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Magnetic resonance imaging–guided laser interstitial thermal therapy for complete corpus callosotomy: technique and 1-year outcomes. Patient series

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BACKGROUND Magnetic resonance imaging (MRI)-guided stereotactic laser interstitial thermal therapy (LITT) is a minimally invasive technique that has been described for the treatment of certain forms of epilepsy through partial or complete callosotomy, with few cases describing single-stage complete LITT callosotomy. The authors aimed to demonstrate this technique's feasibility and efficacy through description of the technique and 1-year outcomes in 3 cases of single-stage complete LITT callosotomy in patients with anatomically normal corpa callosa (CCs).

OBSERVATIONS The patients were aged 14–27 years and experienced atonic seizures. Completeness of callosotomy was determined from MRI scans obtained >3 months after LITT procedures. The estimated ablations of the CC were 94%, 89%, and 100%, respectively. The second patient had a catheter breach the lateral ventricle, resulting in the lowest estimated percentage of ablation in this series (89%), with minimal atonic seizure reduction. The first patient had significant reduction in atonic seizure frequency, and the third patient had complete resolution of atonic seizures. None of the patients experienced any long-term complications. Intensive care length of stay was 1 night for each patient, and total length of stay was between 2 and 7 nights. Postoperative follow-up was between 14 and 18 months.

LESSONS Complete laser callosotomy is achievable and is a safe alternative to microsurgical or endoscopic approaches.

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KEYWORDS laser callosotomy; corpus callosotomy; laser ablation; laser interstitial thermal therapy; LITT; stereotactic; minimally invasive; epilepsy

Corpus callosotomy is a palliative procedure aimed at treating certain forms of epilepsy by inhibiting the bihemispheric spread of epileptic activity.[1,2] A recent meta-analysis found the rates of seizure freedom and freedom from atonic seizures after corpus callosotomy to be 18.8% and 55.3%, respectively.[3] Since its introduction by Dandy in 1922, the surgical technique of corpus callosotomy has evolved, more recently toward less invasive techniques such as radiosurgery, endoscopy, and magnetic resonance imaging (MRI)-guided stereotactic laser interstitial thermal therapy (LITT).[4–12] LITT is a minimally invasive technique that has previously been used in the treatment of radiation necrosis, brain tumors, cavernous malformations, and epileptogenic foci.[13–16] LITT for corpus callosotomy was first reported in 2016 by Ho et al., with several subsequent case reports or short series that have established the technique's validity.[17–24] LITT has been used for completion of callosotomy to supplant redo open surgical approaches and as a standalone approach for anterior two-thirds corpus callosotomy.[19,21–24] A recent systematic review included a brief description of a case of complete corpus callosotomy via LITT.[17] Additional reports on using LITT for corpus callosotomy provide insight into efficacy and outcomes of the technique.[25–28]

Although there is growing evidence regarding the safety and efficacy of LITT for anterior two-thirds corpus callosotomy and completion callosotomy, there is a paucity of literature detailing complete callosotomies performed with LITT in patients with anatomically normal corpa callosa (CCs). Here, we present 3 cases of complete MRI-guided LITT corpus callosotomy with details on surgical strategy, quantitative assessment of completeness of the callosotomy using delayed imaging, and >1-year clinical outcomes.

ABBREVIATIONS CC = corpus callosum; CSF = cerebrospinal fluid; CT = computed tomography; MRI = magnetic resonance imaging; LITT = laser interstitial thermal therapy; LOS = length of stay; SMA = supplementary motor area.

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Study Description

Study Population

This is a retrospective review of patients who underwent LITT for complete corpus callosotomy between 2020 and 2021. The medical record for each patient was reviewed for age, operative details, pre- and postoperative seizure type and frequency, adverse events, imaging records, length of stay (LOS), and last follow-up. All patients had medically refractory epilepsy including atonic seizures and were reviewed at a multidisciplinary epilepsy conference before being offered surgery. In these patients, complete corpus callosotomy was selected over anterior two-thirds callosotomy because of the abundance of reports suggesting that outcomes are superior for atonic seizures after single-stage complete corpus callosotomy, despite reports of lower incidence of disconnection syndromes and neuropsychological deficits in anterior two-thirds callosotomy.[3,29–37] The final decision on extent of callosotomy is made at our multidisciplinary conference with input from neuropsychology on whether a patient's preoperative level of function predicts a meaningful loss of function with a complete callosotomy.

