

Albert H. Kim, MD\*  
 Steven Tatter, MD, PhD<sup>‡</sup>  
 Ganesh Rao, MD<sup>§</sup>  
 Sujit Prabhu, MD<sup>§</sup>  
 Clark Chen, MD, PhD<sup>¶||</sup>  
 Peter Fecci, MD, PhD<sup>#</sup>  
 Veronica Chiang, MD\*\*  
 Kris Smith, MD<sup>††</sup>  
 Brian J. Williams, MD<sup>§§</sup>  
 Alireza M. Mohammadi, MD<sup>¶¶</sup>  
 Kevin Judy, MD<sup>|||</sup>  
 Andrew Sloan, MD<sup>##</sup>  
 Zulma Tovar-Spinoza, MD<sup>\*\*\*</sup>  
 James Baumgartner, MD<sup>†††</sup>  
 Constantinos Hadjipanayis,  
 MD, PhD<sup>§§§</sup>  
 Eric C. Leuthardt, MD\*

\*Department of Neurosurgery, Washington University, St. Louis, Missouri;  
<sup>‡</sup>Department of Neurosurgery, Wake Forest University School of Medicine, Winston-Salem, North Carolina;

(Continued on next page)

#### Correspondence:

Eric C. Leuthardt, MD,  
 Washington University School of  
 Medicine,  
 Department of Neurological Surgery,  
 660 S. Euclid Avenue, Campus Box 8057,  
 St. Louis, MO 63110, USA.  
 Email: leuthardte@wustl.edu

Received, July 31, 2019.

Accepted, January 28, 2020.

Published Online, April 21, 2020.

© Congress of Neurological Surgeons  
 2020.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs licence (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits non-commercial reproduction and distribution of the work, in any medium, provided the original work is not altered or transformed in any way, and that the work is properly cited. For commercial re-use, please contact [journals.permissions@oup.com](mailto:journals.permissions@oup.com)

## Laser Ablation of Abnormal Neurological Tissue Using Robotic NeuroBlate System (LAANTERN): 12-Month Outcomes and Quality of Life After Brain Tumor Ablation

**BACKGROUND:** Laser Ablation of Abnormal Neurological Tissue using Robotic NeuroBlate System (LAANTERN) is an ongoing multicenter prospective NeuroBlate (Monteris Medical) LITT (laser interstitial thermal therapy) registry collecting real-world outcomes and quality-of-life (QoL) data.

**OBJECTIVE:** To compare 12-mo outcomes from all subjects undergoing LITT for intracranial tumors/neoplasms.

**METHODS:** Demographics, intraprocedural data, adverse events, QoL, hospitalizations, health economics, and survival data are collected; standard data management and monitoring occur.

**RESULTS:** A total of 14 centers enrolled 223 subjects; the median follow-up was 223 d. There were 119 (53.4%) females and 104 (46.6%) males. The median age was 54.3 yr (range 3-86) and 72.6% had at least 1 baseline comorbidity. The median baseline Karnofsky Performance Score (KPS) was 90. Of the ablated tumors, 131 were primary and 92 were metastatic. Most patients with primary tumors had high-grade gliomas (80.9%). Patients with metastatic cancer had recurrence (50.6%) or radiation necrosis (40%). The median postprocedure hospital stay was 33.4 h (12.7-733.4). The 1-yr estimated survival rate was 73%, and this was not impacted by disease etiology. Patient-reported QoL as assessed by the Functional Assessment of Cancer Therapy-Brain was stabilized postprocedure. KPS declined by an average of 5.7 to 10.5 points postprocedure; however, 50.5% had stabilized/improved KPS at 6 mo. There were no significant differences in KPS or QoL between patients with metastatic vs primary tumors.

**CONCLUSION:** Results from the ongoing LAANTERN registry demonstrate that LITT stabilizes and improves QoL from baseline levels in a malignant brain tumor patient population with high rates of comorbidities. Overall survival was better than anticipated for a real-world registry and comparative to published literature.

**KEY WORDS:** LITT, Laser ablation, Survival, Quality of life, Brain tumor

Neurosurgery 87:E338–E346, 2020

DOI:10.1093/neuros/nyaa071

www.neurosurgery-online.com

Laser interstitial thermal therapy (LITT) with magnetic resonance imaging (MRI) guidance has been used for more than 10 yr to treat patients with glioblastoma (GBM), brain metastases, gliomas, radiation necrosis, and epilepsy.<sup>1</sup> Since 2015, over 700 patient

**ABBREVIATIONS:** ADL, activities of daily living; CI, confidence interval; EQ-5D, EuroQoL 5-dimensional; FACT-Br, Functional Assessment of Cancer Therapy-Brain; GBM, glioblastoma; IADL, instrumental ADL; IRB, institutional review board; KPS, Karnofsky Performance Score; LAANTERN, Laser Ablation of Abnormal Neurological Tissue Using Robotic NeuroBlate System; LITT, laser interstitial thermal therapy; MRI, magnetic resonance imaging; QoL, quality of life; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; VAS, visual analog scale; WHO, World Health Organization

Neurosurgery Speaks! Audio abstracts available for this article at [www.neurosurgery-online.com](http://www.neurosurgery-online.com). Supplemental digital content is available for this article at [www.neurosurgery-online.com](http://www.neurosurgery-online.com).

experiences have been described in peer-reviewed literature of laser ablation or “LITT” for primary and metastatic brain tumors (PubMed search 2019). However, commercial use of LITT is estimated to be over 5000 procedures at approximately 150 sites in the USA.

Laser Ablation of Abnormal Neurological Tissue Using Robotic NeuroBlate System (LAANTERN) is unique relative to previous studies because it is a prospective, multicenter Real World Evidence registry enrolling up to 1000 subjects who undergo the NeuroBlate (Monteris Medical; Plymouth, Minnesota) LITT procedure. The multicenter nature of the registry provides a more generalized description of utilization and outcomes vs most existing publications, which are limited to single institutions. In addition, the prospective nature of data collection allows reporting on metrics that are difficult to accurately capture retrospectively, such as safety, cognitive assessment, and quality of life (QoL). Initial 30-d safety experiences from LAANTERN showed low rates of complications, which were similar to brain needle biopsy.<sup>2,3</sup> LAANTERN is in its third year of enrollment and has approximately 500 subjects enrolled. Here we present the 12-mo survival and QoL outcome experiences for over 200 subjects undergoing LITT for brain tumors. Measurement of QoL outcomes is an important aspect of the registry because patients with brain tumors often experience cognitive dysfunction associated with the underlying disease and treatments, including surgery, radiation, and chemotherapy.<sup>4</sup> Additionally, repeat surgeries are more likely to result in the worsening of QoL.<sup>5</sup> These data will be useful in future study comparisons and set a benchmark for what QoL outcomes could be expected after LITT for brain tumor.

