

Robot-Assisted Stereotactic Laser Ablation in Medically Intractable Epilepsy: Operative Technique

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BACKGROUND: Stereotactic laser ablation offers an advantage over open surgical procedures for treatment of epileptic foci, tumors, and other brain pathology. Robot-assisted stereotactic laser ablation could offer an accurate, efficient, minimally invasive, and safe method for placement of an ablation catheter into the target.

OBJECTIVE: To determine the feasibility of placement of a stereotactic laser ablation catheter into a brain lesion with the use of robotic assistance, via a safe, accurate, efficient, and minimally invasive manner.

METHODS: A laser ablation catheter (Visualase, Inc) was placed by using robotic guidance (ROSA, Medtech Surgical, Inc) under general anesthesia into a localized epileptogenic periventricular heterotopic lesion in a 19-year-old woman with 10-year refractory focal seizure history. The laser applicator (1.65 mm diameter) position was confirmed by using magnetic resonance imaging (MRI). Ablation using the Visualase system was performed under multiplanar imaging with real-time thermal imaging and treatment estimates in each plane. A postablation MRI sequence (T1 postgadolinium contrast injection) was used to immediately confirm the ablation.

RESULTS: MRI showed accurate skin entry point and trajectory, with the applicator advanced to the lesion's distal boundary. Ablation was accomplished in less than 3 minutes of heating. The overall procedure, from time of skin incision to end of last ablation, was approximately 90 minutes. After confirmation of proper lesioning by using a T1 contrast-enhanced MRI, the applicator was removed, and the incision was closed using a single stitch. No hemorrhage or other untoward complication was visualized. The patient awoke without any complication, was observed overnight after admitting to a regular floor bed, and was discharged to home the following day.

CONCLUSION: This technique, using a combination of Visualase laser ablation, ROSA robot, and intraoperative MRI, facilitated a safe, efficacious, efficient, and minimally invasive approach that could be used for placement of 1 or multiple electrodes in the future.

KEY WORDS: Epilepsy, Heterotopia, Lasers, Robotics, Stereotactic techniques, Treatment

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Laser ablation under real-time magnetic resonance imaging (MRI) guidance for brain pathology is being increasingly used by neurosurgeons. Since the initial cases in France in 2006 targeting metastatic tumors, and subsequent procedures in the United States in 2008 targeting both primary and metastatic brain tumors, surgeons have ablated epileptogenic le-

sions and radiation necrosis.^{1–5} Epileptogenic lesions, including tubers (in tuberous sclerosis), mesial temporal sclerosis (via selective laser amygdalohippocampectomy), as well as focal cortical dysplasias and hamartoma, have been successfully treated.^{3,6} The minimally invasive opening (3.2 mm), small diameter of the laser applicator (1.65 mm), and ease of placement with subsequent short ablation time (usually less than 5 minutes) and MRI scanning time (usually less than 90 minutes) have allowed procedures to be performed in a more efficient and safer manner in

ABBREVIATIONS: EEG, electroencephalography;
SEEG, stereoelectroencephalography

comparison with open procedures (where deep lesion access would be contraindicated because of access-related morbidity).

A key requirement of laser ablation is accurate and safe placement of the laser fiber within the intended target. The ROSA robot (Medtech Surgical, Inc, Newark, New Jersey) has been increasingly utilized to place single or numerous electrodes or catheters into brain targets. Robot-assisted stereotactic placement of intracerebral devices has been extensively performed with demonstrated accuracy and safety.⁷ Additionally, intraoperative MRI allows identification of real-time status of intracranial pathology while maintaining a sterile environment. Based on intraoperative MRI, modification and/or further treatment may be instituted, while maintaining a sterile field and keeping the patient anesthetized. Although not an absolute necessity for performance of the procedure, intraoperative MRI can assist in these notable ways.

The combination of these 3 techniques facilitates robot-assisted stereotactic laser placement, with subsequent MRI confirming placement and allowing subsequent treatment confirmation. This is the first operative technique report, to the authors' knowledge, describing these 3 modalities.

