Stereotactic Radiofrequency Thermocoagulation of Hypothalamic Hamartoma Using Robotic Guidance (ROSA) Coregistered with O-arm Guidance—Preliminary Technical Note

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INTRODUCTION: **Treatment options for hypothalamic hamartoma (HH) include microvascular surgery, stereotactic radiofrequency thermocoagulation (SRT), laser interstitial thermal therapy, or Gamma Knife surgery. During SRT, thermographic monitoring cannot be performed and therefore highly accurate placement of electrode and confirmation of its position are required. We have used robotic guidance (ROSA) and coregistered it with O-arm for performing ablation of hamartoma.**

METHODS: **Five patients with HH and gelastic seizures underwent SRT. Robotic guidance (ROSA) was used for placement of electrodes. An O-arm was used for coregistering and confirming the robotic trajectory with real-time intraoperative imaging. Intraoperative computed tomography was merged with preoperative magnetic resonance imaging to confirm the exact position and trajectory of the electrode. Ablation was performed using a radiofrequency generator (70°C for 60 seconds). Multiple target sites were ablated to achieve proper ablation and disconnection.**

RESULTS: **Most patients (4/5) had International League Against Epilepsy class I outcome. One patient 2 sittings of lesioning. All but 1 electrode could be placed in the planned trajectories. One electrode was detected to have a medial deviation, and it had to be revised. No permanent complication was observed.**

CONCLUSIONS: **SRT is a cost-effective method of treating HH when compared with laser interstitial thermal therapy. With the use of a robotic arm we have demonstrated accurate placement of electrodes. Intraoperative computed tomography acquired using an O-arm can be merged with preoperative magnetic resonance imaging. This confirms electrode location and trajectory on a real-time basis by performing intraoperative imaging. This method is safe and can be used for radiofrequency ablation of HH.**

INTRODUCTION

Gelastic seizures (GSs) are the typical semiology of hypothalamic hamartomas (HH). The available treatment options for HH include microscopic surgery (MS),[1,2] endoscopic disconnection (ED),[3] stereotactic radiofrequency thermocoagulation (SRT),[4,5] laser interstitial thermal therapy (LITT),[6,7] and Gamma Knife surgery (GKS).[8,9] MS and ED are invasive and involve dissection around critical structures. Higher rates of complications have been reported for MS, and this procedure is rarely performed currently.[5] GKS is not a suitable option for big hamartomas. Minimally invasive SRT and LITT have been shown to be effective alternatives to MS.[5,10] LITT requires intraoperative magnetic resonance imaging (MRI) thermographic imaging, which is not readily available at many centers across the world. In addition, it involves disposable laser electrodes, which

Key words
- Hypothalamic hamartoma
- O-arm
- Radiofrequency
- Robotic
- Stereotactic
- Technical report
- Thermocoagulation

Abbreviations and Acronyms

CT: Computed tomography
ED: Endoscopic disconnection
EEG: Electroencephalography
GKS: Gamma Knife surgery
GS: Gelastic seizure
HH: Hypothalamic hamartoma
LITT: Laser interstitial thermal therapy
MRI: Magnetic resonance imaging
MS: Microscopic surgery
SRT: Stereotactic radiofrequency thermocoagulation

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are expensive, especially for countries with financial constraints. SRT for HHs has also been shown to be an effective treatment option.[5,11-13] We used robotic guidance (ROSA, Medtech, Montpellier, France, approved by the U.S. Food and Drug Administration) for stereotactic placement of the SRT electrode. Intraoperative computed tomography was acquired using O-arm (Medtronic Inc., Minneapolis, Minnesota) and merged with preoperative MRI, showing superimposed electrode and preoperative trajectory. Accurate placement of an electrode using a robot and its intraoperative validation improves the safety profile of this procedure. Use of these technologic adjuncts (ROSA and O-arm) are being reported for the first time in this case series.