## METHODS

### Study Design and Participants

This multisite, prospective registry enrolled subjects across 20 centers. Details pertaining to the LAANTERN registry were previously described.<sup>2,3</sup> This real-world registry includes LITT patients who consent to provide follow-up data; there are no other exclusion criteria for participation in the study. Standard data management and monitoring procedures with source verification were applied to ensure accurate entry of deidentified data into a standardized, part 11 compliant electronic database. The institutional review boards (IRBs) of all participating

(Continued from previous page)

<sup>5</sup>Department of Neurosurgery, University of Texas MDA Cancer Center, Houston, Texas; <sup>6</sup>Department of Neurosurgery, University of California San Diego, San Diego, California; <sup>7</sup>Department of Neurosurgery, University of Minnesota, Minneapolis, Minnesota; <sup>8</sup>Department of Neurosurgery, Duke University Medical Center, Durham, North Carolina; <sup>9</sup>Department of Neurosurgery, Yale University, New Haven, Connecticut; <sup>10</sup>Department of Neurosurgery, Barrow Neurological Institute, Phoenix, Arizona; <sup>11</sup>Department of Neurosurgery, University of Louisville, Louisville, Kentucky; <sup>12</sup>Neurological Institute, Cleveland Clinic Foundation, Cleveland, Ohio; <sup>13</sup>Department of Neurological Surgery, Thomas Jefferson University, Philadelphia, Pennsylvania; <sup>14</sup>Department of Neurological Surgery, University Hospitals Cleveland Medical Center, Cleveland, Ohio; <sup>15</sup>SUNY Upstate Medical University, Syracuse, New York; <sup>16</sup>Florida Hospital Advent Health, Orlando, Florida; <sup>17</sup>Department of Neurosurgery, Icahn School of Medicine at Mount Sinai, New York, New York

centers reviewed and approved the study protocol, and informed consent was obtained for all subjects via IRB-approved forms. The LAANTERN study was designed to identify thermocoagulation- or surgery-related complications that occur at >0.1% frequency, with the target sample size of 1000 subjects commonly used in observational studies aiming to characterize the safety of interventions.<sup>6</sup> This manuscript was prepared in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

This analysis includes 223 subjects enrolled in LAANTERN who met the following criteria: procedure date on or prior to May 31, 2018 (allowing for approximately 12-mo follow-up), enrollment occurred at a US center, and patient had at least 1 brain neoplasm ablated during the index procedure (inclusive of tumor with or without radiation necrosis).

### Surgical Management

All centers used the FDA-cleared NeuroBlate System (Monteris Medical), as previously described.<sup>7</sup> The system employs a robotically controlled 1064-nm laser probe and uses MRI thermometry to inform the surgeon of predicted zones of protein denaturation and cell death. Surgical technique, preplanning, and biopsy at the time of LITT were performed as standard of care at each participating institution.

### Outcome Measures

LAANTERN collects disease-specific outcome measures, including adverse events/complications, overall survival, and patient QoL. Baseline, procedural parameters, and follow-up were collected per standard of care practices at each institution. Overall survival was estimated using the Kaplan-Meier method.<sup>8</sup> QoL measures were assessed at baseline and follow-up visits (1, 3, 6, and 12 mo). QoL questionnaires and measurements commonly used in the brain-tumor population were selected for use in LAANTERN to assess the change in patient condition. When assessing the change in QoL, it is common to include a disease-specific questionnaire (Functional Assessment of Cancer Therapy-Brain [FACT-Br]) in addition to a generic questionnaire (EuroQol 5-dimensional [EQ-5D]). Questionnaires were provided for all institutions in the study via a third-party licensing agreement and were previously validated following principles of test construction and evaluation.<sup>9-11</sup> FACT-Br yields information about total QoL for adults with malignant brain tumors and is measured on a scale of 0 to 200, with 200 being best overall well-being.<sup>9</sup> It includes information about the dimensions of physical, social/family, emotional, functional well-being, and disease-specific concerns. The EQ-5D version 3 L is used worldwide to measure patient-reported outcomes for the valuation of health.<sup>12</sup> The 5 dimensions of EQ-5D include mobility, self-care, usual activities, pain/discomfort, anxiety/depression, and a visual analog scale (VAS) that assesses the patients' feelings of “best possible health state.” The overall health state ranges from 1 “full health” to 0 “worst health.” Karnofsky Performance Scale (KPS) index was assessed by the physician on a scale of 0 to 100, with 100 being functionally healthy and having no symptoms of disease.<sup>13</sup>

### Statistical Analysis

Statistical analysis was performed as described previously.<sup>2,3</sup> The Cox proportional hazard model was used for correlative analyses using a lesion size >3 cm in maximum diameter. A *P* value < .05 was considered to indicate statistical significance. Subjects with incomplete data were excluded from pertinent categorical analyses. Per-patient analyses were performed for all longitudinal assessments (KPS and QoL).

**TABLE 1. Baseline and Procedural Characteristics**

Characteristics and measures	All patients (n = 223)	Metastatic tumor (n = 92)	Primary tumor (n = 131)
Age, mean (SD), yr	54.3 (16.5)	59.6 (12.4)	50.6 (17.9)
Female, no. (%)	119 (53.4)	59 (64.1)	60 (45.8)
<b>Race/ethnicity, no. (%)<sup>a</sup></b>			
White	199 (89.6)	77 (84.6)	122 (93.1)
Black/African American	15 (6.8)	10 (11)	5 (3.8)
Asian	3 (1.4)	1 (1.1)	2 (1.5)
Other/unknown	6 (2.7)	4 (4.3)	2 (1.5)
<b>Trajectories, no. (%)<sup>b</sup></b>			
Single	217 (93.9)	92 (96.8)	125 (91.9)
Multiple	14 (6.1)	3 (3.2)	11 (8.1)
Tumors ablated, median [range]	1.0 [1-2]	1.0 [1-2]	1.0 [1-2]
Burr holes, median [range]	1 [1-4.0]	1 [1-4]	1 [1-2]
Blood loss, mean (SD), mL	12.3 (36.9)	20.5 (53.8)	7.0 (18.3)
Total procedure time, mean (SD), min	193.1 (80.9)	185.3 (64.2)	198.8 (91.1)

<sup>a</sup>Hispanic/Latino ethnicity indicated in 5 patients with primary tumor (3.8%).

<sup>b</sup>Patients may have multiple lesions ablated during the procedure; data reported per lesion. The maximum number of trajectories per lesion was 2.

