Robotic thermocoagulative hemispherotomy: concept, feasibility, outcomes, and safety of a new “bloodless” technique

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OBJECTIVE The authors present a new “bloodless” technique for minimally invasive robotic thermocoagulative hemispherotomy (ROTCH). Such a method is being described in the literature for the first time.

METHODS A robotic system was used to plan five sets of different trajectories: anterior disconnection, middle disconnection, posterior disconnection, corpus callosotomy, and temporal stem and amygdalar disconnection. A special technique, called the “X” technique, allowed planar disconnection. Registration was performed with surface landmarks (n = 5) and bone fiducials (n = 1). Co-registration with O-arm images was performed one or two times to confirm the trajectories (once for middle disconnection, and once for disconnection of the temporal stem and amygdala or body of the corpus callosum). Impedance measured before ablation allowed for minor adjustments. Radiofrequency ablation was performed at 75°C–80°C for 60 seconds. Surgical procedures were performed with multiple twist drills. After removal of the electrode, glue was used to prevent CSF leak, and a single stitch was applied. Follow-up CT and MRI were immediately performed.

RESULTS The pathologies included Rasmussen’s encephalitis (n = 2), hemispheric cortical dysplasia (n = 2), posttraumatic encephalomalacia (n = 1), and perinatal insult (n = 1). The mean ± SD (range) age was 6.7 ± 3.6 years (5 months to 10.2 years), and the right side was affected in 4 patients. The mean ± SD seizure frequency was 7.4 ± 5.6 seizures per day (1 patient had epilepsy partialis continua). The mean ± SD number of trajectories was 15.3 ± 2.5, and the mean ± SD number of lesions was 108 ± 25.8. The mean ± SD maximum numbers of trajectories and lesions required for middle disconnection were 7.1 ± 1.7 and 57.5 ± 18.4, respectively. All but 1 patient had class 1 outcomes according to the International League Against Epilepsy Outcome Scale at a mean ± SD (range) follow-up of 13.5 ± 1.6 (12–16) months; the remaining patient had a class 2 outcome. The estimated blood loss was < 5 ml for all patients. Complications included repeat surgery (after 2 weeks) for a “skip” area (n = 1) and a small temporal hematoma (n = 1), which resolved.

CONCLUSIONS ROTCH seems to be a safe, feasible, and bloodless procedure, with a very low morbidity rate and promising outcomes.

https://thejns.org/doi/abs/10.3171/2020.10.PEDS20673

KEYWORDS hemispherotomy; robotic; thermocoagulation; radiofrequency; minimally invasive; epilepsy; hemimegalencephaly; Rasmussen’s encephalitis; surgical technique
technique has become a standard procedure at our institution, and others have also adopted it.13,15,16

This experience pushed us to develop the robotic thermocoagulative hemispherotomy (ROTC) technique. Briefly, other technologies encouraged us to pioneer ROTCH, as follows: 1) establish robotic systems that allow multiple trajectories in a shorter time; 2) report our experience treating large hypothalamic hamartoma with radiofrequency thermocoagulation;3 3) demonstrate corpus callosotomy with laser ablation;18,19 and 4) report our experience of coregistering robotic trajectories with O-arm (Medtronic) imaging to enhance the accuracy of the trajectories significantly.14

Here, we describe the proof of concept, feasibility, safety, efficacy, and early results of ROTCH. Incidentally, “rotch” is also the name of a small dove-like arctic bird, which we felt also symbolized the minimally invasive nature of our procedure.

**Methods**

**Background**

Six patients underwent ROTCH (performed by the senior author) (Table 1). We obtained clearance from our institution’s ethics committee. We initially treated patients with significant cortical atrophy and severe thinning of the corpus callosum (CC), which was virtually absent. Thus, we needed to perform only basal (bilateral ganglionic–thalamic) disconnection on these patients (Table 1 and Figs. 1–5). We later performed ROTCH to treat patients with more complex situations, including 2 patients without atrophy (Figs. 6–8). In addition, before surgery, we performed several mock trials (on phantom brain models) and spent significant time planning the trajectories and deciding the optimal plane of disconnection. We also developed the “X” technique, which allowed us to pass as many as three trajectories through a single drill hole to create contiguous planar disconnections. We obtained detailed informed consent (including the right to publish MR and patient images) from all patients. The first patient had significant cortical atrophy with large ventricles and required only basal nuclei disconnection, the dimensions of which were similar to those of hypothalamic hamartoma, and thus the procedure was similar to radiofrequency ablative disconnection of hypothalamic hamartoma.

