Laser Ablation Therapy for Pediatric Patients with Intracranial Lesions in Eloquent Areas Chao-Hung Kuo^{1,3,4}, Abdullah H. Feroze¹, Sandra L. Poliachik^{5,6}, Jason S. Hauptman^{1,7}, Edward J. Novotny Jr^{2,6}, Jeffrey G. Ojemann^{1,7}

BACKGROUND: Laser interstitial thermal therapy (LITT) is an alternative, less-invasive, and, in some circumstances, effective treatment for patients with intracranial pathology including epilepsy and some tumors. For intracranial lesions in eloquent areas, resection by conventional craniotomy proves often to be a challenge, including in the care of pediatric patients. Herein, we reviewed our experience with magnetic resonance imaging (MRI)-guided LITT as treatment for pediatric patients with intracranial lesions in eloquent areas and evaluate neurologic function and clinical outcomes.

METHODS: We retrospectively reviewed consecutive patients with intracranial lesions in eloquent speech and motor areas who underwent MRI-guided LITT. Clinical evaluation, including neurologic function and neuropsychological testing, was conducted according to clinical considerations. MRI pre- and postoperative imaging was reviewed to compare the change of lesion size.

RESULTS: Five pediatric patients received MRI-guided LITT of intracranial lesions in eloquent cortex. One patient experienced complications secondary to MRI-guided LITT, but neither was discharged with a neurologic deficit.

CONCLUSIONS: For intracranial lesions in the eloquent cortex, conventional craniotomy with surgical resection is a challenge for neurosurgeons, especially pediatric patients. MRI-guided LITT provides a less-invasive and potentially effective option for treatment in the management of pediatric epilepsy and tumors.

INTRODUCTION

aser interstitial thermal therapy (LITT) was first introduced for the treatment of brain lesions in the 1990s.^{1,2} The basic concept of laser therapy relies on the use of thermal energy absorbed by target tissue or scattered adjacent tissue to induce cell death.^{3,4} With further advancements in magnetic resonance imaging (MRI) techniques, it is possible to obtain near-real-time estimates of heating with MRI-guided LITT.⁵ In the adult population, the clinical application of LITT has been used to treat glioma,⁶ recurrent metastases,^{6,7} and radiation necrosis,⁸ as well as patients with epilepsy caused by mesial temporal sclerosis^{9,10} and epidural spinal metastases with cord compression.¹¹

In pediatric patients, Tovar-Spinoza and Choi¹² reported an 11patient series including intracranial tumors treated by MRI-guided LITT. Tumor volume decreased significantly in the first 3 months after surgery and postoperatively at the 4- to 6-month follow-up. For deeper-seated lesions, LITT also provided a partially effective and less-invasive method for pediatric patients.¹³ Furthermore, pediatric epilepsy secondary to focal cortical dysplasia, mesial temporal sclerosis, or other intracranial lesions also demonstrated susceptibility to MRI-guided LITT.¹³

Intracranial lesion over functional areas of eloquence, such as those of sensorimotor cortex or language area, pose a challenge for surgical resection. Iyer et al.¹⁴ demonstrated a case report of a 65-year-old patient who underwent MRI-guided LITT for brain metastases over the motor strip. The result revealed complete obliteration of the lesion without neurologic deficits or evidence of tumor recurrence at follow-up. However, for pediatric patients, there is little literature demonstrating the application of MRIguided LITT for intracranial lesions in eloquent cortex. Herein, we highlight a case series of clinical findings, applications, and outcome of MRI-guided LITT in pediatric patients with intracranial lesions in eloquent areas.

Key words

- Complications
- Epilepsy
- Laser ablation
- LITT
- Pediatric

Abbreviations and Acronyms

CRW: Cosman—Roberts—Wells LITT: Laser interstitial thermal therapy MRI: Magnetic resonance imaging SEEG: Stereoelectroencephalography RT-TC: Radiofrequency thermocoagulation From the Departments of ¹Neurological Surgery and ²Neurology, University of Washington, Seattle, Washington; ³Department of Neurosurgery, Neurological Institute, Taipei Veterans General Hospital, Taipei, Taiwan; ⁴School of Medicine, National Yang-Ming University, Taipei, Taiwan; and Departments of ⁵Radiology and ⁶Neurology and ⁷Division of Neurosurgery, Seattle Children's Hospital, Seattle, Washington, USA

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ORIGINAL ARTICLE

CHAD-HUNG KUD ET AL.

