LM II–Delayed	63%
Wechsler Verbal Memory Scale Logical Memory I–Immediate	WMS-IV LM I–Immediate	50%
California Verbal Learning Test–Delayed Recall	CVLT–Delayed Recall	38%
Categorical Fluency/Animal Fluency Test	CFT	25%
Rey Auditory Verbal Learning Test–Immediate Recall	RAVLT–Immediate	25%
Rey Auditory Verbal Learning Test–Delayed Recall	RAVLT–Delayed	25%
Letter Fluency/FAS Test	FAS	13%
California Verbal Learning Test–Short Recall	CVLT–Short Recall	13%
Rey Auditory Verbal Learning Test	RAVLT	25%
Multilingual Aphasia Examination (Spanish)	MAE-S	13%
Wechsler Memory Scale–Verbal Paired Associate	WMS-IV VPA–Delayed	13%
California Verbal Learning Test–Total Learning	CVLT–Total Learning	13%
Miami Assessment of Memory Instrument (Spanish)	MAMI	13%
Controlled Oral Word Association Test–Semantic	COWAT-S	13%
Controlled Oral Word Association Test–Phonemic	COWAT-P	13%
Visual cognition		
Rey-Osterrieth Complex Figure Test–Delayed	ROCF (Delayed)	75%
Brief Visual Memory Test–Revised	BVMT-R	50%
Wechsler Adult Intelligence Scale–Block Design	WAIS-IV Block Design	25%
Judgment of Line Orientation	JLO	25%
Wechsler Memory Scale IV–Visual Reproduction	WMS-VR	25%
General executive function		
Wechsler Adult Intelligence Scale–Fourth Edition	WAIS-IV	50%
Escala de Inteligencia Wechsler para Adultos	EIWA-III	50%
Trail-Making Test, Part A	TMT A	50%
Trail-Making Test, Part B	TMT B	50%
Full-Scale IQ	FSIQ	50%
Attention & processing speed		
Wechsler Adult Intelligence Scale IV–Digit Span	WAIS IV–Digit Span	100%
Wechsler Adult Intelligence Scale–Arithmetic	WAIS IV–Arithmetic	50%
Escala de Inteligencia Wechsler para Adultos–Digit Span	EIWA-II–Digit Span	50%
Wechsler Adult Intelligence Scale IV–Coding	WAIS IV–Coding	50%
Escala de Inteligencia Wechsler para Adultos–Coding	EIWA-II–Coding	50%
Motor cognition		
Grooved Pegboard Test	GPT	100%

CFT = Categorical Fluency Test; FAS = Letter Fluency Test.

ent variations of verbal cognitive assessments. The Boston Naming Test was used in 75% of studies, making it the most frequently used test to examine verbal outcomes (Table 1). Other common tests were the Wechsler Verbal Memory Scale Logical Memory II (WMS-IV LM II)–Delayed (63%), WMS-IV LM I–Immediate (50%), and California Verbal Learning Test (CVLT)–Delayed Recall (38%) (see Table 1 and Supplementary Table 1 for more details).

A total of 112 patients from 8 studies[6,7,10,12,13,15,16,19] had verbal cognitive outcomes measured. Among these patients, 20.4% had a decline, 54.7% maintained their verbal cognitive function, and 24.9% showed improvement (Fig. 2). As discussed previously in the *Methods*, a decline or improvement in cognitive function was determined by a change of 1 SD from preoperative test scores.