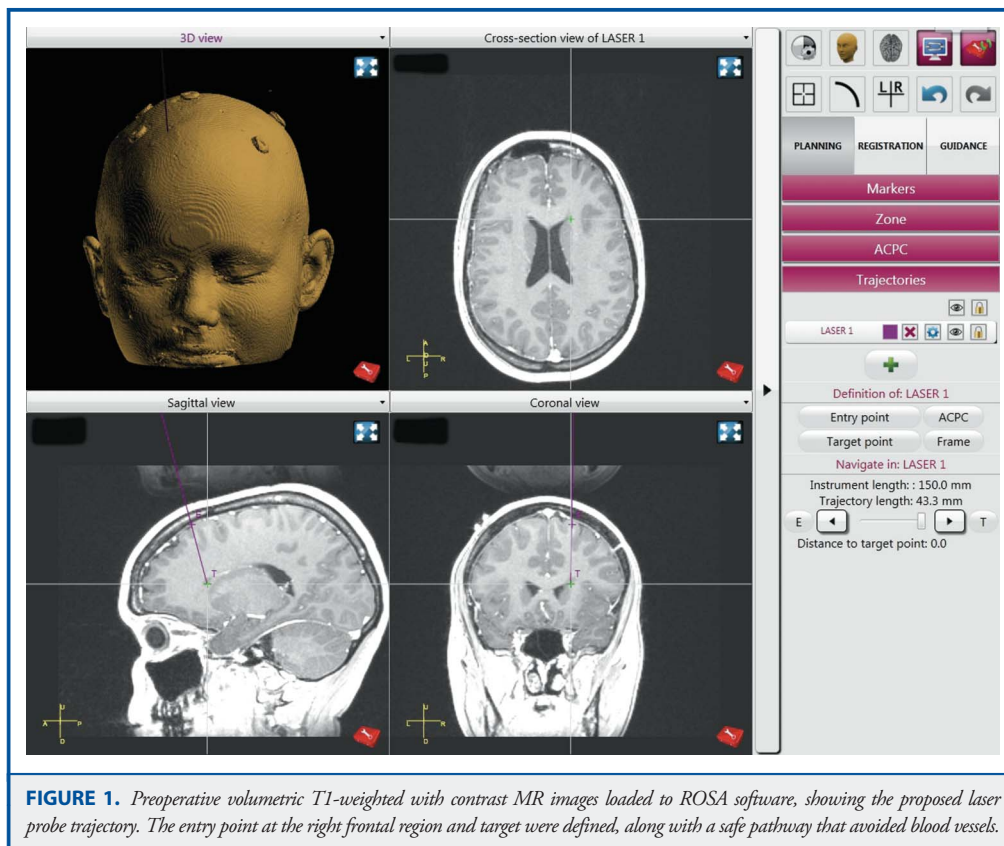
METHODS

The patient, a 19-year-old woman, had experienced medically intractable focal partial epilepsy since the age of 9. The epileptogenic

zone was localized to the right frontal region by using noninvasive data (semiology, scalp electroencephalography [EEG], MRI, positron emission tomography, and ictal single-photon emission computed tomography) complemented by an invasive evaluation using the stereoelectroencephalography methodology (SEEG). MRI revealed a periventricular heterotopic-appearing lesion that proved to be epileptogenic by intralesional depth electrode ictal recordings. Given her 10-year history of medically refractory epilepsy, treatment options were discussed with the patient, and she elected to proceed with the laser ablation procedure.

Working under an institutional review board-approved protocol at the Cleveland Clinic, a preoperative thin-slice MRI with and without contrast was obtained in various sequences (T1, T2, fluid attenuated inversion recovery). The lesion was clearly visualized by using a T1-weighted MRI, suggestive of a hypointense (<1 cm) region adjacent to the right frontal horn and caudate nucleus. This MRI study was uploaded to the ROSA robot and a plan was created whereupon entry point at the right frontal region and target were defined, along with a safe pathway that avoided blood vessels seen on contrasted imaging (Figure 1).

The patient was anesthetized in the operative suite, which was adjoining the MRI suite and separated by a retractable wall, with common ceiling tracks for the IMRIS MRI system (IMRIS, Inc, Winnipeg, Manitoba, Canada). Her head was placed in a Leksell frame (Elekta, Inc, Stockholm, Sweden), with left frontal and posterior posts and pins applied; this frame was affixed to the operative bed. The ROSA robot was then moved into position, registered with the patient using surface landmarks (facial features, eg nasion, tip of nose, canthi, etc). The entry point was marked



once a satisfactory registration was achieved, and the robot remained locked in position.