PEDIATRIC LASER ABLATION

Table 1. Demographic Data of the Patients								
Case	Age, years	Sex	Symptoms	Location	Pathology	Complication		
1	15	Male	Simple partial seizure Right-limb paresthesia	Broca's area	Ganglioglioma	Nil		
2	15	Female	Epilepsy	Broca's area	Focal cortical dysplasia	Nil		
3	16	Female	Hemiparalysis aphasia	Sensorimotor area	Radiation necrosis	Nil		
4	18	Female	Epilepsy	Wernicke's area	Ganglioglioma	Nil		
5	12	Female	Seizure with right hand clenching	Sensorimotor area	Gliosis	Twist drill-related epidural hematoma		

METHODS

After institutional review board approval, we retrospectively reviewed a series of pediatric patients ranging from ages 6 to 18 years old from 2012 to 2018 who underwent surgical management by MRI-guided LITT for intracranial lesions at our institution. All clinical and radiologic data were retrospectively reviewed. Only those patients with MRI-confirmed intracranial lesions in eloquent regions, such as sensorimotor cortex or language areas,





resection, a known area of abnormality was left behind (B, white arrowhead) because of the suspected area's immediate proximity to Broca's area (C, black

has remained seizure-free after MRI-guided LITT treatment.

and using MRI-guided LITT as treatment were included for further study (n = 5).

Surgical Technique

All patients were placed under general anesthesia with endotracheal intubation. The Cosman-Roberts-Wells (CRW) frame was applied in usual standardized fashion. Preoperative noncontrast computed tomography after frame placement was performed and merged with recent brain magnetic resonance imaging. The target of LITT, trajectory, and entry points were selected by using Framelink software on Stealth station software (Medtronic, Minneapolis, Minnesota, USA). The calculated results were subsequently applied to the CRW frame and confirmed with use of the CRW Phantom base. Each patient was were then appropriately positioned in a MAYFIELD cranial fixation system (Integra LifeSciences Corporation, Cincinnati, Ohio, USA) and subsequently prepped and draped in the usual sterile fashion. Skin incision followed the entry point by the CRW coordination system, performed under local anesthesia. In cases requiring pathologic specimen, the biopsy needle trajectory was created, and biopsy performed before laser catheter placement (Visualase; Medtronic). The final laser catheter

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Figure 3. A 16-year-old patient was diagnosed with atypical teratoid/rhabdoid tumor over the left supratentorial region status post-resection and adjuvant chemoradiation with delayed right-sided hemiparesis and progressive aphasia. Magnetic resonance imaging (MRI) revealed a contrast-enhanced lesion in the region of the previous resection and radiation field (**A**) with biopsy confirmation of radiation necrosis.

MRI-guided laser interstitial thermal therapy treatment using 2 laser catheters applied thermal ablation (**B**). After surgery, the patient had improved aphasia, and strength in right-side extremities. Follow-up MRI revealed contraction of the residual primarily peripherally enhancing left posterior frontal-parietal periventricular abnormality (**C**).

positioning was checked by intraoperative fluoroscopy before the CRW frame removal.

After confirmation of catheter positioning, real-time thermometry was performed with 3-Tesla MRI with ablation-controlled Visualase workstation simultaneously under supervision by the neurosurgery team (J.O.). After treatment, postoperative contrast MRI and diffusion-weighted imaging confirmed successful ablation of the region of interest.

Postoperative Follow-up

All patients included within the case series were discharged within 24 hours after laser ablation and scheduled for routine



Figure 4. An 18-year-old patient with history of autism and intellectual disability presented with intractable seizure-like episodes. Electroencephalogram revealed left temporal abnormalities, and magnetic resonance imaging (MRI) revealed a contrast-enhancing mass with solid and cyst components (**A**, arrowhead). Based on clinical presentation related with anatomical location, the lesion was assumed to be neighboring dominant Wernicke's area. Stereotactic biopsy with MRI-guided laser interstitial thermal therapy was performed (**B**, *arrowhead*). Final pathology revealed a diagnosis of ganglioglioma.



secondary to enhancing left parietal mass (**A**). Functional magnetic resonance imaging demonstrated the proximity of the lesion to adjacent postcentral gyrus

(**B**, *arrowhead*). Before ablation, an iatrogenic epidural hematoma was noted at the site of the twist drill craniotomy (**C**) requiring evacuation after near-total ablation (**D**).

outpatient follow-up 6-12 weeks from procedure with repeat MRI.