A subgroup analysis was performed in 5 of the 8 studies;[6,7,10,12,13] this analysis specified dominant and nondominant outcomes based on the hemisphere in which the procedure was performed (Fig. 3). In the dominant cohort, consisting of 51 patients, 23.8% experienced a decline, 64.8% maintained their verbal cognitive function, and

TABLE 2. Summary of studies assessing neurocognitive outcomes in patients with TLE undergoing MRgLITT

Authors & Year	Institution	Study Type	Recruitment Yrs	No. of Pts	Age in Yrs	Sz-Free Rate*	Avg FU in mos	Verbal Cognition	Visual Cognition	Emotional Cognition	Other Cognitive	Visual Deficits
Kanner et al., 2022[14]	UM	Retro	2013–2019	48	43	60%	50	—	—	✓	—	—
Drane et al., 2021[6]	Emory U	Pro	NA	40	40	45%	NA	✓	—	—	—	—
Bermudez et al., 2020[7]	UM	Retro	2013–2016	26	44	81%	8.4	✓	✓	—	✓	—
Dredla et al., 2016[15]	Mayo Clinic	Pro	NA	2	49	100%	3.5	✓	✓	—	—	—
Grewal et al., 2018[16]	Mayo Clinic	Retro	2011–2015	25	43.9	65%	34†	✓	—	—	—	✓
Satzer et al., 2021[17]	UC	Retro	2014–2019	28	42	39%	10.2	—	—	✓	—	✓
Le et al., 2018[18]	Stanford U	Pro	2014–2017	29	43‡	62%	18†	—	—	—	—	✓
Waseem et al., 2015[19]	Multi insts§	Pro	NA	5	60	80%	12	✓	✓	—	✓	✓
Tao et al., 2018[13]	UC	Pro	2014–2017	21	40	52%	24	✓	—	—	—	✓
Jermakowicz et al., 2017[10]	UM	Retro	NA	23	40.9	65%	22.4	✓	✓	—	—	—
Kang et al., 2016[12]	TJU	Retro	2011–2014	20	39	36%	13.4	—	—	—	—	✓
Jermakowicz et al., 2019[11]	Multi insts¶	Retro	NA	90	43	63%	30	—	—	—	—	✓
Cajigas et al., 2019[9]	UM	Retro	2013–2018	26	43.8	62%	42.9	—	—	—	—	✓
Vakharia et al., 2018[20]	TJU	Retro	2012–2016	25	41.4	44%	24.4	—	—	✓	—	✓

Avg FU = average follow-up; multi insts = multiple institutions; NA = not available; Pro = prospective; Pts = patients; Retro = retrospective; Sz = seizure; TJU = Thomas Jefferson University; U = University; UC = University of Chicago; UM = University of Miami.
* Seizure-free rate (%) refers to Engel class I outcomes.
† Grewal et al. and Le et al. reported median duration of follow-up instead of average duration.
‡ Le et al. reported median age at time of surgery instead of average age.
§ Waseem et al. did not recruit from a single institution tested. They used a prospective epilepsy surgery database.
¶ Jermakowicz et al., 2019, surveyed patients at Thomas Jefferson University, University of Miami, University of South Florida, Cook Children's Medical Center, and Vanderbilt University.