After shaving a small region and prepping around the entry site, a cordless power drill was used to both make the scalp “incision” and the hole in the skull (3.2 mm). The dura was coagulated, opened, and entered, and the robot arm was used to determine both trajectory and depth. Using an aligning rod through the robot trajectory guide, a skull bolt (Visualase, Inc) was placed into the hole and secured in place. The bolt contains a silicone diaphragm allowing loosening for passage and securing of the laser applicator. The 1.65-mm-diameter, 3-mm-length laser-reflecting end was passed through the bone screw and advanced just proximal to the distal end of the target initially, and the 980-nm-wavelength laser was placed within the canula and secured. With a sterile field being maintained, the retractable wall between the operative and MRI suites was opened, and the IMRIS MRI was slid into position along the ceiling tracks.

After confirmation of the proper laser applicator position (see Figure 2A, B) using intraoperative multiplanar images on MRI (Siemens, Inc, Munich, Germany), correct trajectory was confirmed, and the surgeon elected to advance the canula to the distal end of the lesion (to optimize lesion coverage, with advancement accomplished in approximately 3 minutes). Images were acquired to verify optimal position, and ablation commenced. As a precaution, “safety points” were designated around the fiber to allow real-time monitoring of heat and to trigger a laser shut-off. If a higher-than-desired (90°C) temperature was reached either close to the laser applicator or in surrounding healthy tissue, the high-limit safety points shut off the laser to protect the cannula. Low-limit safety points were included if protected cerebral structures reached temperatures of 50°C. The laser was powered at 9 W for approximately 60 seconds. Single planar real-time thermal mapping was superimposed upon MRI, being refreshed every 4 seconds (see Figure 2C-F). The creation of an approximately 1-cm “irreversible damage zone” lesion was confirmed on both diffusion imaging intraprocedure and on postprocedure gadolinium-enhanced T1-weighted imaging (Figure 2G). The “irreversible damage zone” was calculated by an Arrhenius rate model of thermal tissue destruction. The MRI was then slid into its original position in its MRI suite, and the laser applicator was removed, with the incision closed with the use of a single stitch (while maintaining sterility throughout the procedure). Figure 3 shows various intraoperative steps in the procedure.

RESULTS

The procedure, from skin incision to end of ablation, was performed in approximately 90 minutes. The actual laser ablation was performed in less than 3 minutes, with approximately 45 minutes of the procedure’s 90 minutes spent acquiring images in the MRI scanner. Approximately 30 additional minutes preoperatively were used to place the patient in the frame and register the robot. Accurate placement of laser applicator (as compared with preplanned trajectories) was achieved by using the robotic guidance and confirmed by the intraoperative MR images.

The postablation MRI showed complete ablation of the focal periventricular heterotopic lesion, with approximately a 1-cm ellipsoid lesion being created by the applicator. A gadolinium-enhancing rim (Figure 3) shows the sharp delineation between