RESULTS

There were 5 pediatric patients with eloquent intracranial lesions treated by MRI-guided LITT with respective demographics as illustrated in **Table 1**. One patient experienced complications secondary to MRI-guided LITT albeit neither was discharged with a neurologic deficit.

Case Illustrations

Case 1. A 15-year-old male patient had history of simple partial seizures with paresthesia over the right extremity since 2016. During his seizure workup, an enhancing intracranial lesion in the

left opecular region was found on MRI of the brain. There was interval growth between MRI examinations, with significant peritumoral edema (Figure 1A) and contrast enhancement (Figure 1B). Language functional MRI results revealed the lesion beneath the likely location of Broca's area (Figure 1C). Diagnosis with biopsy and treatment with laser ablation was performed.

A single treatment was given to ablate the lesion. The final pathologic report revealed ganglioglioma. At the postoperative 10month follow-up, MRI of the brain revealed reduced size and enhancement of the lesion (**Figure 1D**). The patient remains seizure-free after surgery with appropriate speech with normal naming, repetition and word-finding ability.

Case 2. A 15-year-old female patient with a history of medically intractable epilepsy for 8 years underwent invasive monitoring to

Table 2. Literature Summary of MRI-Guided Laser InterstitialThermal Therapy in Pediatric Patients					
Study	Patients				
Lewis et al., 2015 ²¹	Focal cortical dysplasia				
Pupklov at al. 2016^{13}	Hypothelemia and deep				

Buckley et al., 2016 ¹³	Hypothalamic and deep intraventricular lesions				
Tovar-Spinoza and Choi, 2016 ^{12,20}	Low-grade glioma				
Perry et al., 2017 ²²	Insular epilepsy				
Karsy et al., 2018 ²³	Corpus callosotomy				
Xu et al., 2018 ¹⁹	Hypothalamic hamartoma				
MRI, magnetic resonance imaging.					

reveal localization of left frontal onset. She underwent resection of anterior frontal lobe with pathology revealing focal cortical dysplasia, type IIa (Figure 2A). A known area of ictal onset was excluded from resection given its immediate proximity to Broca's area and concern for compromise of language (Figure 2B–C). Although the frequency of epilepsy was decreased after resection, the patient did not achieve complete freedom from seizure. Thus, after a discussion with the patient and parents, MRI-guided LITT was applied for the base of the sulcus underlying inferior frontal language sites, which were determined by previous direct cortical mapping (Figure 2D). The patient tolerated the procedure without complication and was discharged on postoperative day I without any language deficits.

Neuropsychological testing was performed before and 6 months after LITT. Preprocedure testing indicated intact abilities, with average intelligence and average academic screening performances, but low-average performance of verbal naming and fluency. After LITT, there were no decrements including preserved performance of verbal fluency and naming. The patient remains seizure free at 20-month follow-up after laser ablation.

Case 3. A 16-year-old female patient was diagnosed with atypical teratoid/rhabdoid tumor over the left supratentorial region and underwent craniotomy with gross total resection and adjuvant proton radiation therapy and chemotherapy 3 years before presentation. One year thereafter, she developed right-side hemiparesis and progressive aphasia. The MRI images revealed a contrastenhanced lesion in the region of the previous resection and radiation field (Figure 3A). Steroids were initially administered under suspicion of radiation necrosis but demonstrated limited efficacy. She presented for MRI-guided LITT for radiation necrosis, which was confirmed with biopsy in the same setting. The trajectories of 2 laser probes covered the subcortical frontoparietal radiation necrosis along the lateral ventricle (Figure 3B). She tolerated the procedure and by 6-week follow-up had made marked improvements in her degree of aphasia and strength in her right-side extremities. Follow-up MRI demonstrated contraction of the residual primarily peripherally enhancing left posterior frontal-parietal periventricular abnormality (Figure 3C).