**Technique**

**Trajectory-Planning Strategies**

We followed standard prerequisites for imaging and fusion, the most important of which was the fusion of preoperative MR images (with contrast to delineate vessels). We performed imaging by using the prescribed protocol for ROSA (Zimmer Biomet), and we used the standard neuravigation protocol for CT. Planning was always performed 1 day before surgery. Initially, this required approximately 4–6 hours, but later the duration was reduced to 1–2 hours. MRI and CT scans were fused with ROSA software, and we calculated the trajectories by using the 3D images. During planning, we kept in mind the standard steps that we follow in all vertical interhemispheric endoscopic hemispherotomy procedures (Figs. 1 and 2).20–22

Broadly, we classified the trajectories by using anatomical steps. These included extraventricular trajectories for 1) corpus callosotomy, 2) temporal stem disconnection, and 3) amygdalar disconnection. The transventricular trajectories were for 4) anterior disconnection, 5) middle disconnection, and 6) posterior disconnection. We first performed the extraventricular trajectories.

**Corpus Callosotomy**

Planning corpus callosotomy was more challenging than that for all other trajectories (Fig. 2). The CC has a midline orientation and two curves with major vascular structures (Table 2). We always placed the entry point for the trajectories ipsilateral and paramedian (Figs. 2 and 6). We were able to lesion the entire CC with two trajectories in patient 1, four in patient 3, three in patients 4 and 5, and four in patient 6 (Figs. 1, 2, 6, and 7). We were able to lesion the body of the CC by using two trajectories. First,

**TABLE 1. Patient characteristics**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age, Sex</th>
<th>Duration of Seizures</th>
<th>Seizure Frequency</th>
<th>Side</th>
<th>Etiology</th>
<th>No. of Trajectories (lesions)</th>
<th>Outcome ILAE Class</th>
<th>Remarks</th>
<th>Follow-Up, Mos</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 yrs, F</td>
<td>3.2 yrs</td>
<td>5–8/day</td>
<td>Rt</td>
<td>Rasmussen’s encephalitis</td>
<td>15 (71)</td>
<td>2</td>
<td>None</td>
<td>14.5</td>
</tr>
<tr>
<td>2</td>
<td>6 yrs, M</td>
<td>5.8 yrs</td>
<td>5–6/day</td>
<td>Lt</td>
<td>Posttraumatic encephalomalacia</td>
<td>17 (101)</td>
<td>1*</td>
<td>2nd surgery performed to provide lesions in skip areas</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>9 yrs, F</td>
<td>7 yrs</td>
<td>Epilepsia partialis continua</td>
<td>Rt</td>
<td>Rasmussen’s encephalitis</td>
<td>20 (149)</td>
<td>1</td>
<td>3rd nerve palsy &amp; small hematoma in rt temporal lobe, which resolved on MRI</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>10 yrs, M</td>
<td>9 yrs</td>
<td>2–3/day</td>
<td>Rt</td>
<td>Hemispheric cortical dysplasia</td>
<td>12 (98)</td>
<td>1</td>
<td>None</td>
<td>12.5</td>
</tr>
<tr>
<td>5</td>
<td>11 yrs, M</td>
<td>8 yrs</td>
<td>2–3/day</td>
<td>Lt</td>
<td>Perinatal insult</td>
<td>14 (134)</td>
<td>1</td>
<td>No seizures from postop day 1 through 1.5 mos</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>5 mos, M</td>
<td>5 mos</td>
<td>15–20/day</td>
<td>Rt</td>
<td>Hemispheric cortical dysplasia</td>
<td>14 (97)</td>
<td>1</td>
<td>None</td>
<td>12</td>
</tr>
</tbody>
</table>

* Seizures were reduced by 90% after the first surgery, and class 1 outcome was achieved after the second surgery.
a transparietal trajectory was used to lesion the anterior half of the CC. Then, a transfrontal trajectory was used to lesion the posterior half of the CC. We included the genu and splenium depending on their atrophy and the angle to the body of the CC in the sagittal plane. Hence, in 1 patient with Rasmussen’s encephalitis (patient 3), two more trajectories were used: one for the genu (vertical transfrontal) and the other for the splenium (vertical transparietal).