MATERIAL AND METHODS

Five patients with HHs, aged 6 months to 13 years, presented with GS ± behavioral disorder (BD), precocious puberty (PP), and delayed milestones. Seizures were refractory to antiepileptic drugs. We performed MRI T1, T2, 2-FLAIR and contrast-enhanced MRI in 1-mm slices, 0-gap, 1-mm increment, and square matrix in all patients. SRT was performed under robotic (ROSA) and O-arm guidance. A proper, informed consent was taken for each patient, as per our institutional policy. Ethics committee approval was not deemed necessary as the radiofrequency ablation for hypothalamic hamartoma is a well-established treatment modality.

TECHNICAL NOTE

Preoperative volumetric sequences of contrast-enhanced MRI and CT were done. T1 weighted and flair-based MRI sequences were merged with contrast CT scan using ROSA planning software to generate a composite image. Trajectory planning was performed on ROSA console. Multiple trajectories were drawn in such a way that once ablation is complete, hamartoma's interface with hypothalamus is sufficiently disconnected. The first lesion was done at the interface and subsequent lesions at 5-mm intervals since the electrode of 2-mm diameter produced a lesion of 5 mm in diameter. Care was taken that the brain-hamartoma interface was ablated to achieve an "ablative disconnection." All trajectories were planned in such a way that there was no transgression of cerebrospinal fluid or vascular space, and entry points were usually centered around a coronal suture. Thereafter, patients were intubated and the head was fixed in a Mayfield clamp and attached with ROSA.

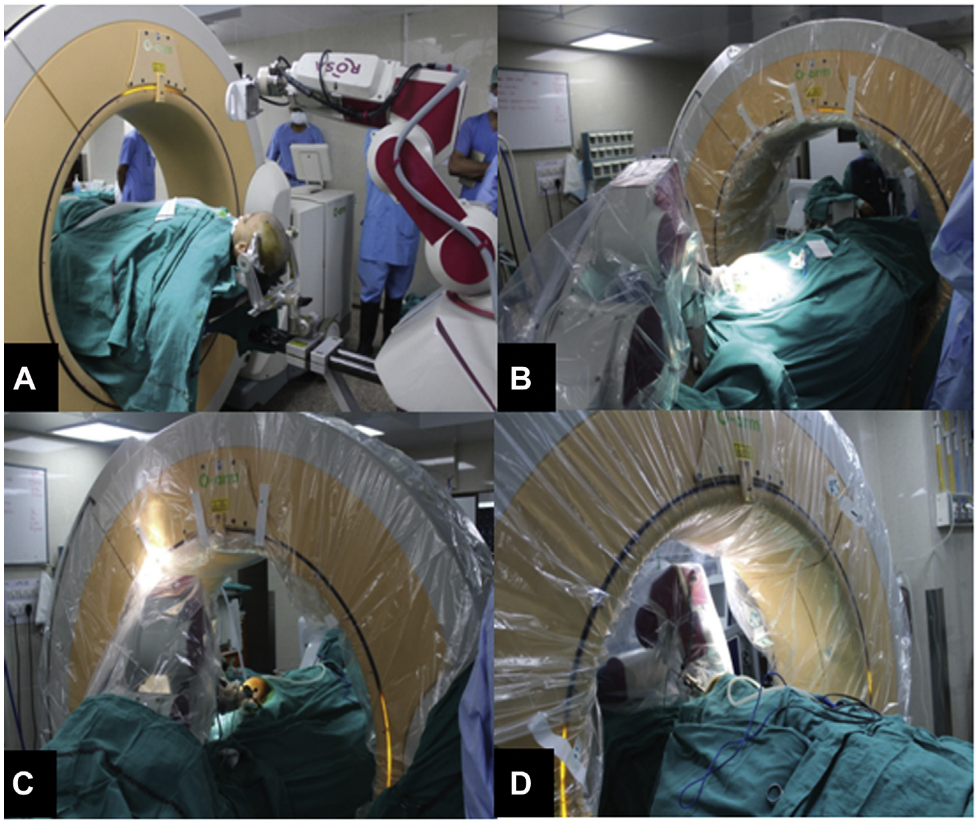

Figure 1. (**A**) Position and height of table in relation to ROSA and O-arm. Mayfield clamp fixation is done in such a manner that a working distance of 75 cm is maintained between the ROSA base and trajectory points. (**B**) Position of O-arm to allow easy access to patient during surgical procedure. (**C**) Memorized position of O-arm in which images are acquired. (**D**) Even in image-acquiring position, a safe distance between ROSA and the O-arm is maintained.