Case 4. An 18-year-old female patient with a history of autism and mild developmental delay presented with intractable seizure-like

episodes. Electroencephalogram revealed left temporal abnormalities and MRI revealed a contrast-enhancing mass with solid and cystic components (Figure 4A). Based on her clinical presentation related with anatomical location, the lesion was assumed to be neighboring dominant Wernicke's area. Thus, stereotactic biopsy with MRI-guided LITT was performed (Figure 4B) without complications. Final pathology yielded ganglioglioma. The patient had uneventful postoperative followup with baseline fluency and comprehension.

Case 5. A 12-year-old female patient with new-onset seizures characterized by right hand clenching and secondary generalization was found to have a left parietal contrast-enhancing mass on further workup (**Figure 5A**). Given patient and family interest for surgical biopsy and the possibility of seizure freedom, MRI-guided LITT was pursued. Preoperative functional MRI confirmed ipsilateral left-sided language cortical activation within the dorsal lateral prefrontal cortex and posterior superior temporal lobe. Visual domain testing demonstrated bilateral occipital lobe activation remote from the lesion. Bilateral finger and toe sensorymotor cortex activation also was seen with functional MRI confirmation of the lesion of interest to sit adjacent to postcentral gyrus (**Figure 5B**).

Intraoperatively, biopsy and placement of the laser probe were performed without apparent complication or excessive bleeding. However, preablation MRI demonstrated a moderately sized epidural hematoma underneath the left parietal twist drill hole site (Figure 5C). Although there appeared to be mild displacement of the laser probe by the hematoma, it was deemed that based on test doses applied, the majority of the lesion could be ablated with this probe placement. Appropriate care was taken based on the monitoring of real-time ablation temperature to avoid thermal injury to postcentral gyrus adjacent to the anterior margin of the lesion. After ablation completion, the patient was returned to the operating room, where laser probe was removed and the epidural hematoma was evacuated.

The patient was extubated successfully and admitted to the neurosurgical floor without postoperative neurologic deficit. She was subsequently discharged home on postoperative day I. Pathology was notable for gliosis with mildly hypercellular white matter but without frank evidence of tumor. She remains seizure-free at I-month follow-up but in the setting of continuation of preoperative antiepileptic dosing (Figure 5D).

DISCUSSION

In this study, we presented 5 patents treated by MRI-guided LITT for intracranial lesion in eloquent areas. Clinical presentations included intractable epilepsy, hemiparesis, and aphasia caused by varying entities including tumor, dysplasia, and radiation necrosis. All patients had clinical improvement after treatment and uneventful follow-up.

In some situations, laser thermal therapy may avoid challenges of reaching deep lesions.⁷ Mohammadi et al.¹⁵ demonstrated a retrospective study including 34 patients who underwent MRIguided LITT for high-grade glioma that was difficult to access for total resection. The results revealed LITT to be an effective treatment, reporting an estimated 68% I-year overall survival rate and also demonstrating more complete coverage of tumor by



Figure 6. A 25-year-old patient with intractable epilepsy and hypothalamic hamartoma (**A**, arrowhead) who underwent magnetic resonance imaging (IMRI)-guided laser interstitial thermal therapy (**B**). The patient had postoperative left-side weakness and facial droop. Coronal view of brain MRI demonstrated the range of

intensity in diffusion-weighted sequencing revealed partial damage over internal capsule (\mathbf{D}). The transient symptoms resolved after a 24-hour burst of steroids were prescribed.

thermal damage area that could improve progression-free survival. In another study, 12 pediatric patients treated by MRI-guided LITT to target deep or inoperable lesions were retrospectively reviewed. Pathologies included hypothalamic hamartoma, subependymal giant cell astrocytoma, and third ventricular tumors. Laser thermal therapy provided an effective treatment for local tumor volume control with superior benefits of treatment compared with conventional resection surgery.¹³