Operative Technique

Preoperative Planning

All patients underwent preoperative MRI with contrast for planning. The neuroinspire planning software (Renishaw PLC) for the neuromate stereotactic robot was used to plan catheter trajectories to adequately disconnect the entire CC for each patient. These trajectories were planned as close to the midline as safely possible, avoiding the frontal sinus, vasculature, ventricles, fornices, and the precentral gyri. The maximum lesion diameter was considered to be 18 mm for the Visualase system (Medtronic Inc.) for planning purposes. Trajectories were planned through the presumed nondominant hemisphere as often as possible. Posterior entry points were avoided to facilitate supine positioning in the MRI scanner (Fig. 1). Four trajectories were planned for each patient, roughly corresponding to the genu, anterior body, posterior body, and splenium.

Surgical Procedure

After induction of general anesthesia, the patient is placed in a Leksell Coordinate Frame G (Elekta AB). Dexamethasone (8–10 mg intravenous) is administered and tapered over 1–2 weeks postoperatively. The Leksell frame is mounted to the neuromate robot, and the computed tomography (CT) indicator is attached. An O-arm (Medtronic Inc.) scan is obtained for registration, and the CT indicator is removed. The O-arm registration scan is fused to the preoperative MRI scan with the previously planned catheter trajectories. At each site, a stab incision is made, and an awl is used to create an initial entry point in the calvaria to prevent trajectory deviation in particularly acute entry angles. This is followed by creation of a 3.2-mm twist-drill hole and placement of the Visualase bone anchor through which each laser applicator is placed and secured. Laser optical fibers with 10-mm diffuser tips were used for all ablations. After all 4 laser applicators are secured, the patient is then transported to the MRI suite, and initial MRI sequences confirm catheter position and generate thermal maps. A test dose is administered using 3.75 W followed by ablations using between 5 and 9 W for up to 3.5 minutes for each catheter. Ablation is initiated at the most distal end of the trajectory and proceeds proximally by withdrawing the fiber within the laser applicator for subsequent ablations. Postablation MRI sequences, including T1 postcontrast and diffusion-weighted imaging, are obtained to evaluate the extent of ablation. After ablation, the laser fibers and applicators are removed, and a gradient echo sequence is obtained to evaluate for hemorrhage. The bone anchors are removed, and the incisions are sutured. The patient is extubated in the MRI suite, followed by transfer to the intensive care unit for overnight monitoring.

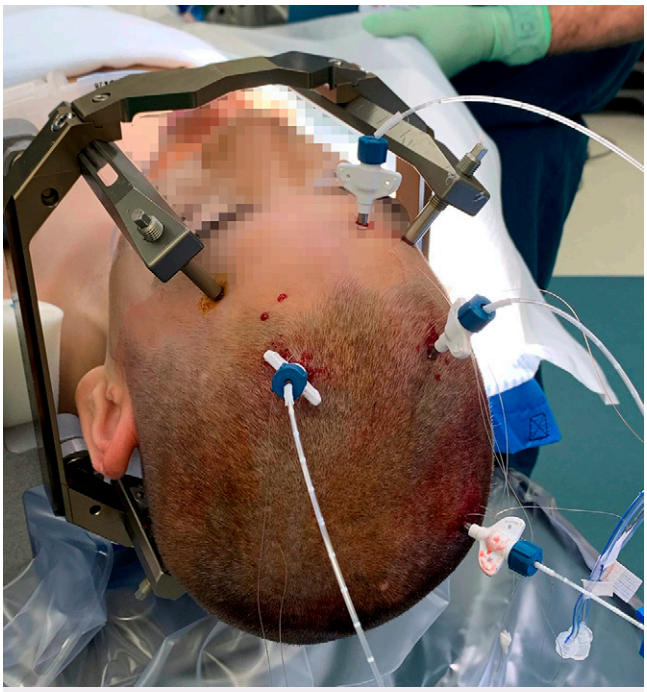

FIG. 1. Intraoperative photograph of patient after robot-assisted stereotactic placement of 4 bone anchors, laser applicators, and catheters before removal of the Leksell headframe and transport to MRI suite for confirmation of catheter position and ablation.

Extent of Ablation

All patients underwent follow-up MRI 3–4 months after ablation. Postablation diffusion tensor imaging sequences were obtained for 2 patients. The extent of ablation of the CC was determined on each coronal T2 image by calculating the percentage of ablation of the CC in the superior-inferior dimension in the region of maximal ablation. A weighted ablation thickness measurement for each coronal slice was calculated as the product of the calculated percentage ablated and the midline thickness of the CC on each image (Fig. 2E and F). A total ablation percentage was calculated using the sum of the weighted ablation thicknesses for each image as a percentage of the sum of the total midline CC thicknesses for each slice.