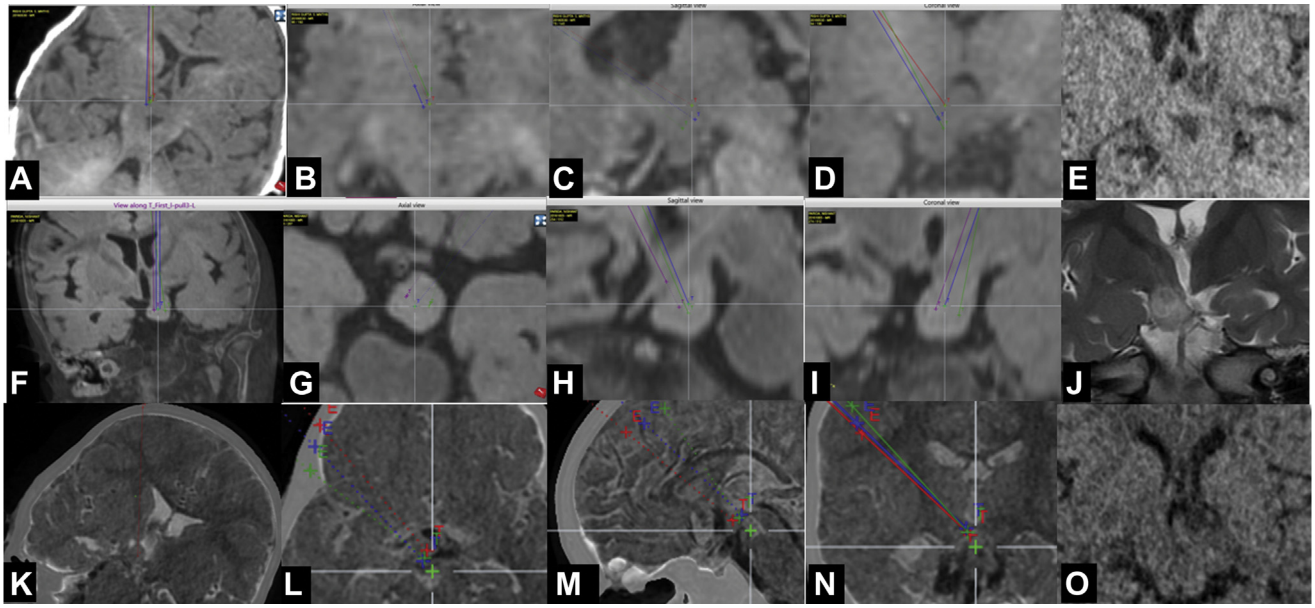

Figure 2. Showing hypothalamic hamartoma in 3 patients with planned trajectories and postoperative image. (**A**–**E**) Show planned trajectories of patient 1. (**A**) View along trajectory. (**B**) Axial image. (**C**) Sagittal image. (**D**) Coronal image. (**E**) Axial computed tomography scan image showing hypodense area of ablation on right side. (**F**–**J**) Show planned trajectories of patient 2. (**F**) View along trajectory. (**G**) Axial image. (**H**) Sagittal image. (**I**) Coronal image. (**J**) Postoperative T2 W coronal image, showing hyperintense area of ablation on right side. (**K**–**O**) Show planned trajectories of third patient (second sitting). (**K**) Entry points on 3-dimensional reconstruction of skull. (**L**) Axial image. (**M**) Sagittal image. (**N**) Coronal image. (**O**) Postoperative image showing hypodense ablated area.

