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Review article

Laser neurosurgery: A systematic analysis of magnetic resonance-guided laser interstitial thermal therapies

Carlito Lagman [a], Lawrance K. Chung [a], Panayiotis E. Pelargos [a], Nolan Ung [a], Timothy T. Bui [a], Seung J. Lee [a], Brittany L. Voth [a], Isaac Yang [a,b,c,*]

[a] Department of Neurosurgery, University of California, Los Angeles, Los Angeles, CA, United States
[b] Jonsson Comprehensive Cancer Center, University of California, Los Angeles, CA, United States
[c] Department of Radiation Oncology UCLA, University of California, Los Angeles, Los Angeles, CA, United States

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ABSTRACT

Magnetic resonance-guided laser interstitial thermal therapy (MRgLITT) is a novel minimally invasive modality that uses heat from laser probes to destroy tissue. Advances in probe design, cooling mechanisms, and real-time MR thermography have increased laser utilization in neurosurgery. The authors perform a systematic analysis of two commercially available MRgLITT systems used in neurosurgery: the Visualase® thermal therapy and NeuroBlate® Systems. Data extraction was performed in a blinded fashion. Twenty-two articles were included in the quantitative synthesis. A total of 223 patients were identified with the majority having undergone treatment with Visualase ($n = 154$, 69%). Epilepsy was the most common indication for Visualase therapy ($n = 8$ studies, 47%). Brain mass was the most common indication for NeuroBlate therapy ($n = 3$ studies, 60%). There were no significant differences, except in age, wherein the NeuroBlate group was nearly twice as old as the Visualase group ($p < 0.001$). Frame, total complications, and length-of-stay (LOS) were non-significant when adjusted for age and number of patients. Laser neurosurgery has evolved over recent decades. Clinical indications are currently being defined and will continue to emerge as laser technologies become more sophisticated. Head-to-head comparison of these systems was difficult given the variance in indications (and therefore patient population) and disparate literature.

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1. Introduction

Laser neurosurgery has surpassed its 5th decade in existence. In 1965, Earle, Fine and colleagues used pulsed-ruby lasers to obliterate murine brains [1,2]. In 1966, Rosomoff and Carroll attempted focal brain tumor ablation in humans and demonstrated the unpredictable nature of low-energy pulsed ruby lasers [3]. In 1983, Brown and colleagues used a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser to perform focused thermal coagulation in brain tumor models [4]. These early experiments are a stark contrast to the focused laser ablation of splenium, to achieve total corpus callostomy, as recently described by Ho and colleagues [1,2,5]. The latter is only one example of lasers being used to transform traditional neurosurgical procedures.

Magnetic resonance-guided laser interstitial thermal therapy (MRgLITT) uses optical radiation from a laser probe to heat surrounding tissue and cause cellular damage. This novel minimally invasive modality employs thermography to monitor the localized temperature change induced by optical radiation (Fig. 1). Light energy is transmitted through fiberoptic probes and translated into thermal energy by a photo-thermal process. Photons from the laser applicator are launched into the surrounding tissue, scattered into the local field, and eventually absorbed by the tissue resulting in temperature increase. This rise in temperature initiates a cascade involving enzyme induction, protein denaturation, membrane dissolution, vessel sclerosis, and coagulative necrosis [6–9].

The clinical indications for MRgLITT are currently being defined. Ablation of deep-seated, eloquently situated brain tumors, epileptogenic foci, radiation necrosis (RN), cerebral edema, and cingulum (for chronic pain syndromes) have been described in the literature, but the long-term outcomes of such procedures are not fully elucidated. Novel indications for MRgLITT will continue to emerge as laser technologies improve and are developed. The two commercially available technologies used in neurosurgical practice are

* Corresponding author at: Department of Neurosurgery, University of California, Los Angeles, 300 Stein Plaza Suite 562, 5th Floor Wasserman Building, Los Angeles, CA 90095-6901, United States. Fax: +1 (310) 825 9385.
E-mail address: iyang@mednet.ucla.edu (I. Yang).