## RESULTS

### Participants and Demographic Data

Of the 223 subjects enrolled at 14 centers with 231 ablated tumors, there were 104 males and 119 females with a mean age of 54.3 yr (Table 1; **Figure. Patient Flow Diagram, Supplemental Digital Content**). The cohort included 10 pediatric patients (<18 yr of age). Average body mass index was 45.2. In total, 72.6% of patients had a baseline comorbidity. A total of 95 patients (42.6%) were current or former smokers, 17 (7.6%) had a prior pulmonary/arterial/air embolism, and 33 (14.8%) had a history of heart disease. Patients with metastatic brain tumors had statistically higher rates of immune system disease (10.9%;  $P = .034$ ), pulmonary disease (48.9%,  $P < .0001$ ), and hypertension (45.7%,  $P = .038$ ) than the primary tumor group. Abnormal gait and reduced mobility were reported in 26% of patients.

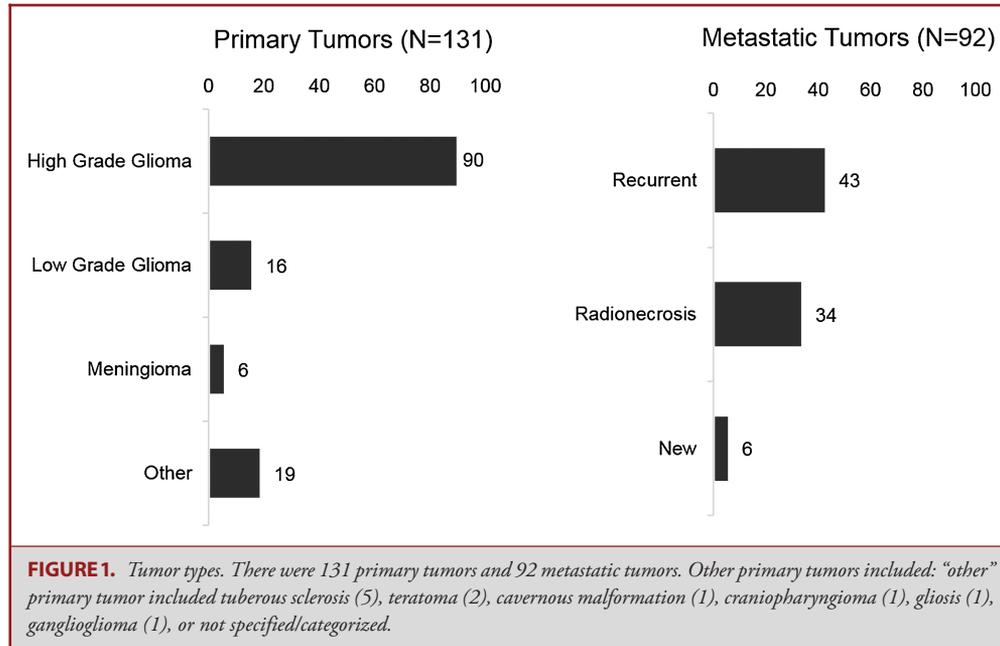
In total, 73.6% of patients had baseline neurological symptoms ranging from subjective (patient reported) (20%), objective (observable in clinic) but mild (43.6%), objective allowing activities of daily living (ADL), but not instrumental ADL (IADL) (5%), and objective restricting ADL and IADL (5%). History of seizures and current moderate to extreme anxiety/depression was reported in 44.4% and 45% of patients, respectively. A total of 90 patients (40.3%) were on a steroid at baseline (32.2% of which was dexamethasone). Baseline anticonvulsant use was reported as 39% levetiracetam, 2.69% lacosamide, 2.24% lamotrigine, 0.45% phenytoin, 0.45% carbamazepine, and 12% others. At baseline, 14.5% of patients with primary brain tumors were given temozolomide and 35.9% of patients with metastatic brain tumors were on chemotherapy for systemic or brain disease. Bevacizumab was used in 3.6% of patients within 60 d prior to

the procedure. The median baseline KPS was 90.0 [50.0, 100.0], with 15 patients having a KPS score below 70.

LITT indications included primary brain tumor (131; 58.7%) or metastatic brain tumor (92; 41.3%) (Figure 1). Primary brain tumors were predominantly gliomas (80.9%), and WHO (World Health Organization) grade classifications were 15.1% (16/106) low grade (I and II) and 84.9% (90/106) high grade (III and IV). Of the 90 high-grade gliomas, 30 were newly diagnosed. Nearly all metastatic lesions (92.4%) were previously treated, and the LITT procedure was indicated for tumor recurrence (50.6%), radiation necrosis (40%), or unknown (9.4%). Stereotactic radiosurgery was used more frequently (82%) than whole brain radiation (7.8%) or local radiation therapy with a fractionated treatment schedule (4.2%) in patients with metastatic tumors. Of the patients with a prior surgical treatment that occurred within the last 2 yr, resections were 50.5% gross total, 15.2% near gross total, 13.1% subtotal, 18.2% biopsy/partial, and 3% unknown. Overall, 24.9% of the tumors undergoing LITT were considered difficult to access through open surgery and 58.6% of physicians stated LITT was performed because a minimally invasive procedure was preferred by the patient.

### Procedural Outcomes and Hospitalization Data

Procedural experiences are described in Table 1, and the results remain consistent with previous hospitalization and safety publications from the LAANTERN study.<sup>2,3</sup> Ablated tumors were primarily supratentorial (frontal 41.6%, parietal 19% temporal 15.2%, occipital 8.2%, corpus callosum 2.6%, thalamus 8.7%, and deep nuclei 0.4%). However, 4.4% of tumors were in/near the cerebellum (3.5%) or brainstem (0.9%). The average lesion volume was  $7.1 \pm 14.7 \text{ cm}^3$ . Greater than 90% tumor ablation

**TABLE 2. Hospitalization and Health Economics**

Characteristics and measures	All patients (n = 223)	Metastatic tumor (n = 92)	Primary tumor (n = 131)
Length of hospital stay, median (range), h	33.4 (13–733)	32.9 (13–733)	33.8 (20–695)
Length of ICU <sup>a</sup> stay, median (range), h	18.8 (0–672)	2.7 (0–336)	21.7 (0–672)
Post-LITT discharge location, no. (%)			
Home	186 (83.4)	77 (83.7)	109 (83.2)
Acute care hospital	5 (2.2)	1 (1.1)	4 (3.1)
Rehab facility	20 (9.0)	6 (6.5)	14 (10.7)
Skilled nursing facility	9 (4.0)	7 (7.6)	2 (1.5)
Hospice	0 (0)	0 (0)	0 (0)
Other	3 (1.3)	1 (1.1)	2 (1.5)
LITT/surgery-related serious adverse events, no. (%)	4 (1.8)	2 (2.2)	2 (1.5)
Repeat hospitalization within 30 d of procedure, no. (%)	4 (1.8)	2 (2.2)	2 (1.5)