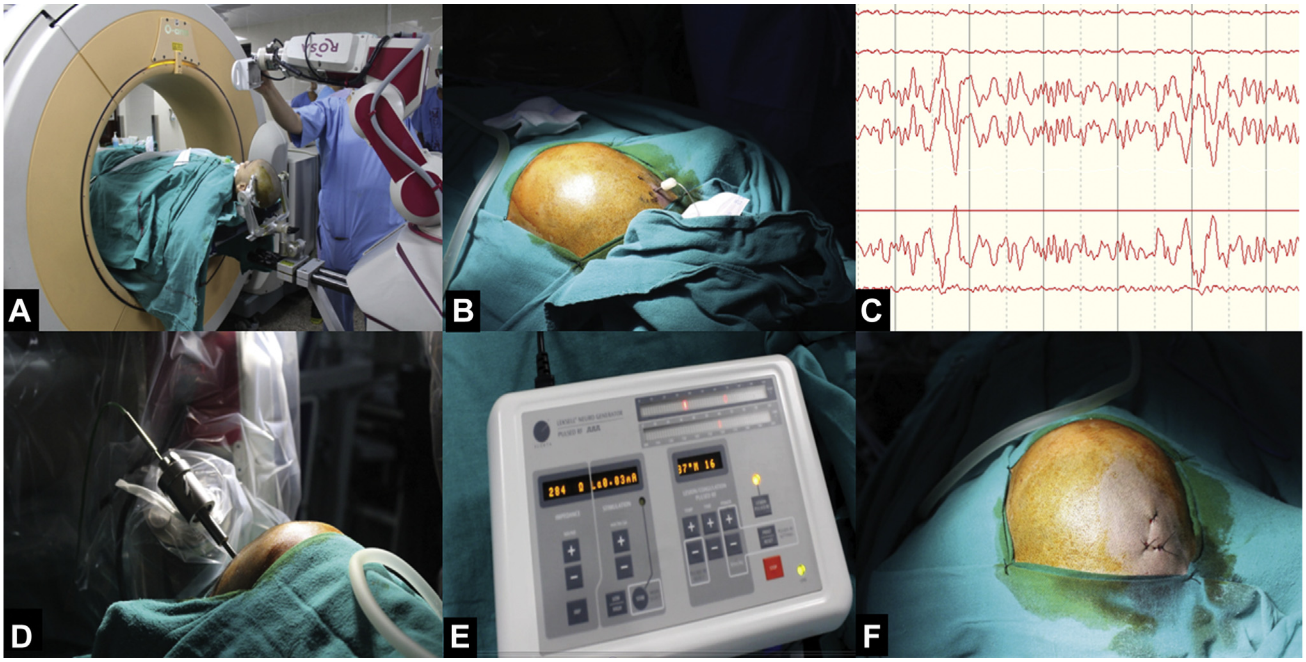

Figure 3. Showing steps of the procedure. (**A**) Registration. (**B**) Placement of depth electrode. (**C**) Recording from depth electrode, showing epileptoform discharges. (**D**) Placement of stereotactic radiofrequency thermocoagulation electrode. (**E**) Lesioning by radiofrequency generator. (**F**) Sutured wound with just single suture at the entry sites.

Table 1. Demographic Data, Clinical Data, Surgical Data, Postoperative Outcomes, and Morbidities of Patients

S. Number	Age/Sex	History	Frequency	VEEG	MRI Size (mm)	Classification (Regis)	Symptoms	Number of Lesions in First SRT	Number of Lesions in Second SRT	ILAE Class	Follow-Up Period (Months) After 1st/2nd SRT	Complications
1.	6 months/Male	5.5 months	3–6/day	Diffuse SWC	18.5 × 10.5 × 12	III	GS	3	-	I	21	None
2.	3 years/Male	1.5 years	10–12/day	Diffuse SWC	12.1 × 12.9 × 13.3	III	GS	4	-	I	19	None
3.	6 months/Male	5.5 months	6–7/day	Diffuse SWC	16.33 × 13.79 × 14.89	III	GS	5	7	I	11	None
4.	10 years/Male	5 years	50–70/day	F4,T4,T3	11.2 × 12.1 × 11.1	III	GS, PP	6	-	I	8	Transient sodium imbalances, hyperthermia
5.	13 years/Male	7 years	20–30/day	F3,F4	23.1 × 26.2 × 14.2	III	GS, BD	12	-	IV	7	None-

VEEG, video EEG; MRI, magnetic resonance imaging; SRT, stereotactic radiofrequency thermocoagulation; ILAE, International League Against Epilepsy; SWC, spike wave complexes; GS, gelastic seizures; HH, hypothalamic hamartoma; PP, precocious puberty; BD, behavioral disorder.