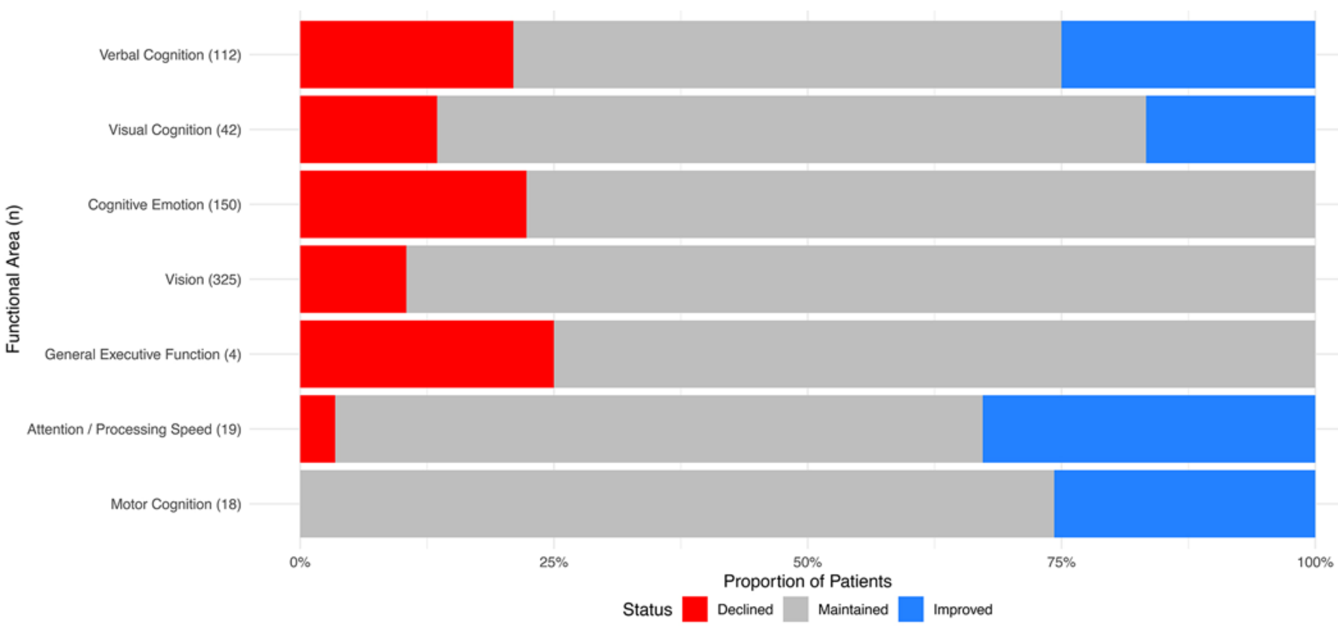

FIG. 2. Distribution of patient outcomes across cognition domains following MRgLITT: decline, maintenance, and improvement percentages. Figure is available in color online only.

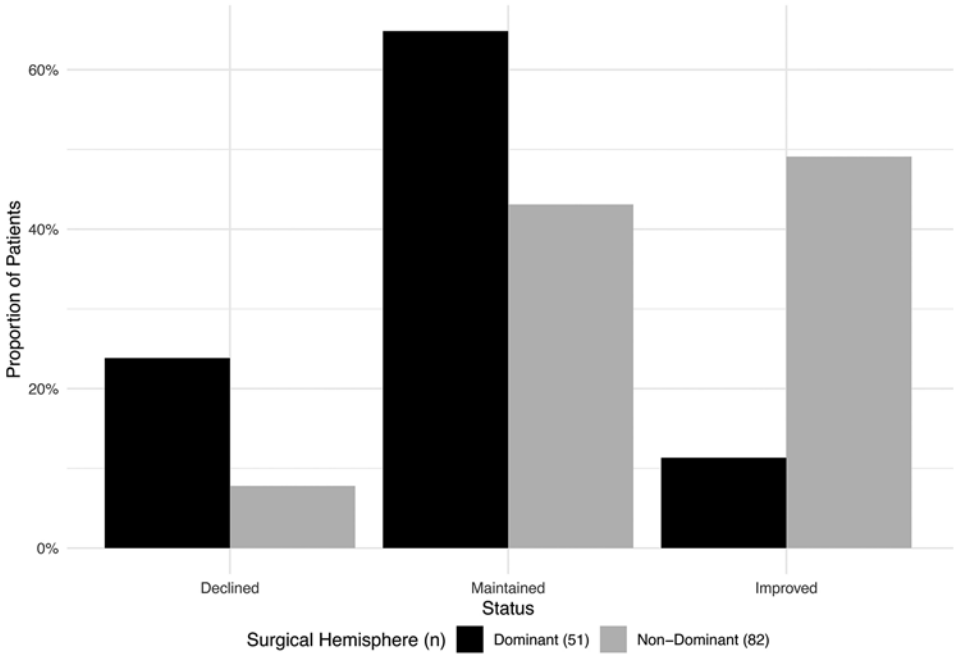

FIG. 3. Verbal cognitive outcomes by hemisphere targeting in MRgLITT.