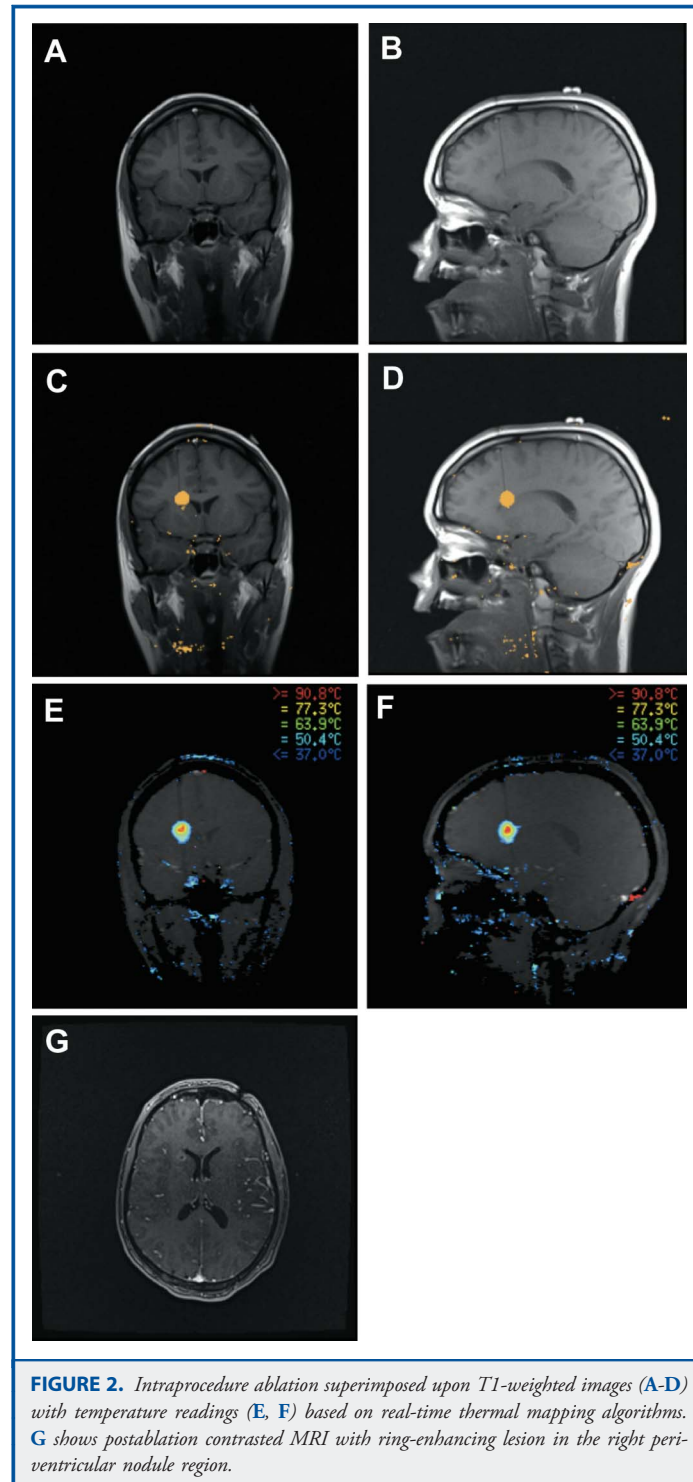
normal brain and the lesion, with significant drop-off in heat between these areas as planned and described in the Methods section previously.

The patient did not experience any neurological or other complications, and awoke immediately following the procedure. Because the postablation scan revealed no bleed, she was transferred to the floor (without intensive care unit or step-down monitoring being required), and was discharged to home the following day after an uncomplicated hospital course.

DISCUSSION

Laser ablation, whether for superficial or deep lesions of brain, offers a minimally invasive method for accessing tumors, epileptic foci, or other lesioning targets within the brain. The 1.65-mm Visualase laser applicator is placed through a 3.2-mm opening, with the applicator’s distal portion able to create a lesion using heat-based ablation. Depending on temperature and duration of time, lesions from approximately 5 mm to 20 mm in width can be created with a single heating episode, and the fiber optic can be retracted within the catheter to create larger lesions. Larger lesions can be ablated with additional trajectories. Using this laser technique, neurosurgeons have treated metastatic and primary brain tumors, using 1 or more applicators when larger tumors were encountered. Laser ablation has also been used by neurosurgeons recently for treatment of symptomatic radiation necrosis, where immediate, significant diminution in edema and symptoms resulted in several patients.⁵ In epilepsy, even curved structures such as the hippocampus have been ablated, with 6-month seizure cure results comparable to some 12-month openly performed temporal lobectomy procedures.³ Difficult-to-reach lesions such as hypothalamic hamartoma, where other techniques offer 40% to 60% cure rate, have been treated with over 80% cure rate and a markedly lower complication rate.^{3,8} Because laser ablation does not typically cause damage to the corridor through which it enters the lesion, it is advantageous over open procedures. Deep-located epileptogenic zones, frequently associated with focal cortical dysplasias located in depths of sulci, insula, or the interhemispheric fissure, have been difficult to treat because of the damage in the corridor being used for the conventional surgical approach especially when lesions are located in or near eloquent cortical and subcortical structures. In addition, stereotactic radiosurgery use in younger children is questionable owing to the radiation imparted and possible delayed side effects. Hence, stereotactic laser ablation may be preferable for deep lesions for these reasons, as well as for small and well-circumscribed superficial epileptic lesions due to the minimal (several-millimeter) incision created, allowing many procedures to have been done with the patient awake.