Patient Positioning and Registration

Patient positioning is of critical importance when the O-arm is being used in conjunction with ROSA. The operating table was shifted (maximally) toward the head end of the patient, where ROSA was stationed. Height of the table was also adjusted to provide free access to an O-arm and allowed easy attachment of Mayfield clamp with ROSA. The O-arm was positioned in a way that it did not hinder the robotic arm during surgery. Surface matching registration was performed, and accuracy was confirmed for robotic arm. The robotic arm was used to identify and mark the entry sites. During this maneuver, it was checked that the O-arm was not hindering the robotic arm's movement. The correct position of the acquiring state was confirmed by lateral and anteroposterior radiographs. During surgery, the surgeon could move the O-arm to desired and saved positions to avoid any collision with the robotic arm or table. We used large transparent drapes for covering the entire surface area of the O-arm and ROSA that remains in operative field (**Figure 1**).

Procedure

Using a robotic arm, twist drill holes were made at the entry point. The first hole was made along the trajectory, which was not transgressing the ventricles to avoid cerebrospinal fluid leak. Through this hole, first a depth electrode (8–10 contacts, stereotactic electroencephalogram, PMT Corporation, Chanhassen, Minnesota) is placed to record and confirm the discharges from the hypothalamus. After this, an SRT electrode of 2 mm (monopolar) was placed at the calculated depth and intraoperative CT was performed to localize the electrode. Intraoperative CT (DICOM images) was merged with preoperative MRI, and the SRT electrode was seen running on the predefined trajectory. Deviation of 1 mm was considered as acceptable, provided that is not close to the mesencephalic cisterns. This helped us in localizing the position of the electrode with a high degree of accuracy. Following this, SRT was performed using ELEKTA's (ELEKTA, Stockholm, Sweden) radiofrequency generator and a 2-mm diameter electrode at a temperature of 74°C for a duration of 60 seconds. This produces a coagulative lesion of 5-mm diameter. The electrode was withdrawn once the temperature had reached normal values. The next electrode was placed in a similar manner as described earlier. After completion of the procedure, a single suture was applied at the entry site (**Figures 2** and **3**). Patients were extubated. We performed a postoperative CT scan/noncontrast MRI to rule out any procedure-related bleed/complication and to establish the site of ablation. CT was performed to register only 1 electrode to prevent undue exposure of radiation to the patient. Since most of the targets were placed close to each other, this gave us fairly a good idea regarding the accuracy and prevented major deviation.

RESULTS

We operated on 5 male patients, with age ranging from 6 months to 13 years. Patients' demographic data, clinical data, surgical data, outcome, and follow-up data are shown in **Table 1**. The duration of epilepsy ranged from 5.5 months to 7 years. Video electroencephalography (EEG) in all cases were nonlocalizing and widespread. Video EEG was performed to confirm that these were true seizures. MRI revealed hypothalamic hamartoma of mean size 3.56 ± 2.88 cm^3 (all type III as per Regis classification).[14] The number of lesions varied ranging from 3 to 12. Two patients had incomplete disconnections. In the first patient, a second SRT was done with 7 more lesions,