For patients with intractable epilepsy caused by mesial temporal sclerosis, MRI-guided LITT provides advantages associated with minimal invasion, decreased length of stay, elimination of intensive care unit stay, and reduced procedure-related discomfort compared with conventional open resection.^{16,17} Especially in the case of dominant-hemisphere lesions, in terms of language testing, laser ablation may provide superior naming and recognition functions to anterior temporal lobectomy, although equivalent seizure efficacy is yet to be determined.¹⁸ For pediatric patients, MRI-guide LITT was applied for the treatment of epilepsy caused by different pathologies, including hypothalamic hamartoma,¹⁹ low-grade glioma,²⁰ and focal cortical dysplasia²¹ (**Table 2**). Moreover, the technique was reported and applied on a patient with Lennox–Gastaut syndrome and drug-resistant drop seizures for anterior two-thirds corpus callosotomy.²³ As demonstrated by Perry et al.,²² MRI-guided LITT also has

demonstrated promise in seizure reduction and good neurologic outcomes for intractable epilepsy secondary to insular regions.

Complications secondary to LITT have been reported in existing literature. Pruitt et al.²⁴ reported a series of 46 patients who underwent MRI-guided LITT. One patient had postoperative intracranial hemorrhage, which was secondary to vascular injury during laser catheter placement. Another patient suffered an epidural hematoma at the entry site. Neurologic deficit, including paraplegia, hemiparesis, and bilateral cranial nerve VI and VII palsies, caused by thermal damage occurred in 3 patients. In a series of 13 patients with mesial temporal lobe epilepsy, one suffered a homonymous hemianopia associated with insertion of laser catheter.25

In our own experience in adult patients, the key to limiting deficits secondary to iatrogenic injury is to stay within the lesion of interest. As an example, we report a 25-year-old patient with intractable epilepsy and an associated hypothalamic hamartoma (Figure 6A) who underwent MRI-guided LITT (Figure 6B). The course of catheter placement and laser ablation was performed without apparent difficulty. However, the patient had postoperative left side weakness and facial droop. Further evaluation of MRI in this instance suggested that the range of thermal ablation may have exceeded the boundaries of the lesion (Figure 6C), found to be too rostral with insult to the interface of the neighboring internal capsule (Figure 6D). Fortunately, the transient symptoms resolved after a 24-hour burst of steroids were prescribed.

Both MRI-guided LITT and stereoelectroencephalography (SEEG)-guided radiofrequency thermocoagulation (RF-TC), a technique to perform thermocoagulation via implanted SEEG electrodes, may target the seizure-onset foci as an epilepsy treatment.²⁶ In a study over 10 years, including 162 patients with drugresistant focal epilepsy, patients underwent Phase II invasive SEEG evaluation and subsequent RF-TC of the presumed epileptic foci.

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The results demonstrated more than one-half of patients had at least 50% decreased seizure frequency.27 Another study also pointed out that SEEG-guided RF-TC could double confirm epileptic foci and reduce the risk of mistreatment in patients with nonepileptic lesions.²⁸ However, there is no direct evidence comparing the treatment outcome of MRI-guided LITT with SEEG-guided RF-TC. Thus, for patients with intractable epilepsy caused by mesial temporal sclerosis, anterior temporal lobectomy was the gold standard for surgical resection. MRI-guided LITT was demonstrated to be an effective treatment to eliminate seizure frequency for this etiology.⁹ The quality of life for patients who underwent MRI-guided LITT was as good as of those who had under anterior temporal lobectomy.²⁹ For patients that underwent SEEG-guided RF-TC, none of the patients was seizure free at 12 months. The treatment effect of SEEG-guided RF-TC was not as effective as anterior temporal lobectomy.³⁰ More studies are needed to further investigate these outcomes.

There are limitations to the current study. As a limited retrospective case series of 5 patients, a significantly larger study is required before attempting to draw any generalizable conclusions Similarly, although all patients in this study recovered well without complication, long-term observation with more cases are necessary to adequately study as MRI-guided LITT as it becomes a more common approach for neurosurgical indications in both pediatric and adult populations.

CONCLUSIONS

For intracranial lesions in eloquent cortex, conventional craniotomy with surgical resection is a challenge for neurosurgeons, especially pediatric patients. MRI-guided LITT provides a less invasive and potentially effective option for treatment in the management of pediatric epilepsy and tumors but with risks that should be recognized.

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