Illustrative Cases

Three patients with medically refractory epilepsy including atonic seizures underwent complete callosotomy via LITT. All patients had a vagal nerve stimulator placed before surgery, were receiving at least 3 antiseizure medications before surgery, and had seizure onset at least 12 years before underdoing corpus callosotomy. None of the patients had previously undergone corpus callosotomy before the procedure, and all patients underwent placement of 4 Visualase laser catheters targeting complete ablation of the CC. For each case, the section of

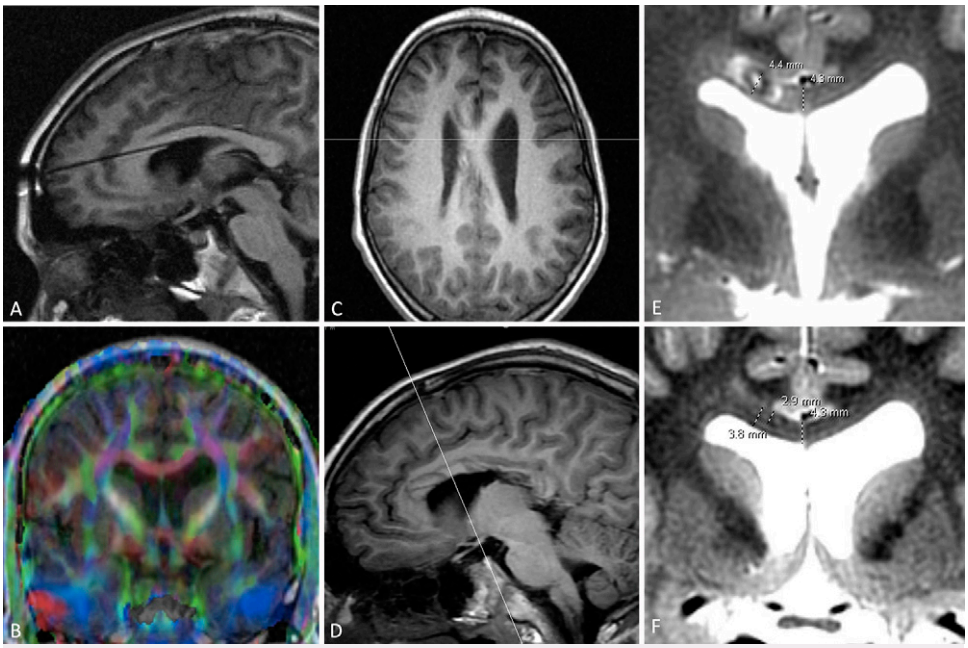

FIG. 2. Illustration of misplaced anterior body catheter and calculated extent of ablation in case 2. **A:** T1 MRI sequence obtained before ablation showing catheter trajectory resulting in likely entry into lateral ventricle. **B–D:** Sequences obtained 3 months after ablation with residual intact body of corpus callosum in coronal diffusor tensor imaging (DTI) sequence (B), axial 3-dimensional T1-weighted sequence (C), and sagittal T1-weighted sequence (D); scout lines in C and D referenced to position of coronal DTI image in B. **E and F:** Coronal T2-weighted slices with measurements of extent of ablation for a slice with a weighted ablation thickness of 4.3 mm (100% ablated at region of maximal ablation; E) and 3.3 mm (76.3% ablated at region of maximal ablation; F).

CC along each trajectory with the thinnest height, as well as the extent of ablation, is reported in Table 1.

Case 1

The first patient is a 27-year-old man with autism and Lennox-Gastaut syndrome. His seizure types include atypical absence, atonic, and generalized convulsive seizures. His atonic seizures were the only active seizure type at the time of surgery, occurring roughly once per week, with a history of facial trauma associated with falls during his seizures. He underwent laser callosotomy with 1 catheter placed through the left hemisphere targeting the genu of the CC and the other 3 catheters placed through the right hemisphere (Fig. 3). Postoperatively, he had no atonic seizures in the first month, followed by 1 or 2 per month but with a significant decrease in falls associated with the seizures. His felbamate was discontinued from his antiseizure medication regimen with improvement in his aggressive behaviors, calmer demeanor, and improved appetite. His parents did note slightly more frequent dysarthria that persisted to his last follow-up appointment 14 months postoperatively. An estimated 94% of the CC was ablated on a 4-month follow-up MRI.