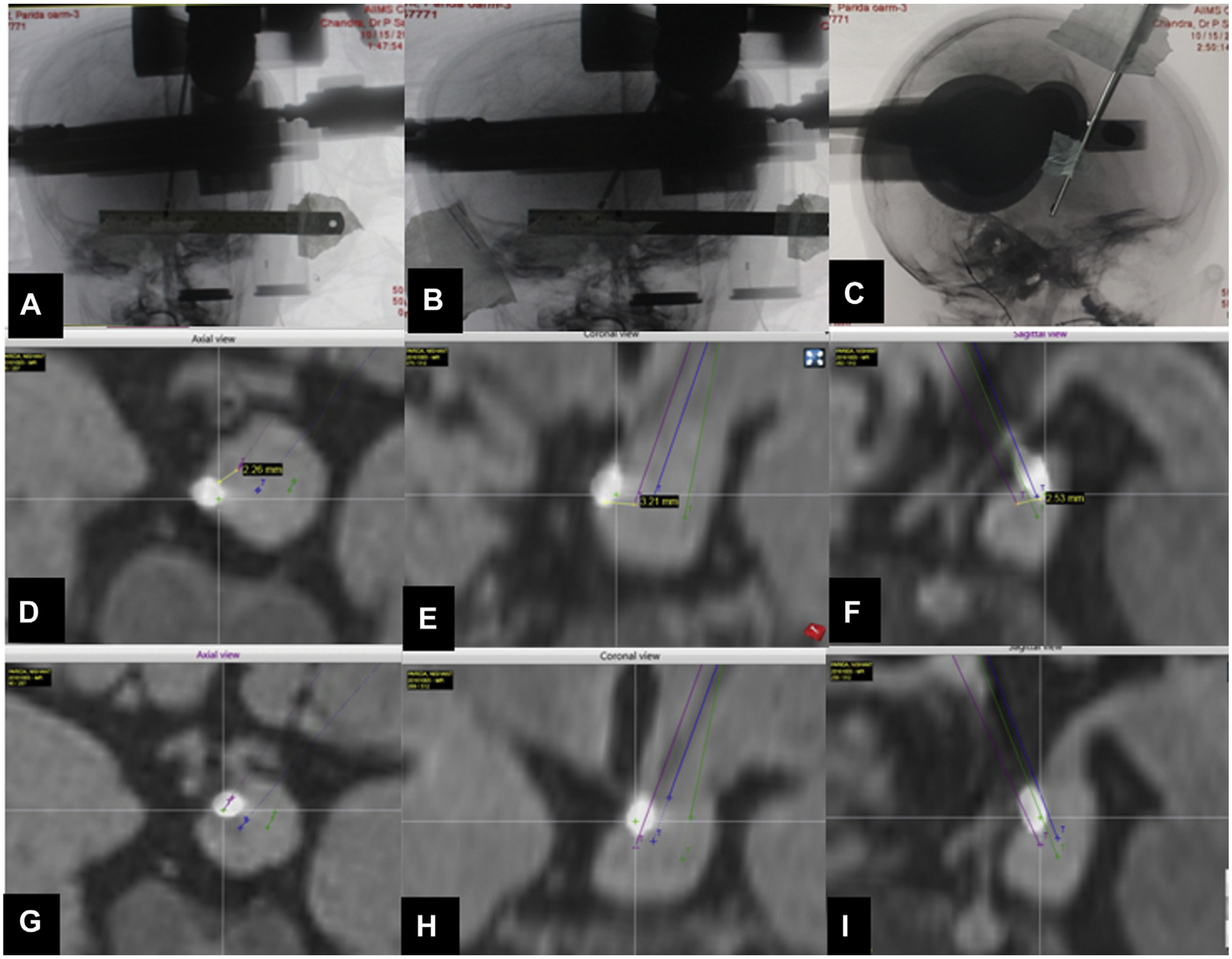

Figure 4. (**A**) Anteroposterior fluoroscopic image showing correct placement of catheter in first trajectory. A scale is placed on the screen to calculate medial or lateral deviation in the trajectory of the next catheter. (**B**) Shows >8 mm deviation from the site of the previous electrode. The calculated deviation should have been 6 mm. This image shows that the present catheter is more medially placed than the desired position. (**C**) Lateral image showing a K wire, denoting the depth of the previous electrode. The depth of the present electrode is shown to be less than optimal. (**D**–**F**) Images show fusion of intraoperative images with MRI and superimposed on planned trajectory. Deviation is evident in axial (**D**), coronal (**E**), and sagittal (**F**). (**G**–**I**) Fused intraoperative computed tomography (CT) and preoperative magnetic resonance imaging (MRI) show correct placement of electrode after revision. Correct placement along the planned trajectory is evident in axial (**G**), coronal (**H**), and sagittal (**I**).

which resulted in International League Against Epilepsy class I outcome. The second patient had an 8.5-cm^3 lesion, in which second sitting was planned, but he moved to another center. All the lesions were performed in such a manner to effectively disconnect the HH from the diencephalic area (see Figure 2), calculating the fact that the effective diameter of each lesion was 5 mm. O-arm was used to confirm the correct position of the electrode, except in 1 case (Figure 4). Figure 5 shows the intended trajectory (red line) and superimposed CT having an electrode running exactly over the preplanned trajectory.