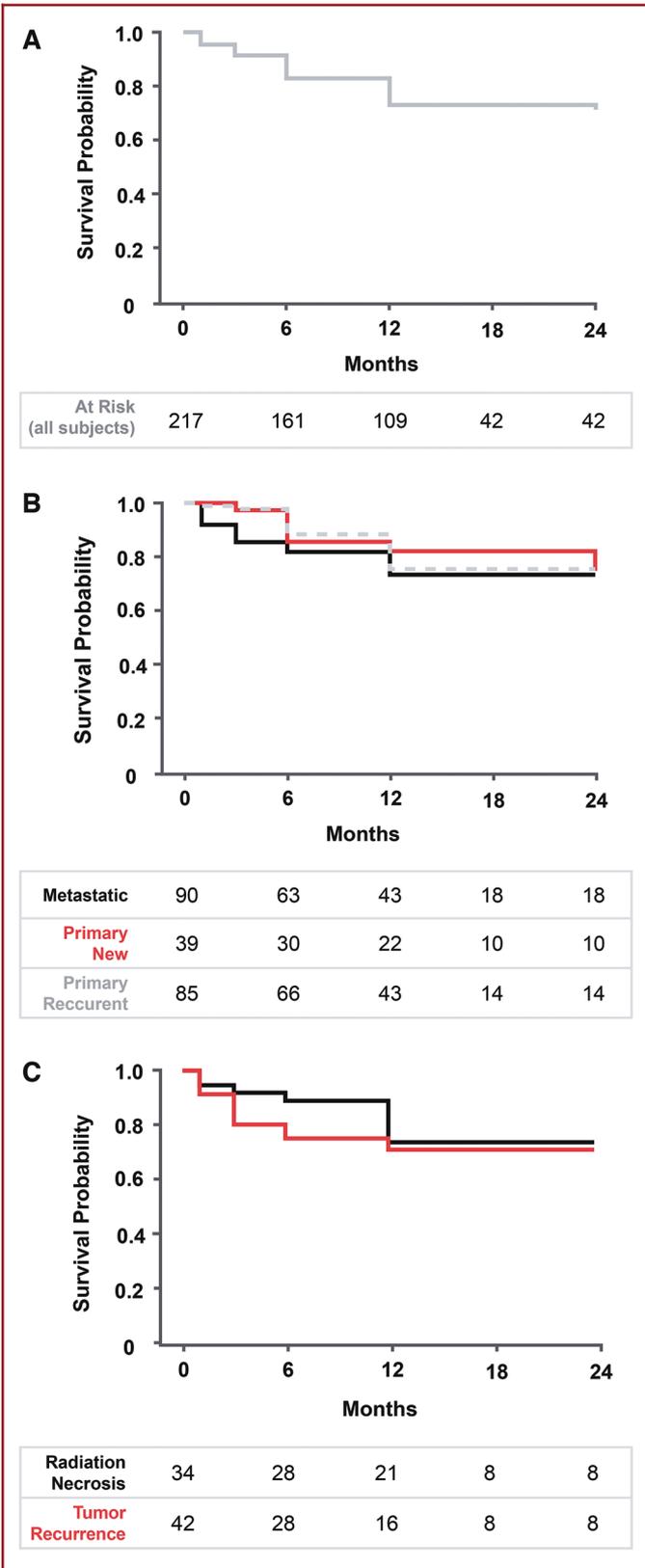
<sup>a</sup>Intensive care unit (ICU); some institutions require ICU stay for all neurosurgery procedures.

was reported by the operating physician in 77.7% of procedures. Hospitalization and safety experiences are presented in Table 2. Most patients were discharged to home (83.4%) after the procedure following a median 33.4-h hospital stay (range 12.7–733.4 h) with some extended stays due to planned staged procedures rather than adverse events; however, one 30-d stay was related to a procedurally related adverse event of left hemiplegia. Only 9% of patients were discharged to a rehab facility and 4% to a nursing facility. There were 24/223 (10.7%) patients with adverse events that were considered possibly/definitely related to the brain surgery or thermocoagulation; only 4/223 (1.8%) of these were considered serious or resulted in rehospitalization within 30 d of the procedure. Occurrence of procedurally related

adverse events was not correlated to lesion size ( $P = .858$ ). There was one death within 30 d that was not related to the LITT procedure. Steroid use increased from 40.3% to 64% within 30 d of the procedure; however, there were only 2 patients (0.9%) with edema-related adverse events attributable to surgery.

### Main Results: QoL Outcomes and Overall Survival

The median length of follow-up at the time of this report was 223 d. Figure 2 displays the results of the Kaplan-Meier Product Limit analysis and provides raw counts of the available data analyzed at each study interval. The 1-yr estimated survival rate is 73%, with a 95% CI of 65.3% to 79.2%. There was no significant difference observed between patients with metastatic or primary



**FIGURE 2.** Overall survival by tumor type. Kaplan-Meier curves estimate overall survival through 24-mo follow-up. **A**, Survival in the overall tumor cohort was 73.0% at 12 mo. **B**, Survival for patients with primary vs metastatic tumors was 74.6% and 70.7% at 12 mo, respectively ( $P = .2581$ ). There was no difference in 12-mo survival in patients with new vs recurrent primary tumors ( $P = .4831$ ). **C**, Survival at 1, 3, 6, 12, and 24 mo for patients with metastatic brain tumor recurrence was 90.5%, 78.3%, 72.7%, 68.1%, and 68.1% vs for patients with radiation necrosis due to metastatic disease was 94.1%, 91.1%, 87.8%, 71.1%, and 71.1%. These differences trended toward favoring better early survival for patients with radiation necrosis; however, the differences were not statistically significant ( $P > .05$ ).