11.3% showed improvement. The nondominant cohort included 82 patients, and 7.8% experienced a decline, 43.1% maintained their verbal cognitive function, and 49.1% showed improvement.

One study on this topic further modeled the effect of additional variables—such as preablation outcomes and preablation volume—on post-LITT verbal cognitive outcomes.[4] In doing so, the investigators found that decreases in verbal memory were associated not only with dominant LITT procedures, but also with higher baseline verbal cognition and greater ablation volume.

Visual Cognitive Outcomes

Visual cognition was evaluated using a total of 5 distinct test variations. The Rey-Osterrieth Complex Figure Test–Delayed (ROCF–Delayed) was the predominant test used, accounting for 75% of the studies and serving as the primary measure for assessing verbal outcomes (see Table 1). Additionally, other frequently used tests included the Brief Visual Memory Test–Revised (BVMT-R; 50%), Judgment of Line Orientation (JLO; 25%), Wechsler Adult Intelligence Scale–Fourth Edition (WAIS-IV) Block Design (25%), and Wechsler Memory Scale IV–Visual Reproduction (WMS-VR; 25%) (refer to Table 1 and Supplementary Table 1 for more comprehensive information).

A total of 42 patients from 4 studies[7,10,15,19] had visual cognitive outcomes measured. Of these patients, 13.5% had a decline, 69.8% maintained their visual cognitive function, and 16.7% improved (Fig. 2).

Two studies[7,10] reported dominant and nondominant hemisphere outcomes for visual cognition, totaling 36 patients (Fig. 4). Of the 19 patients in the dominant cohort, 17.9% had a decline, 62.5% maintained their visual cognition, and 19.6% improved. Of the 17 patients in the nondominant cohort, 7.7% had a decline, 73.1% maintained their visual cognitive function, and 19.2% improved.

Cognitive Emotion Outcomes

For our review, the term "cognitive emotion" is used to capture a range of psychiatric conditions, including anxiety, depression, panic disorder, suicidal ideation or attempts, and insomnia. The assessment of these outcomes only encompassed the evaluation of new-onset or worsening symptoms associated with underlying psychiatric disorders, as reported by the study authors. Therefore, relative increases in cognitive emotion were not measured. Of the 150 patients who had reported cognitive emotion outcomes, 23.3% reported either new or worsening symptoms.

Notably only 1 study, Kanner et al.,[14] conducted assessments measuring both pre- and postoperative severity of anxiety among patients diagnosed with the condition, providing an opportunity to track potential improvements. In their cohort of 29 patients with diagnosed anxiety, 17 patients (58.6%) registered an improvement in their symptoms.[14]

Visual Deficits

We classified a visual deficit as either palsy of cranial nerve III or IV or a visual field cut following MRgLITT. This particular subset comprised the largest sample size in our investigation, including a total of 325 patients across 10 different studies.[8,9,11,12,16–21] Among these patients, 34 individuals (10.5% of the total group) were identified as having visual deficits. Specifically, 24 patients (7.4%) exhib-