TABLE 1. Corpus callosum thinness and extent of ablation

Thinnest Region Along Each Trajectory	Case 1	Case 2	Case 3
Genu, mm	5.71	8.1	8.0
Anterior body, mm	4.54	5.3	5.0
Posterior body, mm	2.98	2.9	4.2
Splenium, mm	7.5	7.1	4.7
Extent of ablation, %	94%	89%	100%

Case 2

The second patient is a 14-year-old male with multiple genetic abnormalities and intellectual deficits. His seizure types include atonic and generalized tonic-clonic seizures. Before surgery, he was experiencing 6–20 atonic seizures daily and 3 or 4 generalized clonic seizures per week. He underwent laser callosotomy with 1 catheter placed through the left hemisphere targeting the genu of the CC and the others placed through the right hemisphere (Fig. 3). The catheter targeting the anterior body of the CC did not follow the planned trajectory and veered inferiorly, breaching the ependyma (Fig. 2A). Postoperatively, he experienced no atonic seizures for 1 month, followed by a gradual increase from 1 atonic seizure daily to 10 seizures daily, whereas his generalized clonic seizures increased to 4–20 per day, albeit with decreased duration. An estimated 89% of the CC was ablated on a 4-month follow-up MRI; there is a section of intact CC in the middle portion of the body (Fig. 2). A revision LITT procedure was offered to address the residual connection, but the family declined. His last follow-up was 18 months after ablation.

Case 3

The third patient is a 17-year-old male with autism who presented with atonic and focal onset aware seizures. Before surgery,