**TABLE 3. Change in KPS (Follow-up to Baseline)<sup>a</sup>**

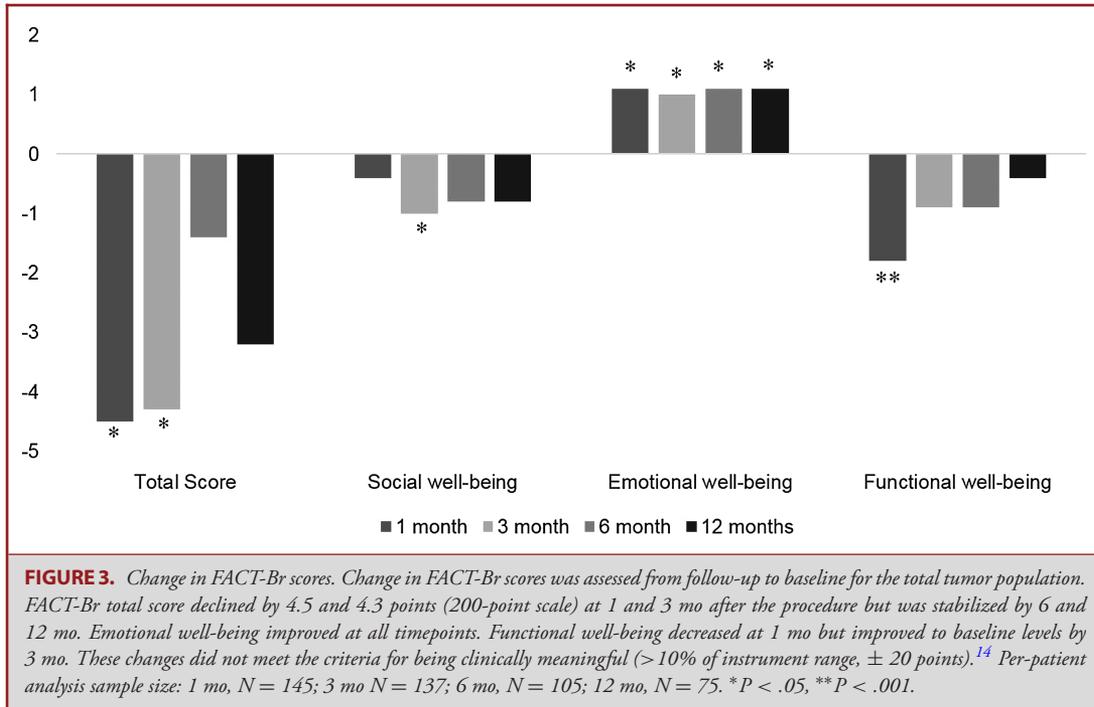
Timepoint (mo)	All patients (n = 140)	Metastatic tumor (n = 61)	Primary tumor (n = 79)
Baseline score	85.5 (12.8)	84.7 (14.0)	86.2 (11.8)
1	-5.7 (12.1)	-6.1 (12.6)	-5.4 (11.7)
3	-7.0 (13.2)	-5.8 (13.7)	-7.8 (12.9)
6	-7.5 (13.0)	-5.4 (13.8)	-9.1 (12.2)
12	-10.5 (19.6)	-7.3 (18.6)	-13.2 (20.3)

<sup>a</sup>Reported as mean (SD), per-patient analysis. Change at 1, 3, 6, and 12 mo;  $P < .0001$ . KPS was collected per standard of care and is not conducted for all patients either due to being not done or for pediatric patients where the assessment is not age appropriate.

tumors in overall survival ( $P = .32$ , log-rank test). However, at 1 and 3 mo there was a statistical difference in estimated survival favoring the primary tumor cohort (98.4% vs 91.1%,  $P = .01$  and 96.7% vs 84%  $P = .0012$ , respectively). Diagnosis with recurrent primary tumors >3 cm in maximum diameter resulted in an increased risk of mortality despite a complete ( $P = .014$ ) or near-complete ablation ( $P = .007$ ). The estimated survival rate of patients with high-grade gliomas at 12 mo was 68.55% (CI 54.96%, 78.81%). There was no difference in the estimated overall survival between patients with recurrent metastatic brain tumor who had recurrence (50.6%) vs radiation necrosis (40%) ( $P = .41$ , log-rank test). After it was determined that the long-term survival between the metastatic and primary tumor cohort was comparable, data were pooled for analyses of QoL outcomes.

KPS declined for the overall tumor cohort at follow-up visits 1, 3, 6, and 12 mo by an average of 5.7 to 10.5 points;  $P < .0001$  (Table 3). There was no (0) change in median score at 1, 3, and 6 mo; however, there was a median decrease of 10 points at 12 and 24 mo. In a categorical analysis, 50.5% had no change or an improvement in KPS at 6 mo. There were no significant differences between the primary and metastatic patient populations.

FACT-Br and EQ-5D patient-reported questionnaire scores were assessed at 1, 3, 6, and 12 mo post-LITT procedure. The baseline median FACT-Br and EQ-5D scores were 141.3 [54.0, 199.0] and 0.8 [0.1, 1.0], respectively. The overall patient population had an average decline of 4.5 and 4.3 points (on a scale



of 200) in overall FACT-Br scores at 1 and 3 mo; however, there was no significant change at 6 and 12 mo compared to baseline (Figure 3). These changes did not meet the criteria for being clinically meaningful (>10% of the instrument range; 20 points).<sup>14</sup> Emotional well-being improved by an average of 1 point (all timepoints). There were no differences between FACT-Br scores reported in the primary and those reported in metastatic patient populations. EQ-5D general questionnaire scores reported similar trends with no differences between patients with metastatic or primary tumors. EQ-5D subscores for mobility, self-care, and usual activities improved and scores for pain/discomfort, anxiety depression, and VAS were stable (Table 4). The overall EQ-5D index score declined -0.1 points from an average baseline score of 0.8 ± 0.2, possibly driven by a nonstatistically significant change in VAS score (baseline of 66.3 ± 24.4; range 0-100). Figure 4 summarizes the results of the FACT-Br and EQ-5D assessments.

**TABLE 4. Change in EQ-5D (Follow-up to Baseline)<sup>a</sup>**

	1 mo (n = 145)	3 mo (n = 132)	6 mo (n = 101)	12 mo (n = 70)
EQ Index total score	-0.1 (0.2)	-0.1 (0.2)	0.0 (0.2)	-0.1 (0.2)
P value	<b>.0009</b>	<b>.0014</b>	.1327	<b>.0020</b>
<b>EQ-5D Subscores</b>				
Mobility	0.2 (0.6)	0.2 (0.5)	(0.6)	0.1 (0.6)
P value	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>.0105</b>	<b>.0404</b>
Self-care	0.1 (0.5)	0.2 (0.5)	0.2 (0.5)	0.2 (0.6)
P value	<b>.0006</b>	<b>.0002</b>	<b>.0005</b>	<b>.0036</b>
Usual activities	0.3 (0.6)	0.2 (0.6)	0.2 (0.6)	0.2 (0.6)
P value	<b>&lt;.0001</b>	<b>&lt;.0001</b>	<b>.0106</b>	<b>.0029</b>
Pain/discomfort	0.0 (0.6)	0.1 (0.6)	0.0 (0.5)	0.1 (0.5)
P value	.7865	.1745	.7169	.0882
Anxiety/depression	0.0 (0.6)	-0.1 (0.6)	-0.1 (0.6)	0.1 (0.6)
P value	.8870	.2497	.1143	.3395
VAS	-0.7 (21.9)	-1.4 (23.7)	-0.0 (21.6)	3.8 (18.1)
P value	.6980	.5068	.9816	.0818