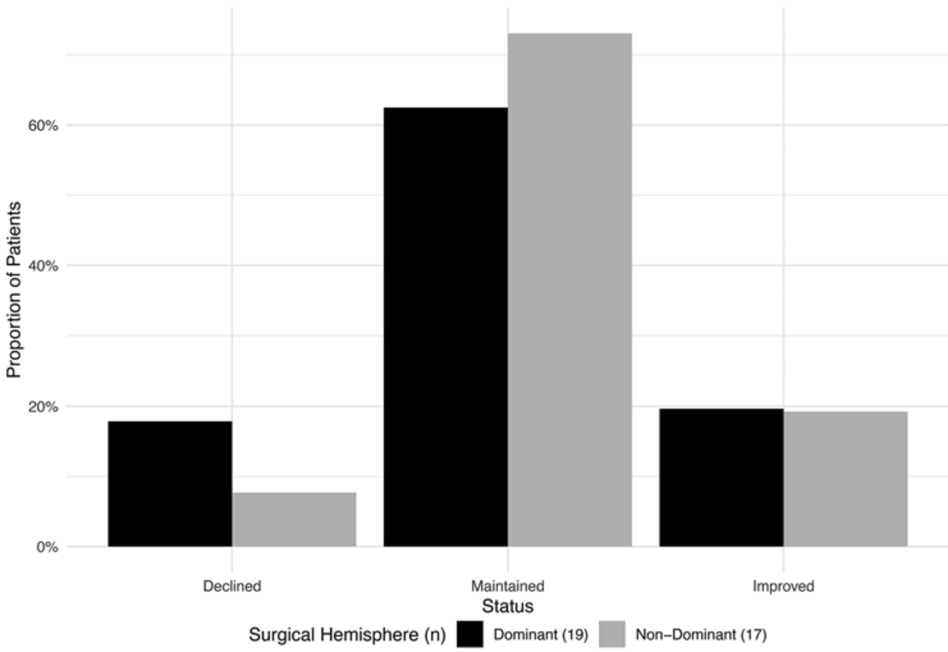

FIG. 4. Distribution of visual cognitive outcomes by hemisphere targeting in MRgLITT.

ited a visual field cut, and 10 patients (3.1%) presented with a cranial nerve palsy. The visual deficits were either self-reported or observed clinically. More formal postoperative ophthalmological evaluation was rarely conducted.[11]

Other Cognitive Outcomes

Four of the 17 articles included in this study undertook an examination of cognitive outcomes beyond just verbal and vision, investigating components such as general executive function, attention, processing speed, and motor cognition.[7,15] General executive function was assessed using tools like the WAIS performance IQ subtest, the Trail-Making Test, and other IQ measurement instruments. Due to overlapping cognitive domains in certain assessments, we decided to merge attention and processing speed into a single category known as "Attention/Processing Speed." To evaluate these domains, we used the Digit Span, Arithmetic, and Coding subtests of the WAIS-IV. Last, motor cognition was assessed using the Grooved Pegboard Test (see Table 1 for details).

Within the general executive function category, only 4 patients had reportable results. Among these patients, 25% experienced a decline in function, whereas 75% showed an increase in function. Attention and processing were assessed in 19 patients. Among them, 3.4% experienced a decline, 63.8% maintained their performance, and 32.8% showed improvement.

Motor cognition was assessed in 18 patients. None of the patients experienced a decline, 74.3% maintained their motor cognition, and 25.7% showed improvement (Fig. 2).

Discussion

MRgLITT is rapidly gaining traction as a therapeutic approach for epilepsy. Despite its lesser efficacy compared to traditional open resection, MRgLITT represented 13.2% of surgical interventions for drug-resistant epilepsy as of 2016, an impressive increase of more than 10-fold in just 4 years.[23–28] The procedure's continuous ascendancy, despite lower seizure freedom rates, can likely be attributed to its minimally invasive nature resulting in reduced duration of hospital stay. An important contributing factor to the increased utilization of MRgLITT is its capability to safely target deep-seated areas near eloquent cortices. These regions would typically pose significant challenges and hazards if accessed through traditional open resection.[5,6,29–31] Epilepsy, if left untreated, can have detrimental impacts on patients, with a mortality rate that is 4 to 7 times higher and a decrease in quality of life related to the decrease in marriage and employment rates. The serious consequences of untreated epilepsy underscore the need for intervention.[32]

As MRgLITT technology and our understanding of structural-functional relationships in the human brain continue to improve, it has become clearer that there is a need to broaden the scope of measured outcomes beyond just seizure freedom rates. Following open surgical treatment for deep-seated foci, there can be significant deficits in overt language and motor functions.[33–37] Although less frequent after MRgLITT, it is still crucial to acknowledge that patients may still experience deficits in less obvious higher-order cognitive functions. These deficits can lead to significant morbidity, restrict patient quality of life, and impede successful reintegration into the workforce.[7,10,19] Here, we show that there is nonnegligible risk of having impairments in either cognitive emotion (23.3%), verbal cognition (20.8%), or visual cognition (13.5%) after MRgLITT. We aimed to quantify the increased risk associated with operating on the dominant hemisphere. The higher risk associated with dominant hemisphere procedures can be supported by the increased incidence of cognitive decline in these patients within our cohort. Specifically, there was a 16.0% increased incidence of verbal cognitive decline and a 10.2% rise in visual cognitive decline when compared to those in whom the operation was performed in the nondominant hemisphere.