**Temporal Stem Disconnection**

The temporal stem is a large bundle of white matter with an anteroposterior extent. We targeted only the portion at the level of the limen insulae because we disconnected the rest while performing middle disconnection. The temporal stem lies in a different plane, anterior and lateral to the amygdala, and we needed to disconnect this while performing vertical hemispherotomy. The temporal stem was targeted with an orthogonal trajectory via an entry point in the anterior temporal lobe, anterior to the temporal horn through the inferior temporal gyrus.

**Amygdalar Disconnection**

We targeted the ventral portion of the amygdala with a single orthogonal trajectory through the anterior temporal pole (Fig. 1E). We avoided ventricular entry in all cases by placing the trajectory anterior to the temporal horn.

**Posterior Disconnection**

Posterior disconnection was the first transventricular trajectory, which passed through the atrium and targeted the tail of the hippocampus (Fig. 3). We targeted the junction of the tail and the body of hippocampus in 2 patients to avoid the choroid plexus, which covered the entire surface of the hippocampal tail. This step disconnected the efferents of the temporal lobe (fornix) that are connected to diencephalic structures (mammillary bodies). We used a single trajectory in all patients.

**Anterior Disconnection**

We used multiple trajectories to disconnect the frontal lobe from the diencephalon (Fig. 1). Disconnection extended from the falx cerebri medially until the temporal stem laterally, and inferiorly until the basal frontal lobe. We used the olfactory tract bifurcation as the landmark for the posterior limit of anterior disconnection, similar to the open technique. The lateral point of the anterior disconnection must be continuous with the anterior portion of the middle disconnection to ensure complete disconnection (Fig. 5F and G; see the junction of the limbs that form the “7”-shaped disconnection).

**Middle Disconnection**

The middle disconnection passed roughly along the internal capsule, disconnecting the thalamus and caudate medially from the pallidum placed laterally (Figs. 1 and 5–8). We placed the trajectories to pass vertically, starting from the frontal and parietal cortices and passing through the body of the lateral ventricle and internal capsule, and

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**FIG. 1.** Trajectories used to perform radiofrequency thermocoagulative hemispherotomy with the X technique for middle disconnection (MDC), anterior disconnection (ADC), and amygdala–temporal stem disconnection (Amg & TS). Middle disconnection (7–8 trajectories and 60–70 lesions) was performed in the parasagittal plane (A–C, E, H, and I). Anterior disconnection (roughly consisting of 3–5 trajectories and 15–25 lesions) (C) was performed in the coronal plane (B–D, F, and G). In contrast, the trajectory for lesioning the amygdala and temporal stem was performed through the temporal bone in a lateral-to-medial direction (C). The X technique allows three trajectories to be performed with a single twist drill (A–C), thus reducing the number of skin sutures. Figure is available in color online only.
finally reach the temporal horn (Fig. 5C). This part of the disconnection had the greatest number of trajectories.

The X Technique

To avoid leaving behind “skip” areas, we developed the X technique. In this technique (Figs. 2 and 3), we planned three trajectories through the same drill hole in such a manner that these trajectories crossed each other like an “X.” The X technique allowed us to perform planar disconnection at the subcortical level. Using this technique, we were able to pass multiple trajectories through the same drill hole, thus reducing the number of skin sutures. In addition, the proximity of the trajectories ensured continuous planar disconnection in the vertical plane, thus achieving complete disconnection (Video 1).

VIDEO 1. Brief presentation of the technique for performing a single lesion with ROTCH. Copyright P. Sarat Chandra. Published with permission. Click here to view.

Surgical Technique

We used a position similar to those of other robot-assisted procedures performed with ROSA. We preferred to use the Leksell frame. We performed a trial run for all trajectories by marking the entry points before draping. This allowed the plan to be modified if a trajectory was not feasible. In our series, the planned trajectory was modified for only 1 patient, who required a posterior callosal trajectory. Here, we could not reach the entry point with the robotic arm, despite changing the orientation of the robotic arm. In all cases, we used a twist drill (2.5-mm diameter) directly over the skin, after the robotic adaptor was placed flush with the skin. Then, we performed direct drilling from the skin down to the dura mater. The dura was then coagulated with an insulated diathermy probe. We measured the distance to the target on the ROSA workstation. After this, we passed the stereotactic thermocoagulation electrode (2-mm diameter, monopolar) to the calculated depth, and we performed CT with the O-arm. Then, we merged the CT DICOM images with preoperative MR images to confirm the position of the stereotactic thermocoagulation electrode. We considered a deviation as large as 1 mm to be acceptable, provided it was not close to any cisterns (e.g., mesencephalic cisterns), while we performed disconnection of the amygdala and temporal stem. Following this, we performed radiofrequency lesioning (Elekta) with a 2-mm-diameter electrode at a temperature of 75°C–80°C for 60 seconds. This produced a lesion with a diameter of 5–8 mm. We withdrew the electrode after the temperature reached normal values (usually after another minute). We took care to gently rotate the electrode a couple of times before removing it to prevent traction over the surrounding tissues.
Impedance Check