Seizure Outcome and Follow-Up

Four of five (80%) patients achieved International League Against Epilepsy class I outcome. Follow-up ranged from 7 months to 21 months.

Complications

One patient had transient sodium disturbances and hyperthermia, which resolved after 7 days. There was no permanent morbidity or mortality.

DISCUSSION

HH is an intrinsically epileptogenic lesion causing intractable epilepsy, characterized by GS. Though most commonly occurring in the hypothalamic area, it may also occur in other areas like the cerebellum to cause epilepsy.[15] Cognitive impairment and behavioral disorders can also occur due to epileptic encephalopathy.[16-18] These can improve with timely surgical intervention.[19,20] These include MS (pterional, transcallosal, or orbitofrontal approaches),[21,22] ED,[23] GKS,[24,25] SRT, and

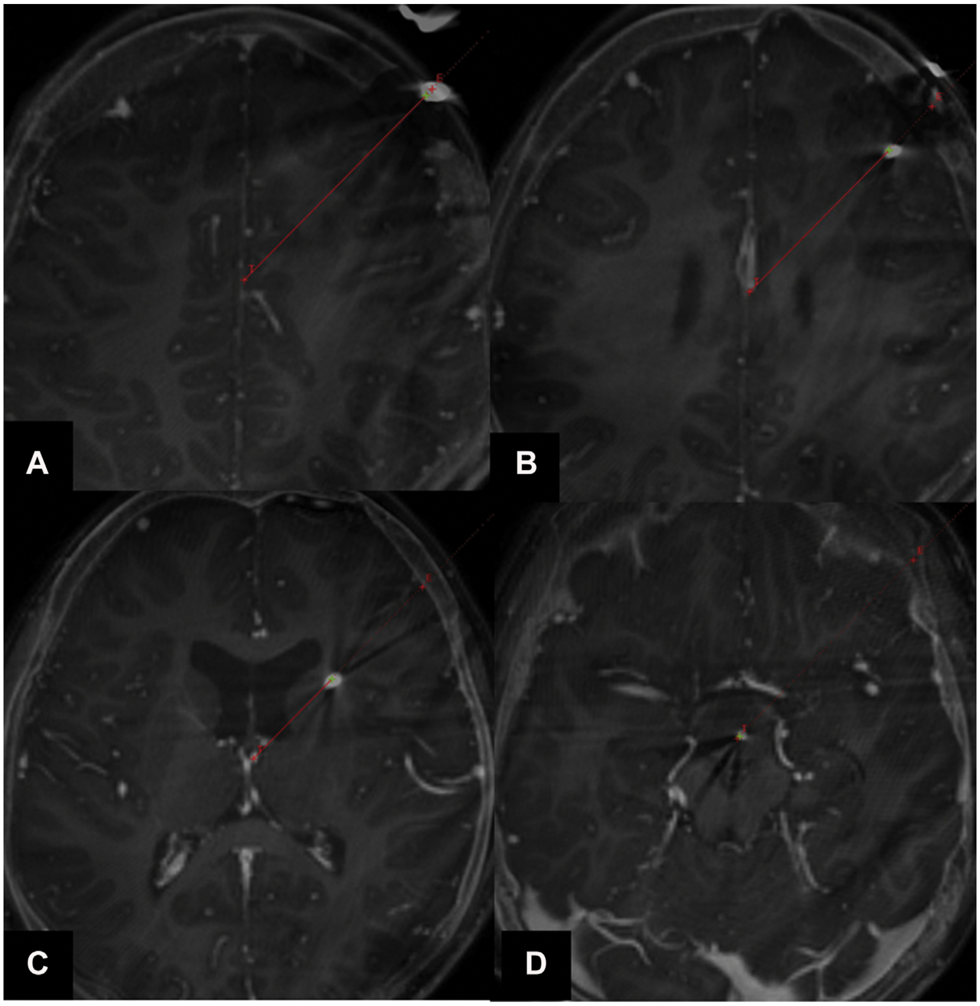

Figure 5. Intended trajectory (red line) and superimposed computed tomography having electrode exactly running over the preplanned trajectory. **A–D** shows the entry to target points.