The burden experienced by patients with uncontrolled epilepsy can lead to a significant emotional decline. Measuring the relief that patients feel after treatment was challenging, primarily because only 1 study defined pre- and posttreatment cognitive emotion changes. In the study by Kanner et al.,[14] it was illustrated that more than half of their patients experienced improvements in cognitive symptoms. This supports the notion that achieving seizure freedom and the subsequent release from the burden of seizures lead to a higher quality of life. TLE procedures offer immense emotional benefits, because they not only alleviate the emotional distress caused by epilepsy but also provide cognitive improvements, underscoring the holistic advantages of these treatments.

Aggregating data from various studies posed significant challenges due to the lack of uniformity in neurocognitive testing. As indicated in Table 1, patients underwent 31 distinct cognitive assessments, underscoring an urgent need for standardization in both pre- and postoperative cognitive testing. This would enable more accurate insight into the outcomes by facilitating clinical outcome comparisons between hospital systems and patient populations. In this review, we navigated the diversity of assessments by categorizing tests into distinct groups. Implementing a predefined set of cognitive assessments to define each category could significantly enhance this standardization process. While selecting suitable tests, it is imperative to consider the available resources. As illustrated in the study by Bermudez et al., comprehensive neurocognitive testing was achievable due to the presence of a well-trained, bilingual team of neuropsychologists with substantial experience in cognitive testing.[7] To generate a broader dataset on neurocognitive outcomes, the standardized testing should incorporate easily administered assessments, such as the Boston Naming Test. Ultimately, the goal is to establish a suite of neurocognitive assessments that not only are efficient to administer but also accurately measure changes across the full spectrum of cognitive outcomes. There is a need for more reviews like ours, or the insightful work seen in other publications[5,6,8] that focus on cognitive assessments to enhance standardization and facilitate more precise data compilation. Incorporating detailed patient-specific data is pivotal for enhancing the precision of future meta-analyses, allowing for a nuanced consideration of diverse patient attributes. For instance, examining the correlation between cognitive decline and the age at which surgery was undertaken becomes intriguing, given the inherent variations in brain plasticity across age groups. The topic of age was discussed in some of the papers included in our study, but no definitive relationship was established. A more robust understanding of the functional adverse effects of MRgLITT will help better define the role this therapy could play in the continuum of epilepsy treatment.

In addition to enhancing our understanding of cognitive changes, this standardization will facilitate a direct comparison of MRgLITT with other surgical interventions. Currently, there are few studies that compare the cognitive outcomes between MRgLITT and traditional open resection.[5,6,26,38,39] Whereas some studies have demonstrated that patients undergoing MRgLITT have more favorable verbal learning outcome and have a decreased frequency of cognitive deficits in naming tasks, other studies have found patients treated with MRgLITT to have worse seizure freedom rates.[5,6,40] A prospective study detailing the verbal and visual cognitive outcomes of 110 patients 1 year after open resection serves as a benchmark to shape our anticipatory cognitive outcomes for MRgLITT.[41] From this study, verbal and visual cognition saw declines of 9% and 4%, respectively. However, our findings present a more pronounced decline of 20.4% in verbal cognition and 13.5% in visual cognition. Interestingly, despite these steeper declines, MRgLITT demonstrated a higher rate of improvement: 24.9% in verbal cognition and 16.7% in visual cognition. This contrasts with the open-resection study's improvement rates of 10% for verbal cognition and 5% for visual cognition.[41] There is a need for a more thorough investigation into comparing the cognitive outcomes between open resection and MRgLITT.