Simultaneous impedance recordings gave us good additional feedback. Impedance ranged from 180 to 220 $\Omega$ for the cortical mantle and from 220 to 260 $\Omega$ for the basal ganglia. Impedance was usually < 140 $\Omega$ for the ventricles. Impedance was monitored with both sound and the values of the generator: low-frequency sound indicated lower impedance, and high-frequency sound indicated higher impedance (Video 1). This was especially useful when the electrode tip at the CSF-brain interface indicated impedance values < 140 $\Omega$. In such instances, the electrode was advanced a few millimeters until impedance increased to approximately 200 $\Omega$ (thereby confirming its position in the parenchyma). Hence, a combination of impedance feedback and O-arm coregistration allowed us to accurately place lesions over the targets.

Use of an O-Arm

Use of an O-arm was beneficial and allowed real-time confirmation of the robotic trajectory. We performed lesioning along the planned trajectories according to the preset sequence. To minimize radiation exposure, we usually used an O-arm one or two times to verify the position of the electrode: once for middle disconnection and once for disconnection of either the CC or amygdala. We checked the coregistered images on the monitor or laptop (Video 1).

Outcomes

The primary outcome measures included assessments of seizure frequency and severity according to the ILAE Outcome Scale. Secondary outcome measures were the Stanford Binet Kamat Test for IQ/social quotient, the

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**FIG. 3.** Trajectory used to perform posterior disconnection. A single trajectory (consisting of 2–3 lesions) is shown. The target is at the junction where the hippocampus and the fornix turn from the temporal horn into the body of the lateral ventricle and consists of temporal efferents (i.e., the tail of the hippocampus and fornix). The trajectory starts at the parietal eminence and passes inferiorly and medially to reach the target (A). Axial (B), coronal (C), and sagittal (D) sections show the target of posterior disconnection. Figure is available in color online only.
Child Behavior Checklist for behavioral problems, and the Pediatric Quality of Life Inventory for quality of life.

Results

A total of 6 patients have undergone ROTCH since May 2019 (Tables 1 and 2, Figs. 1–8). We scheduled our surgical procedures to provide us with a good learning curve (i.e., we initially treated a patient with large atrophy, and then patients with increasingly complex conditions). The mean ± SD (range) age was 6.7 ± 3.6 years (5 months to 10.2 years), and 4 patients were male. We performed the procedure on the right side in 4 patients (Table 1). The mean ± SD duration of epilepsy was 5.6 ± 2.9 years, with a mean ± SD frequency of 7.4 ± 5.6 seizures per day. One patient had epilepsia partialis continua and 2–3 generalized seizures per day. The pathologies included Rasmussen’s encephalitis (2 patients), posttraumatic encephalomalacia (2 patients), hemispheric cortical dysplasia (1 patient), and perinatal insult (1 patient).

We always planned the trajectories at least 1 day before surgery, and this required approximately 2–3 hours. The mean shift of the probe and the trajectory was less than 0.3 mm in all patients, and the most common directions of shift were posterior and lateral. The O-arm was used once for 4 patients (who underwent middle disconnection) and twice for 2 patients (one patient underwent middle disconnection and disconnection of the temporal stem, and the other patient underwent middle disconnection and disconnection of the CC body). The mean ± SD number of trajectories was 15.3 ± 2.5 (12–20), and the mean ± SD number of lesions was 108 ± 25.8. The minimum (n = 71) and maximum (n = 149) numbers of lesions were applied to patients with Rasmussen’s encephalitis. The mean ± SD numbers of trajectories and lesions for the various disconnection planes were 3.5 ± 2.1 trajectories and 18.2 ± 10 lesions for anterior disconnection, 7.1 ± 1.7 trajectories and 57.5 ± 18.4 lesions for middle disconnection, 1 trajectory and 3 lesions in each patient who underwent posterior disconnection, 3.2 ± 0.74 trajectories and 29.2 ± 10.4 lesions for CC disconnection, 1.0 ± 0.5 trajectories and 4.8 ± 2.6 lesions for disconnection of the amygdala, and 1 trajectory each and 3.1 ± 3.4 lesions in the 3 patients who underwent disconnection of the temporal stem.