Proper placement of the laser fiber within the lesion is paramount. One advantage of the robotic system, which uses a similar concept as frameless stereotaxy in its registration of the patient’s affixed head to previously acquired MR images, is its accurate targeting of the lesion. Recent studies have shown robot-



assisted trajectories to be “safe, accurate, efficient, and comparable to other procedures employing either frame-based stereotaxy or frameless, nonrobotic stereotaxy.”⁹⁻¹⁴ Another important advantage is the stabilization its arm provides to the drill, allowing

an accurate trajectory that leads to the target lesion. This operative technique illustration, utilizing both navigation capabilities of the robot and stabilization, allowed both targeting and placement of the laser fiber to be performed in less than



FIGURE 3. Intra-operative photographs showing robot guiding trajectory (A, B), laser applicator passage into brain through skull bolt (C), robot disconnection and removal after laser probe placement, allowing intraoperative MR imaging procedure (D), and final aspect with dressing applied (E).

45 minutes; this short time duration, coupled with the minimal incision (made with the drill), minimizes infection risk. The Cleveland Clinic Epilepsy Center's experience with the ROSA robot has included accurate placement of multiple intracranial depth electrodes for stereo-EEG lead placement, both efficiently and with minimal complications. Hence, the laser fiber was placed by using this technique. Presumably, future technique could include the placement of numerous depth electrodes into a nonlesional epilepsy patient, with ablation subsequently performed through the same entry hole corresponding to the electrode most proximal to the epileptogenic focus (or interpo-

lated between several such electrodes). Thus the robotic and laser systems are complimentary.

Use of the intraoperative MRI has found benefit in neurosurgery,¹⁰ with one of its main attributes being the identification of success while maintaining sterility of the operative field, while the patient remained anesthetized. In our scenario, describing the robotically placed laser applicator, the patient's bed remained in the same position, as the intraoperative MRI was slid into position along ceiling-affixed tracks. This allowed for modification as needed, with only approximately 3 minutes being required to advance the applicator up to 1 cm to reach the distal-most part

of lesion (while still maintaining sterility for the system). While possession of an intraoperative MRI does not preclude a Visualase laser ablation operation from being done, it helped our operation for the reasons cited above.

CONCLUSION

This case illustrated the feasibility of a unique combination of the robot, laser, and intraoperative MRI. Although we acknowledge that further study is needed, the success of the presently described laser procedure allows the possibility of a future diagnostic-therapeutic combination that offers minimal invasiveness, duration of treatment, and subsequent recovery, without compromising efficacy.

Disclosure

Dr Patwardhan is a past consultant and present licensor of patented technology, clinically employed, and an equity holder with Visualase, Inc. None of the other authors have a personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors reported on a case of combined use of stereotactic laser ablation, robotic assistance, and intraoperative MRI. This unique and first-time published combination of 3 modern, state-of-the-art techniques, allowed them to ablate an epileptogenic periventricular gray matter nodule in a drug-resistant 19-years-old woman. The procedure was minimally invasive, quick and safe, with only minimal discomfort to the patient who was discharged from the hospital the day after the treatment. Both the robotic assistance and the intraoperative MRI guidance, although not mandatory, increased the probability of being successful and avoiding complications.

This report is aimed at describing the surgical technique, and, for this reason, detailed information about the individual clinical frame is not given. Nevertheless, the reader must be warned against the idea that ablating the lesion could certainly lead to seizure freedom. Thus, it must be positively highlighted that the authors performed a long-term Video-SEEG monitoring before indicating the laser ablation. Only once the heterotopic nodule was demonstrated as epileptogenic by the intracerebral recordings, the stereotactic procedure was performed and the lesion ablated.

Our group reported 4 of 5 similar cases treated successfully with SEEG-guided radiofrequency thermal lesioning.¹ Moreover, the efficacy of laser ablations on other epileptogenic conditions such as hippocampal sclerosis has been reported yet.² This evidence led us to be optimistic about the outcome of the reported case, but no information about the result on seizures is given in this report. More clinical studies are needed to consider the immediate “neuroradiological outcome” as a positive predictor of seizure freedom. If the efficacy of SEEG-laser ablation on seizures will be confirmed by further studies, this new technique will certainly contribute to reducing the invasiveness and decreasing the morbidity of a number of procedures aimed at treating drug-resistant epilepsies.