LITT,[10,26] which have been used for the resection or dissection of HHs.

MS has a success rate of 50%–60%, though higher mortality and morbidity have been ascribed to it, as it involves dissection around critical structures. Endoscopic surgery is less invasive, but since it's difficult to differentiate normal hypothalamus from hamartomatous tissue, achieving complete disconnection can be a challenge, through endoscopic transventricular approach. In addition, since the ventricles are not enlarged, the ED must be guided through neuronavigation through the contralateral ventricle, which again raises the issues of surgical access, limitation of the procedure in larger HH, and potential damage to the fornix due to the access through the foramen of Munro. GKS is a safer alternative to MS, but large and giant HHs are not suitable. Seizure exacerbation has also been reported in the immediate post-GKS phase in some patients.[5] LITT is a minimally invasive procedure and in recent times has shown a better safety profile. LITT is performed under intraoperative MRI monitoring. While thermographic scanning provides, intraoperative validation of location and size of ablation,[10,26] this setup is not readily available in most parts of the world. In addition, since the laser fiberoptic cables are disposable and expensive, they raise the issue of its usage, especially in resource-limited countries. In its comparison, SRT can be readily performed, wherever facilities for stereotaxy are available. The only other requirement is availability of radiofrequency generator and fluoroscopy.

Traditionally, SRT is performed, using a stereotactic frame, and position of the electrode is confirmed using fluoroscopy.[5] The exact location of the electrode in the 3-D space is difficult to interpret on fluoroscopic images. Compared with LITT, no intraoperative thermographic monitoring can be performed. Due to the reasons mentioned earlier, neurosurgeons are skeptical of SRT's usage in HHs and therefore we recommend the O arm + MRI fusion + SRT as a better procedure than only MRI-guided SRT. We could overcome the shortcomings in the SRT procedure by making the following alterations to the technique:

1. Accurate placement of electrode was done using robotic assistance. This also decreased the time consumed in adjusting the frame for every new trajectory.
2. Before ablation, we recorded EEG from the site using a depth electrode. This helped in confirming the site.
3. Intraoperative CT was done to confirm the exact location of the electrode. These images were merged with preoperative MRI and superimposed on planned trajectories to understand the exact location of the electrode.

In a series of 202 patients, Servello et al[27] reported that intraoperative CT (by O-arm) is a “fast, safe and useful tool in the evaluation” of the implanted deep brain stimulation lead. Similarly, Lee et al[28] have also demonstrated O-arm’s utility in “accurate 3D visualization of depth and subdural electrodes.” Intraoperative images, when merged with preoperative MRI on which trajectories were planned, yield a composite image. When this is superimposed on a planned trajectory, it provides highly accurate localization of the SRT electrode. This improves the safety profile of SRT. Use of ROSA to accurately place DBS[29,30] and LITT catheters[31,32] has been well documented. In a recent RCT by the author, surgery was shown to be better than medical treatment alone.[33]

We have demonstrated that use of the robotic arm and O-arm, in sync, can allow a surgeon to place SRT electrodes with a high degree of precision. Thus even in the absence of intraoperative thermographic monitoring, as done in LITT, SRT can be performed safely for HHs. This procedure has an added advantage of lower costs. Minimal consumable items are used during the procedure since the electrode of SRT is reusable. Moreover, it can be performed in the absence of intraoperative MRI. Intraoperative CT (O-arm) is more readily available at many centers. We do accept that the main shortcoming of this technical report is the short follow-up. However, the main purpose of this report was to demonstrate the safety, efficacy and accuracy of this technique.

CONCLUSIONS

SRT electrodes can be placed accurately using robotic assistance and seem to be safe. Intraoperative validation of an electrode’s location by doing intraoperative CT can help in reconfirming the site of the electrode in comparison with a planned trajectory.

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