The mean ± SD impedance of the parenchyma was 230 ± 32 Ω before lesioning. The temperature was set to 76°C (but the lesion temperature sometimes increased to 83°C), and lesioning was performed for 60 seconds in all patients. One patient required repeat surgery (after 2 weeks) for a skip lesion, after which the patient was seizure free (Tables 1 and 2). We performed the second surgery with only two trajectories and 8 lesions. We were able to avoid any skip areas using the X technique.

Blood Loss, Operative Time, and Hospital Stay

The mean estimated blood loss was < 5 ml for all patients, and blood loss only occurred during twist-drill craniostomy. The mean ± SD (range) duration of surgery was 10.58 ± 3.3 (5.5–14.5) hours, and the mean ± SD length of hospital stay was 5.5 ± 0.95 days. Most patients were fit for discharge within 1–2 days, but considering the new nature of the procedure, we kept the patients in the hospital. We extubated 3 of 6 patients immediately after surgery, and the other patients were electively ventilated overnight. CT performed immediately postoperatively showed radiofrequency thermocoagulation as a curvilinear hypodensity on axial sections (Figs. 3–5, 7, and 8). All patients underwent postoperative MRI to confirm adequate disconnection. One patient underwent a second surgery and a repeat disconnection.

Outcomes and Complications

With the exception of 1 patient with an ILAE class 2 outcome, all patients had a class 1 outcome (mean ± SD [range] follow-up 13.5 ± 1.6 [12–16] months).
Only 1 patient developed any complications. None developed postoperative fevers, which were observed in as many as 50% of our patients who underwent endoscopic hemispherotomy and open procedures.5,21,24,25 One patient with Rasmussen’s encephalitis developed a small hematoma in the amygdala, which resolved completely with conservative management. This patient also developed third nerve palsy, for which we advised surgical correction for strabismus and ptosis.

We assessed the secondary outcome scores at 1 year for 5 of 6 patients (1 patient was only 3 months old). No significant differences were noted in IQ (mean ± SD estimated IQ score 62 ± 18.4 preoperatively vs 64.3 ± 12.6 postoperatively). The Pediatric Quality of Life Inventory (normal range 0–100; mean in normal population 65.4) improved significantly after surgery (mean ± SD total T-score 42 ± 9.1 preoperatively vs 63.5 ± 11.5 postoperatively; p < 0.01). The mean ± SD Stanford Binet Kamat Test score (normal range 85–100) was 63 ± 12.64 preoperatively versus 63.25 ± 4.99 at follow-up (p value not significant). The mean ± SD total score on the Child Behavior Checklist (normal score < 60) was 71.0 ± 6.5 preoperatively versus 65.2 ± 4.99 at follow-up (p value not significant).

**Discussion**

Hemispheric surgery is the only definitive treatment of drug-resistant epilepsy with a hemispheric substrate. It usually involves pathologies such as Rasmussen’s encephalitis, hemimegalencephaly, postinfarct epilepsy, and hemispheric cortical dysplasia. Less commonly, hemispheric surgery can involve pathologies such as Sturge-Weber’s syndrome and perinatal insult.1,3–7,9,13,16–30 A recent randomized controlled trial demonstrated at least a 10-fold improvement with surgical intervention compared with medical therapy for children with drug-resistant epilepsy.24,25