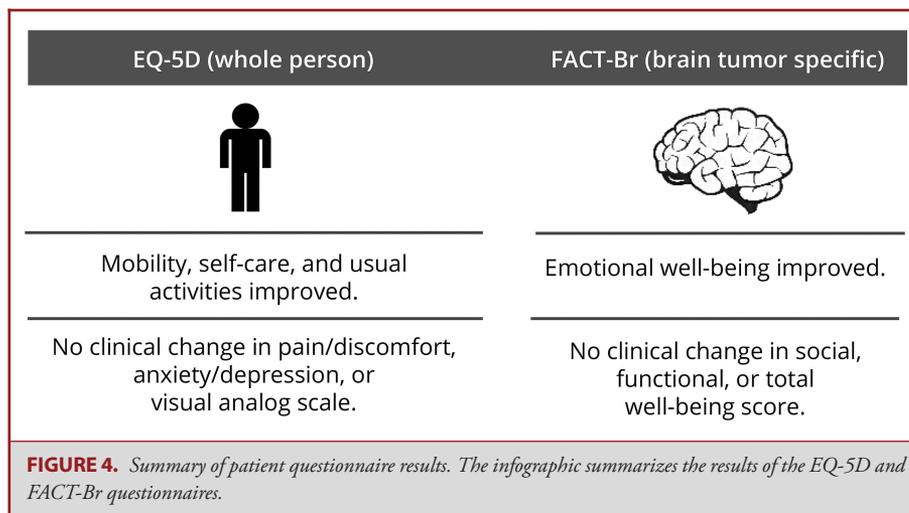
<sup>a</sup>Reported as mean (SD).  
VAS on a scale of 1 to 100 with 100 being “best possible health today.”

**DISCUSSION**

**Key Results and Interpretation**

The safety profile for the LITT procedure remains consistent with or favorable to previous publications<sup>1,3,15,16</sup> and is similar to the 5% to 7% complication rate reported for stereotactic biopsy.<sup>17-19</sup> LITT is a surgical tool, and in the appropriate-use scenarios, it can achieve a similar extent of resection to craniotomy with a lower risk of complications.<sup>20</sup> Length of stay, readmission rates, and cost were also favorable to those reported in the literature for craniotomy.<sup>21-24</sup>

Overall survival in the total cohort of patients was consistent with prior publications in similar patient populations. In the recurrent brain metastases population, 26-wk overall survival and progression-free survival after a LITT procedure ranged from 52% to 79% and 27% to 76%, respectively.<sup>25-28</sup> This is in a comparable range reported by Barnholtz-Sloan et al<sup>29</sup> from a 2367 patient study indicating that the median survival from time



of diagnosis for patients with brain metastases is 19.4 wk. LITT has been successfully used in cases of radiation necrosis occurring in both primary and metastatic tumors, and results reported from this study are consistent with previous literature.<sup>26,28,30</sup> Up to 68.6% of patients develop radiation necrosis 9-mo postirradiation,<sup>31</sup> and ablation could be more cost-effective than Avastin or have fewer side-effects than increasing doses of steroids. In fact, recent data also indicate that LITT allows patients to wean off steroids within 1 mo of the procedure just as would be expected for an open craniotomy.<sup>25</sup>

Trials in newly diagnosed GBM report the median overall survival as 15.8 mo for a complete/partial resection, and retrospective studies after LITT report similar results.<sup>32,33</sup> Of note, the overall survival in LAANTERN (and the majority of LITT publications) is calculated from the date of LITT procedure rather than date of original diagnosis (which is typically used in resection trials). In addition, LITT is more frequently performed at the time of recurrence or second recurrence in primary and metastatic brain tumors, indicating that this population is further along in their disease than comparable surgical cohorts. Despite these differences, outcomes in this study are still favorable.

Similar to the extent of resection,<sup>34</sup> the extent of ablation continues to be an important factor in predicting outcomes—publications on the primary tumor<sup>33,35</sup> and metastatic tumor populations<sup>25,26</sup> find that a complete/near-complete ablation is predictive of lower instance of disease-specific death and progression.<sup>35</sup> With that, gliomas are unlikely to achieve a true complete resection since these tumors are diffuse, lacking well-defined brain-tumor interfaces, and are heterogeneous.<sup>36-38</sup> Initial trends in this study show that larger gliomas (>3 cm diameter) with incomplete ablation may have a greater residual tumor burden that impacts the rate of progression and overall survival. For patients with residual tumor, more aggressive medical management with chemotherapy and radiation may be considered.<sup>39</sup>

FACT-Br and EQ-5D data indicate that QoL is stabilized post-LITT and that mobility, self-care, and ability to participate in usual activities are improved. To our knowledge, this is the first report of EQ-5D results in a population undergoing LITT. The results in this study showed better than anticipated outcomes in a population of patients with brain tumors who had mostly recurrent disease and a short life expectancy. Although the EQ-5D questionnaire is not brain tumor-specific, it is well established and requires only a few minutes to complete.<sup>40,41</sup> EQ-5D scores are impacted by factors such as KPS, tumor grade, and recurrence status in the GBM population, and symptom burden has a significant impact on health status.<sup>42</sup> Baseline EQ-5D scores in LAANTERN were similar to those reported in other studies of patients with brain tumors ( $0.8 \pm 0.2$  vs  $0.83 \pm 0.16$ , respectively).<sup>43</sup> Average scores for mobility, self-care, and usual activities improved at all follow-up timepoints, and other subscores were stable. It should be noted that there is no consensus regarding the minimally important difference in EQ-5D scores.<sup>44</sup> Meaningful clinically important change is thought to range from 0.03 to 0.52 and estimates for the glioma population range from 0.13 to 0.15.<sup>45,46</sup> While the overall EQ-5D scores in LAANTERN declined slightly, this was driven by a nonsignificant variability in the VAS subscores and was unlikely to be clinically meaningful.