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Epilepsy strikes about 38,000 new patients per year.¹ It is estimated that up to one-third of these patients will be refractory to medical management, necessitating a surgical solution. Yet it is estimated that, nationally, epilepsy surgery centers only operate on 1962 cases a year on average, leaving about 82% of the surgical cases untreated.¹ Englot et al² have addressed this treatment gap and among the reasons given for low surgical intervention was patient choice, citing the invasiveness of the surgical intervention as a deterrent. Epilepsy surgery in the future will need to mitigate morbidity, both diagnostically and therapeutically, if we are ever to narrow the treatment gap.

The authors submit a welcome article in the development of minimally invasive epilepsy surgery, achieving both invasive diagnostic seizure focus localization and effective surgical treatment in a patient while leaving the cranium intact. The patient did not need extensive hospitalization for recovery of access-related injury. The surgical robot

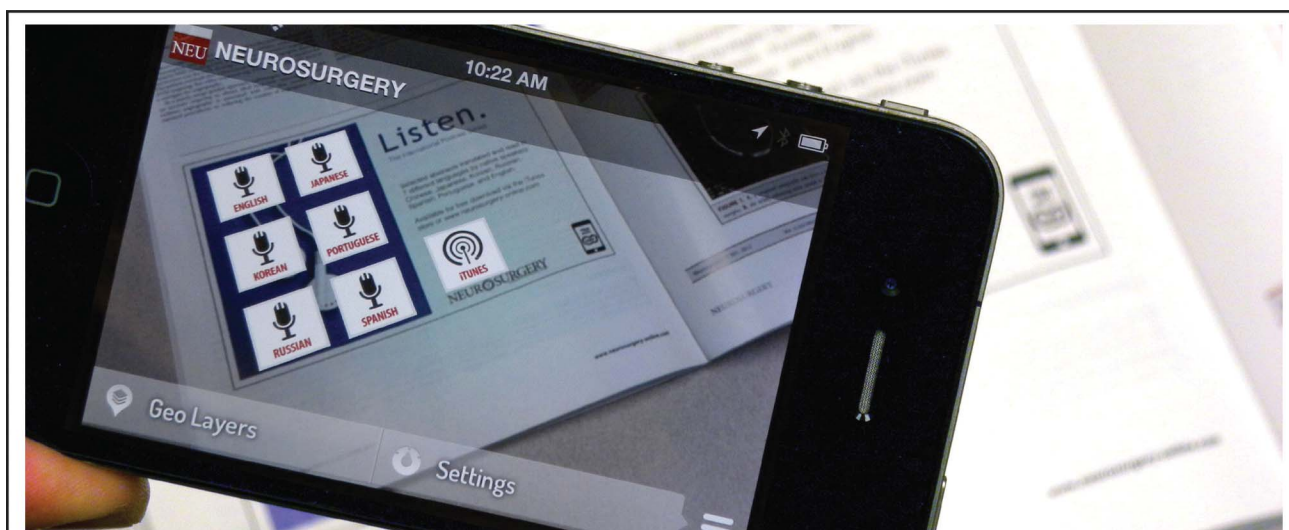
achieved good accuracy to a subcentimeter target at a 43-mm stereotactic depth. The intraoperative MRI clearly facilitated the safe and effective completion of the surgery as it mitigated the need for patient transport with all the risks of endotracheal tube dislodgement, laser cannula dislodgement, and exposure to unsterile environments. The combination of these minimally invasive and intraoperative guidance techniques can serve as a model for minimally invasive epilepsy surgery in the future.

We thank the authors for their contribution and believe that this is a helpful article in the development of ablative epilepsy surgery. We recognize the authors extensive experience in stereoelectroencephalography, and acknowledge that, although this report is a proof-of-principle of the combination of these technologies on a single target, the greater utility of

this technological combination will be when multiple targets will need to be treated, such as in tuberous sclerosis and other multifocal epilepsy cases.

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