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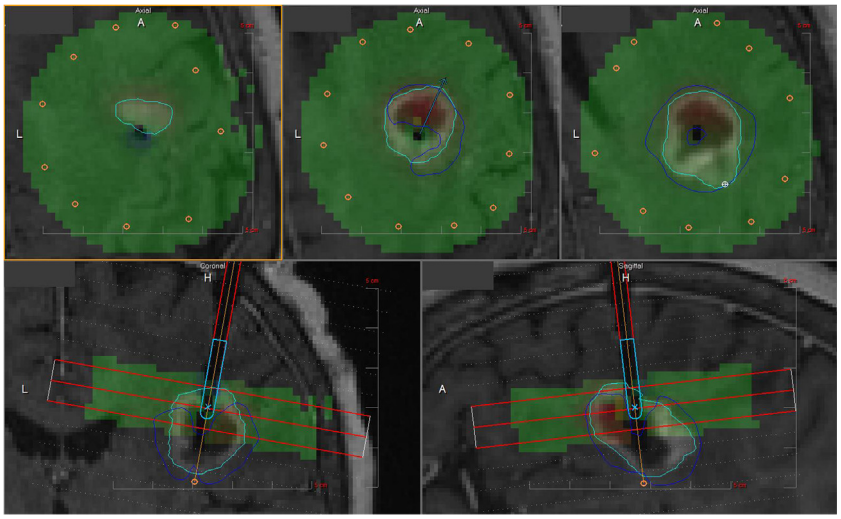

Fig. 1. Real-time thermography showing ablation zones with thermal-damage threshold (TDT) lines (teal and dark blue lines). Used by permission. The use of any NeuroBlate® System (Monteris Medical, Plymouth, MN) medical photo or image does not imply NeuroBlate® review or endorsement of any article or publication.

Table 1
Quick reference comparison of Visualase® thermal therapy system (Medtronic, Inc) and NeuroBlate® (Monteris Medical) System.

Component	Visualase	NeuroBlate
Patient interface platform		
Laser probe		
Composition	Silica within polymer sheath	Silica within Sapphire capsule
Diameter (mm)	1.65	2.2 and 3.3
Direction	Diffusing	Diffusing or directional
Output (W)	15 CW	Up to 12, pulsed
Wavelength (nm)	980 (diode)	1064 (diode)
Cooling mechanism	Saline	CO_2 with temperature feedback control
Probe driver	N/A	Advanced (APD) and Robotic (RPD)
Frame	Frame-based or frameless	Frame-based or frameless
MRI-compatible	Yes	Yes
Physician workstation		
Software	Medtronic	M*Vision Pro
Shut-off	Automatic* and manual	Automatic† and manual

* Automatic shut-off in the Visualase® System engages if a surgeon selected temperature limit is reached near a critical structure.
† Automatic shut-off in the NeuroBlate® System engages if patient movement in the MRI is detected.

the Visualase® thermal therapy system (Medtronic, Louisville, CO) and the NeuroBlate® System (Monteris Medical, Plymouth, MN). For comparative purposes, a quick reference guide summarizing the technical components of each system is provided in Table 1. The main differences between these two systems are probe design, probe advancement, cooling mechanism, and laser wavelength [8,10]. Both systems are MR/head frame compatible and utilize probe tip cooling to maximize target zone heating penetration by controlling temperatures at the probe-tissue interface.

The Visualase System comes with a diffusing laser applicator tip that is saline-cooled, has a maximum output of 15 W, and delivers continuous wave energy with a wavelength of 980 nm. This wavelength has a slightly higher absorption coefficient in both water and blood as compared to wavelengths of 1064 nm and can result in higher heating near the probe [8,11]. Probe tip cooling is provided by saline circulation. The patient interface platform is connected to the physician workstation through an Ethernet cable. The physician workstation displays the Medtronic proprietary software interface (Fig. 1) that allows for planning the trajectory, firing of the laser, and monitoring of thermal ablation maps modeled by the Arrhenius process, which uses temperature and time to calculate tumor cell kill [8,9,12–15] (see Figs. 3 and 4).

The NeuroBlate System offers both diffusing (FullFire™) and side-firing (SideFire™) directional laser delivery probes (LDPs) (Fig. 1) that are CO_2-cooled, have a maximum output of 12 W, and deliver pulsed energy at a wavelength of 1064 nm also using a diode laser. The NeuroBlate system uses a closed-loop, feedback controlled-cooling mechanism with a thermocouple embedded within the probe tip to measure internal probe temperature during cooling cycles. Pulsed energy delivery, along with low internal probe tip cooling temperatures, aid focal energy delivery for the directional probe. Automatic (APD) and robotic probe-drivers (RPD) are available and used to increase the fidelity of probe insertion. Similar to the Visualase® System, the NeuroBlate platform is connected by way of Ethernet to a physician workstation, which displays the M*Vision proprietary software interface (Fig. 2).

2. Methods

2.1. Search strategy, study selection, and data extraction

Publications describing the use of MRgLITT in neurosurgery were obtained from the PubMed database using a strategic combination of search terms and from Visualase and NeuroBlate webpages, on July 6, 2016. English-articles published between years 2006 and 2016 were considered. Patients undergoing MRg-LITT with the Visualase and NeuroBlate Systems were eligible,

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