Understanding the risks and benefits of available TLE treatments compared to open resection is crucial for patients. Although outside the scope of this study, these data support the notion that LITT cognitive outcomes are at least comparable to those of open resection. Future investigations are needed to thoroughly compare the cognitive implications of different treatment options.

Recently it has become clearer that cognitive functions can be better understood through considering the complex structural and functional circuitry that underlies them,[22,42] providing significant opportunities for MRgLITT treatment moving forward. The brain connectome, consisting of the complete set of structural and functional connections in the brain, has recently begun to provide insight to epilepsy surgery that is not otherwise provided by standard clinical assessments. Like brain regions, seizure foci can be examined as individual nodes in a network surrounded by interconnecting structural and functional brain connections. By examining these brain networks and epilepsy networks, safer and more efficient plans for resection can be created solely based on standard MRI to avoid critical brain connections[43] and treat effective targets,[44,45] while also predicting postoperative neurocognitive trajectories.[46] Similarly, these applications can be extended to MRgLITT to improve cognitive functional outcomes in addition to seizure freedom. Connectome-based LITT can use information obtained from individualized brain connectomes to identify favorable ablation volumes and approaches[44–46] while sparing critical networks.[47] Currently, connectome-based MRgLITT is in its infancy, but it provides a logical next step to reduce the cognitive and functional morbidity of this treatment, which is largely based on anatomical targeting.

Limitations

The purpose of the current review was to better understand the functional outcomes after MRgLITT for TLE. However, like all reviews, this work is inherently limited by the quality of the reported literature with inherent selection bias, which only included patients with pre- and postoperative measurements. One notable limitation of this study is the potential for publication bias, whereby the tendency to publish studies with positive or statistically significant results may lead to an incomplete representation. Another important consideration in this study is the utilization of various cognitive assessment measures, which inherently possess different sensitivities and specificities in detecting changes from baseline cognition. As discussed in this paper, this variability in assessment tools may introduce a potential limitation in accurately capturing and comparing cognitive changes across the study population. The definition of what defines a significant change in cognitive assessment also varied among studies, with some defining a significant change by using the reliable change index and others using standard deviation methodologies. Due to the absence of preoperative cognitive emotion disorder reporting in all studies except one, we could not state improvements in cognitive emotion. Another potential limitation of this study is that the visual deficits and cognitive emotion deficits were occasionally determined by self-reporting by the patient or a clinical diagnosis. Last, the discrepancies in follow-up durations across studies may hinder a comprehensive analysis of the sustained nature of the observed deficits or improvements.

Conclusions

MRgLITT is swiftly emerging as a promising alternative to open resection for managing refractory TLE. This study provides a comprehensive overview of postablation functional outcomes. These outcomes extend beyond seizure control to influence various facets of the daily life of a patient with epilepsy, including verbal cognition, visual cognition, and cognitive emotion; other higher-order cognitive functions; and visual acuity. To enhance our understanding of factors influencing these outcomes, there is an imperative need for further standardization of cognitive testing methods.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Sun, Brenner, Valdivia, Dadario. Acquisition of data: Brenner, Valdivia, Aiyathurai, Wong. Analysis and interpretation of data: Sun, Brenner, Valdivia, Dadario, Aiyathurai, Mashiach, Ginalis. Drafting the article: Brenner, Valdivia, Dadario, Aiyathurai, Mashiach, Ginalis, Quinoa. Critically revising the article: Brenner, Valdivia, Dadario, Aiyathurai, Mashiach, Ginalis, Quinoa. Reviewed submitted version of manuscript: Sun, Brenner, Valdivia, Dadario, Ginalis. Approved the final version of the manuscript on behalf of all authors: Sun. Statistical analysis: Brenner, Valdivia, Aiyathurai. Administrative/technical/material support: Sun, Brenner. Study supervision: Sun, Brenner, Ginalis.

Supplemental Information

Online-Only Content

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