FACT-Br is commonly used to assess QoL in patients with primary tumors; however, it is becoming a popular tool to assess QoL for the brain metastases population.<sup>41</sup> This analysis did not show differences in FACT-Br scores between the metastatic and primary tumor populations, and FACT-Br scores were stable after the LITT procedure. In a different LITT study of the recurrent metastatic population by Ahluwalia et al,<sup>26</sup> a decline in QoL was correlated with an increased likelihood of death or being moved to hospice; therefore, preservation of QoL may be a predictor for improved survival in the metastatic patient population. Various studies of QoL in the recurrent glioma population have shown

that FACT-Br scores do not add prognostic value, but the presence of cognitive impairment is associated with poor survival.<sup>47,48</sup>

### Limitations

Because LAANTERN is a standard of care registry, data are not available for all timepoints or patients. This is a limitation of the registry and something all standard-of-care studies are impacted by; however, the demographics and attrition are representative of patients and experiences described in other publications.<sup>49,50</sup>

### CONCLUSION

Data in this first outcome analysis of the LAANTERN registry show that the overall survival in this population of patients with brain tumors reflects similar if not improved outcomes to those previously reported for a population of patients with mostly recurrent disease. Patient-reported QoL outcomes were also stabilized and better than expected in a population with malignant brain tumors. Enrollment is ongoing, and further subanalyses of these data are planned and are likely to yield additional learning regarding patient selection and management.

### Disclosures

The LAANTERN registry is sponsored by Monteris Medical Inc Clinical-Trials.gov study ID #NCT02392078. Nissa Mollema, PhD, of Monteris Medical, assisted with the preparation of this manuscript. Drs Leuthardt, Mohammadi, Tovar-Spinoza, Chiang, Fecci, Williams, and Baumgartner are consultants for Monteris Medical Inc. Dr Smith is a consultant for Monteris Medical Inc and Medtronic Inc.

### REFERENCES

- Kamath AA, Friedman DD, Hacker CD, et al. MRI-guided interstitial laser ablation for intracranial lesions: a large single-institution experience of 133 cases. *Stereotact Funct Neurosurg.* 2017;95(6):417-428.
- Rennert RC, Khan U, Tatter SB, et al. Patterns of clinical use of stereotactic laser ablation: analysis of a multicenter prospective registry. *World Neurosurg.* 2018;116:e566-e570.
- Rennert RC, Khan U, Bartek J, et al. Laser Ablation of Abnormal Neurological Tissue using Robotic NeuroBlate System (LAANTERN): procedural safety and hospitalization. *Neurosurgery.* 2020;86(4):538-547.
- Abu-Hegazy M, El-Hadaad HA. Neurocognitive effects of primary brain tumors. In: Agrawal A, ed. *Neurooncology - Newer Developments*. London: InTech; 2016.
- Chang SM, Parney IF, McDermott M, et al. Perioperative complications and neurological outcomes of first and second craniotomies among patients enrolled in the glioma outcome project. *J Neurosurg.* 2003;98(6):1175-1181.
- Kim W-K, Hengstenberg C, Hilker M, et al. The SAVI-TF registry: 1-year outcomes of the European post-market registry using the ACURATE neo transcatheter heart valve under real-world conditions in 1,000 patients. *JACC Cardiovasc Interv.* 2018;11(14):1368-1374.
- Sloan AE, Ahluwalia MS, Valerio-Pascua J, et al. Results of the NeuroBlate System first-in-humans Phase I clinical trial for recurrent glioblastoma. *J Neurosurg.* 2013;118(6):1202-1219.
- Kishore J, Goel M, Khanna P. Understanding survival analysis: Kaplan-Meier estimate. *Int J Ayurveda Res.* 2010;1(4):274.
- Weitzner MA, Meyers CA, Gelke CK, Byrne KS, Cella DF, Levin VA. The Functional Assessment of Cancer Therapy (FACT) scale. Development of a brain subscale and revalidation of the general version (FACT-G) in patients with primary brain tumors. *Cancer.* 1995;75(5):1151-1161.
- Cella DF, Tulskey DS, Gray G, et al. The functional assessment of cancer therapy scale: development and validation of the general measure. *J Clin Oncol.* 1993;11(3):570-579.
- Szende A, Janssen B, Cabases J, eds. *Self-Reported Population Health: An International Perspective Based on EQ-5D*. Dordrecht: Springer; 2014.
- Rabin R, Gudex C, Selai C, Herdman M. From translation to version management: a history and review of methods for the cultural adaptation of the EuroQol five-dimensional questionnaire. *Value Health.* 2014;17(1):70-76.
- Karnofsky D, Burchenal J. The clinical evaluation of chemotherapeutic agents in cancer. In: MacLeod CM, ed. *Evaluation of Chemotherapeutic Agents*. New York: Columbia University Press; 1949: 196.
- Ringash J, O'Sullivan B, Bezjak A, Redelmeier DA. Interpreting clinically significant changes in patient-reported outcomes. *Cancer.* 2007;110(1):196-202.
- Pruitt R, Gamble A, Black K, Schulder M, Mehta AD. Complication avoidance in laser interstitial thermal therapy: lessons learned. *J Neurosurg.* 2016;126(4):1-8.
- Kamath AA, Friedman DD, Akbari SHA, et al. Glioblastoma treated with magnetic resonance imaging-guided laser interstitial thermal therapy: safety, efficacy, and outcomes. *Neurosurgery.* 2019;84(4):836-843.
- Brown DA, Himes BT, Major A, et al. Cranial tumor surgical outcomes at a high-volume academic referral center. *Mayo Clin Proc.* 2018;93(1):16-24.
- Waters Jd, Gonda D, Reddy H, Kasper E, Warnke P, Chen C. Diagnostic yield of stereotactic needle-biopsies of sub-cubic centimeter intracranial lesions. *Surg Neurol Int.* 2013;4(4):176.
- Kreth FW, Muacevic A, Medele R, Bise K, Meyer T, Reulen HJ. The risk of haemorrhage after image guided stereotactic biopsy of intra-axial brain tumours—a prospective study. *Acta Neurochir (Wien).* 2001;143(6):539-546; discussion 545-546.
- Barnett GH, Voigt JD, Alhuwalia MS. A systematic review and meta-analysis of studies examining the use of brain laser interstitial thermal therapy versus craniotomy for the treatment of high-grade tumors in or near areas of eloquence: an examination of the extent of resection and major complication rates associated with each type of surgery. *Stereotact Funct Neurosurg.* 2016;94(3):164-173.
- Dasenbrock HH, Liu KX, Devine CA, et al. Length of hospital stay after craniotomy for tumor: A National Surgical Quality Improvement Program analysis. *Neurosurg Focus.* 2015;39(6):E12.
- Dickinson H, Carico C, Nuño M, et al. Unplanned readmissions and survival following brain tumor surgery. *J Neurosurg.* 2015;122(1):61-68.
- Leuthardt EC, Voigt J, Kim AH, Sylvester P. A single-center cost analysis of treating primary and metastatic brain cancers with either brain laser interstitial thermal therapy (LITT) or craniotomy. *Pharmacoecon Open.* 2017;1(1):53-63.
- Marcus LP, McCutcheon BA, Noorbakhs A, et al. Incidence and predictors of 30-day readmission for patients discharged home after craniotomy for malignant supratentorial tumors in California (1995-2010): clinical article. *J Neurosurg.* 2014;120(5):1201-1211.
- Hong CS, Deng D, Vera A, Chiang VL. Laser-interstitial thermal therapy compared to craniotomy for treatment of radiation necrosis or recurrent tumor in brain metastases failing radiosurgery. *J Neurooncol.* 2019;142(2):309-317.
- Ahluwalia M, Barnett GH, Deng D, et al. Laser ablation after stereotactic radiosurgery: a multicenter prospective study in patients with metastatic brain tumors and radiation necrosis. *J Neurosurg.* 2018;130(3):1-8.
- Rao MS, Hargreaves EL, Khan AJ, Haffty BG, Danish SF. Magnetic resonance-guided laser ablation improves local control for postradiosurgery recurrence and/or radiation necrosis. *Neurosurgery.* 2014;74(6):658-667; discussion 667.
- Chaunzwa TL, Deng D, Leuthardt EC, et al. Laser thermal ablation for metastases failing radiosurgery: a multicentered retrospective study. *Neurosurgery.* 2018;82(1):56-63.
- Barnholtz-Sloan JS, Yu C, Sloan AE, et al. A nomogram for individualized estimation of survival among patients with brain metastasis. *Neuro Oncol.* 2012;14(7):910-918.
- Smith CJ, Myers CS, Chapple KM, Smith KA. Long-term follow-up of 25 cases of biopsy-proven radiation necrosis or post-radiation treatment effect treated with magnetic resonance-guided laser interstitial thermal therapy. *Neurosurgery.* 2016;79(Suppl 1):S59-S72.
- Narloch JL, Farber SH, Sammons S, et al. Biopsy of enlarging lesions after stereotactic radiosurgery for brain metastases frequently reveals radiation necrosis. *Neuro Oncol.* 2017;19(10):1391-1397.