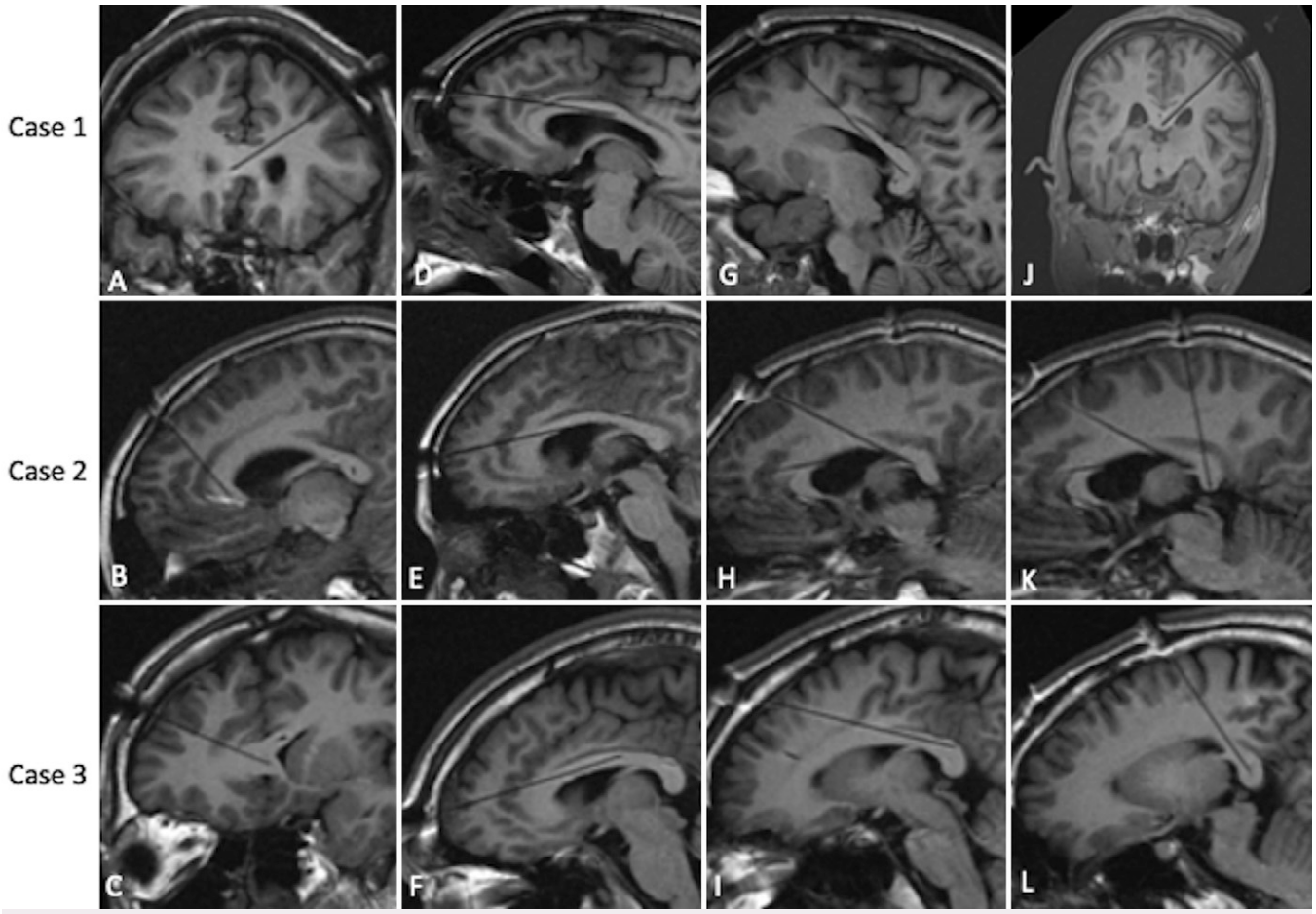

FIG. 3. T1-weighted MRI sequences for all 3 cases obtained before ablation showing catheter trajectory with targets of the genu (**A**–**C**), anterior and middle body (**D**–**F**), posterior body and splenium (**G**–**I**), and splenium of the corpus callosum (**J**–**L**).

he experienced atonic seizures 3–8 times per week and focal seizures 2 or 3 times per week. He underwent laser callosotomy with 1 catheter trajectory through the left hemisphere targeting the body of the CC and the other 3 catheters through the right hemisphere (Fig. 3). Postoperatively he exhibited diminished volitional movement in his left hemibody, more pronounced in the lower extremity, consistent with a supplementary motor area (SMA) syndrome, which gradually resolved by the time he was discharged on postoperative day 7. He did not have any atonic seizures and had 1 or 2 focal onset aware seizures during the first 6 months postoperatively, after which he was completely seizure free up to his last follow-up 18 months after ablation. Clobazam was discontinued from his antiseizure medication regimen. One hundred percent of the CC was ablated on 3-month follow-up MRI.

Discussion

The efficacy of corpus callosotomy as a palliative surgical treatment for medically refractory epilepsy, particularly atonic seizures, is well established.[31,38,39] Multiple reports have demonstrated the utility of MRI-guided LITT in partial corpus callosotomy.[17–24] There are few reports of complete corpus callosotomy using LITT as a standalone procedure.[25–28] This study aimed to further demonstrate the efficacy and safety of complete corpus callosotomy using LITT and is the first to include multiple complete callosotomies with normal callosal anatomy, detailed technical description, follow-up beyond 1 year, and a quantitative assessment of the extent of ablation based on delayed imaging.

Observations

There are numerous technical considerations that are crucial to successful planning and ablation. The anatomy of the CC is the main determinant of candidacy for laser callosotomy, as well as the number of trajectories needed for complete ablation. Thin areas of CC are a smaller ablation target, which can result in less effective ablation due to the heat sink properties of cerebrospinal fluid (CSF); therefore, patients with very thin CCs are poor candidates. The diameter of the Visualase catheter is 1.65 mm, and the smallest Monteris Neuroblate catheter is 2.2 mm. Thus, we would recommend against attempting ablation in a callosum that is not much thicker than the laser catheter being used. All 3 patients in this series had normal-thickness C-shaped callosa, and extent of ablation did not appear to correlate with CC thickness along the trajectories (Table 1). Trajectories should be planned to allow longitudinal ablations that overlap along the length of the callosum (Fig. 4). Entry sites as close to the midline as possible maximize the catheter length within the CC. Avoidance of key structures reduces the risk of infection

(frontal sinus), inadequate ablation (ventricle), hemorrhage (vessels), and functional deficits (precentral gyri, fornices). The dominant hemisphere is avoided when possible; however, in each case, a single trajectory was planned through the presumed dominant hemisphere to avoid interference with other trajectories. Posterior entry points can result in torque on the bone anchor and may preclude supine positioning in the MRI head coil (which may be required for macrocephalic patients). The use of an awl to initiate the calvarial opening helps prevent slippage of the drill bit for more acute entry angles.

The extent of ablation for complete LITT callosotomy cases has been estimated in the literature for 3 patients, ranging from 74% to 100%. However, technique in measuring this has been variable, with 1 report generating 3-dimensional models of the CC and using custom programming analyses to calculate length and volume disconnected, whereas another report used MRI scans to calculate the length of ablation as a percentage of the total CC length. The calculated extent of ablation in this series is similar to that in other cases reported and is loosely correlated with outcome.[27,28]

Seizure outcomes with laser callosotomy are comparable to those of open corpus callosotomy.[25,40] Two of 3 patients presented here had significant improvement in their seizures after laser callosotomy, with 1 patient having complete resolution of atonic seizures. The patient with the least complete disconnection (89%) unfortunately did not experience significant improvement. A recent systematic review of 40 patients with atonic seizures (39 partial or completion callosotomies, 1 complete) from 10 reports demonstrated complete freedom from atonic seizures in 52.8% of cases.[40] Caruso et al.[25] compared open corpus callosotomy with laser callosotomy and found both experienced reduction of atonic seizure frequency postoperatively, whereas the group that underwent LITT had a shorter intensive care LOS and lower estimated blood loss and trended toward having a shorter overall LOS.

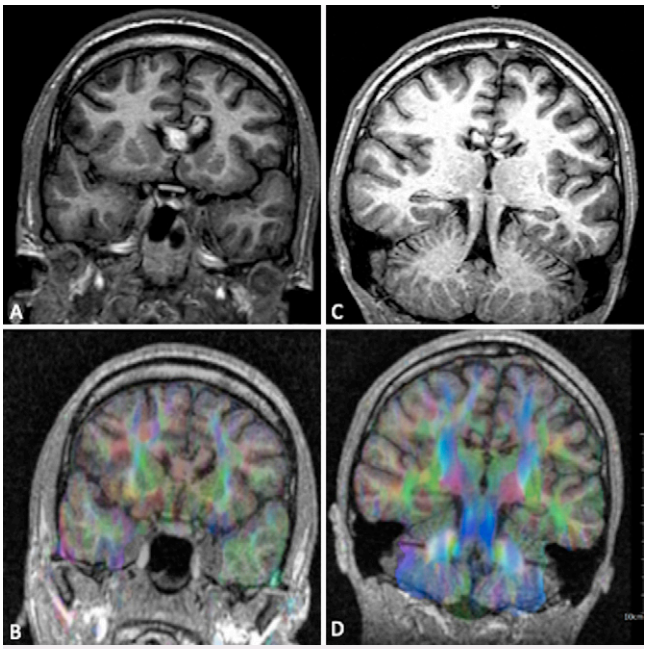

FIG. 4. MRI sequences obtained 3 months after ablation in case 3. Coronal T1-weighted and diffusor tensor imaging MRI sequences showing overlapping areas of ablation in the genu (**A and B**) and body (**C and D**).

Transient hemiparesis has been described after open corpus callosotomy and ranges from 2% to 10%.[41–43] This has previously been labeled as almost identical to SMA syndrome with uncertainty in its etiological relationship to corpus callosotomy as either a disconnection syndrome or a complication of an open interhemispheric approach.[26,33] One patient in this series experienced transient left hemiparesis, and there are 3 other reports of patients who also experienced this complication after laser callosotomy.[20,27,44] This suggests that this phenomenon is a true disconnection syndrome because there was no exposure or manipulation of the SMA in these cases. Other temporary neurological deficits were reported in the literature, including truncal ataxia and imbalance, whereas 1 patient experienced permanent dysarthria after complete LITT callosotomy.[26–28] Five patients experienced intraparenchymal hemorrhage associated with LITT for corpus callosotomy.[20,27,44,45]

Lessons

Complete laser callosotomy is achievable and is a safe alternative to microsurgical or endoscopic approaches, with seemingly similar seizure outcomes. This report describes technical tips and nuances that may be helpful for other surgeons who perform this operation. If the laser catheter breaches the ventricle, the CSF acts as a heat sink and will prevent ablation of the adjacent callosum. Thus, attempting laser callosotomy on patients with thin CCs poses a greater risk of incomplete ablation. This report is limited by the small sample size and retrospective nature of case reports, which includes lack of generalizability. This study was also completed at a single institution. The limited availability of literature on this subject also precludes meaningful comparison with existing knowledge and risks the possibility of overinterpretation.

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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: all authors. Acquisition of data: Best, Lew. Analysis and interpretation of data: all authors. Drafting the article: Best. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Best.

Supplemental Information

Previous Presentations

The abstract was previously presented as a digital poster at the annual meeting of the Congress of Neurological Surgeons in San Francisco, CA, October 8–10, 2022.

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