32. Stupp R, Mason WP, van den Bent MJ, et al. Radiotherapy plus concomitant and adjuvant temozolomide for glioblastoma. *N Engl J Med*. 2005;352(10):987-996.
33. Mohammadi AM, Sharma M, Beaumont TL, et al. Upfront magnetic resonance imaging-guided stereotactic laser-ablation in newly diagnosed glioblastoma: a multicenter review of survival outcomes compared to a matched cohort of biopsy-only patients. *Neurosurgery*. 2019;85(6):762-772.
34. Lacroix M, Abi-Said D, Fourny DR, et al. A multivariate analysis of 416 patients with glioblastoma multiforme: prognosis, extent of resection, and survival. *J Neurosurg*. 2001;95(2):190-198.
35. Mohammadi AM, Hawasli AH, Rodriguez A, et al. The role of laser interstitial thermal therapy in enhancing progression-free survival of difficult-to-access high-grade gliomas: a multicenter study. *Cancer Med*. 2014;3(4):971-979.
36. Aum DJ, Kim DH, Beaumont TL, Leuthardt EC, Dunn GP, Kim AH. Molecular and cellular heterogeneity: the hallmark of glioblastoma. *Neurosurg Focus*. 2014;37(6):E11.
37. Capper D. Addressing diffuse glioma as a systemic brain disease with single-cell analysis. *Arch Neurol*. 2012;69(4):523.
38. Mahlokoza T, Vellimana AK, Li T, et al. Biological and therapeutic implications of multisector sequencing in newly diagnosed glioblastoma. *Neuro Oncol*. 2018;20(4):472-483.
39. Buckner JC, Shaw EG, Pugh SL, et al. Radiation plus procarbazine, CCNU, and vincristine in low-grade glioma. *N Engl J Med*. 2016;374(14):1344-1355.
40. Devlin NJ, Brooks R. EQ-5D and the EuroQol group: past, present and future. *Appl Health Econ Health Policy*. 2017;15(2):127-137.
41. Lien K, Zeng L, Nguyen J, et al. FACT-BR for assessment of quality of life in patients receiving treatment for brain metastases: a literature review. *Expert Rev Pharmacoecon Outcomes Res*. 2011;11(6):701-708.
42. Vera E, Acquaye AA, Mendoza TR, Gilbert MR, Armstrong TS. Relationship between symptom burden and health status: analysis of the MDASI-BT and EQ-5D. *Neuro-Oncol Pract*. 2018;5(1):56-63.
43. Pickard AS, Jiang R, Lin H-W, Rosenbloom S, Cella D. Using patient-reported outcomes to compare relative burden of cancer: EQ-5D and functional assessment of cancer therapy-general in eleven types of cancer. *Clin Ther*. 2016;38(4):769-777.
44. McClure NS, Sayah FA, Xie F, Luo N, Johnson JA. Instrument-defined estimates of the minimally important difference for EQ-5D-5 L index scores. *Value Health*. 2017;20(4):644-650.
45. Coretti S, Ruggeri M, McNamee P. The minimum clinically important difference for EQ-5D index: a critical review. *Expert Rev Pharmacoecon Outcomes Res*. 2014;14(2):221-233.
46. Sagberg LM, Jakola AS, Solheim O. Quality of life assessed with EQ-5D in patients undergoing glioma surgery: what is the responsiveness and minimal clinically important difference? *Qual Life Res*. 2014;23(5):1427-1434.
47. Meyers CA, Hess KR, Yung WKA, Levin VA. Cognitive function as a predictor of survival in patients with recurrent malignant glioma. *J Clin Oncol*. 2000;18(3):646.
48. Peters KB, West MJ, Hornsby WE, et al. Impact of health-related quality of life and fatigue on survival of recurrent high-grade glioma patients. *J Neurooncol*. 2014;120(3):499-506.
49. Hui D, Glitza I, Chisholm G, Yennu S, Bruera E. Attrition rates, reasons, and predictive factors in supportive care and palliative oncology clinical trials. *Cancer*. 2013;119(5):1098-1105.
50. Rinck GC, van den Bos GA, Kleijnen J, de Haes HJ, Schadé E, Veenhof CH. Methodologic issues in effectiveness research on palliative cancer care: a systematic review. *J Clin Oncol*. 1997;15(4):1697-1707.

## Acknowledgments

The authors would like to acknowledge Nissa Mollema, PhD, of Monteris Medical for assistance with manuscript preparation.

---

**Neurosurgery Speaks!** Audio abstracts available for this article at [www.neurosurgery-online.com](http://www.neurosurgery-online.com).

**Supplemental digital content** is available for this article at [www.neurosurgery-online.com](http://www.neurosurgery-online.com).

**Supplemental Digital Content. Figure. Patient Flow Diagram.** The patient flow diagram describes the patient status at 12-mo post-LITT procedure.

---