![FIG. 5. The X technique. A–C: A single twist-drill craniostomy was used to create three trajectories with a divergent pattern to allow planar disconnection. A: The blue dots indicate thermocoagulative lesions, which are approximately 5–8 mm in size and spherical in shape (produced with a temperature of 75°C–80°C for 60 seconds). B: Superior view of the entry points of the X technique. A robotic adaptor was held flush with the skin to allow the surgeon to drill in multiple directions. Thus, after a hole was drilled, its direction could be changed and reshaped with the support of the robotic adaptor (see Video 1). The trajectories are placed so that the distance between the inferior limits of each trajectory is around 3 mm. C: Disconnection on the coronal section of an MR image. D: The principle of lesion placement. An overlap of 2 mm is allowed. Thus, if applying a 75°C burn for 60 seconds produces a 5-mm lesion, lesions would have to be spaced every 3 mm to produce contiguous lesions with 2-mm overlap. Similarly, applying an 80°C burn for 60 seconds would produce an 8-mm lesion; thus, lesions are applied every 3 mm. The electrode is advanced 3 mm from the target (superior part of the disconnection) until it reaches the most inferior part of the hemispheric disconnection. The temperature in some areas may be low (e.g., only 50°C at an impedance of 261 Ω). This may happen if the burns lesions are very close to each other. E: The hemispheric disconnection footplate (inner red semicircle) is approximately one-fifth of the cortical surface (outer red semicircle). Thus, a thermocoagulative hemispheric disconnection plane is possible. F and G: Disconnection on axial CT (F; immediately postoperative) and MRI (G; obtained within 1 week postoperatively). Figure is available in color online only.](image-url)
Because most hemispheric surgical procedures are performed in children, there have been recent developments to make these procedures minimally invasive (especially endoscopic techniques) and to prevent complications such as hypothermia and blood loss. In addition, laser ablation of the CC is increasingly minimally invasive. Interstitial laser ablation is a promising technique for safe lesioning, but it has certain shortcomings, such as the inability to use multiple trajectories, high cost, and poor availability in some countries. Kameyama et al. and Fukuda et al. popularized frame-based, stereotactic, radiofrequency thermocoagulative disconnection for hypothalamic hamartoma. With this technique, they demonstrated the safety, efficacy, and good outcomes of multiple radiofrequency thermocoagulation for large hamartomas. We developed O-arm–guided robotic surgical procedures to perform radiofrequency ablative disconnection of moderate to large hamartomas. This procedure is safe and effective, even for large (> 30 burns in a single sitting) hypothalamic hamartomas.

Our experience with endoscopy provided us with the necessary information to understand the critical anatomy of this region. In addition, our experience using robotic systems (ROSA) and O-arm provided us with the neces-
sary knowledge and expertise to enhance the safety and accuracy of electrode placement. We were also quite satisfied with radiofrequency thermocoagulation, especially its ability to perform several lesions in the same sitting. The abovementioned strategies provided us with the necessary tools to develop ROTCH.

Based on our calculations, we concluded that creating approximately 7–12 trajectories with 7–12 lesions along each trajectory would achieve optimal hemispheric disconnection in most patients (Fig. 2E). Furthermore, by using the X technique, we could reduce the number of skin sutures and also provide contiguous planar disconnection (Figs. 2 and 3).

Overall, the patients tolerated the procedure very well. Postoperatively, 3 patients continued to receive ventilation overnight and were extubated the next day. The other 3 patients were extubated immediately after surgery. Postoperatively, we administered antibiotics for 2 days and steroids for 1 day and immediately performed postoperative noncontrast CT on all patients. We did not note any instances of intraoperative hyperthermia. We found the procedure to be very satisfying for the following reasons: negligible blood loss, rapid recovery and tolerability (especially in very young children), the absence of postoperative fevers, the ease of performing the procedure, the minimally invasive nature of the surgery, and a significantly shortened hospital stay. We believe that this is a significant breakthrough because blood loss is a well-known complication of hemispheric surgery.

We accept the significant limitations of the procedure, which include the long operative time and risk of creating skip lesions. However, if this happens, a second surgery may be easily performed. There is also a potential risk of hematoma formation because this is a blind procedure. However, to date, radiofrequency thermocoagulation has been used to treat several hundred patients in the literature and is considered safe. One of our patients developed a small amygdalar hematoma. Since this, we have been more careful to place the lesions more laterally. Five patients achieved an ILAE class 1 outcome at the last follow-up (1 patient had a class 2 outcome).

The extended operative time is the major shortcoming of this procedure. This is because the existing single-arm robotic systems can produce only 1 lesion at one time. Then again, this procedure creates exciting future opportunities to develop automated robotic systems with radiofrequency electrodes capable of simultaneously performing multiple lesions with thermocoagulation. For instance, if a radiofrequency electrode has 10 points for performing thermocoagulation, then complete linear disconnection...
could be performed in one-tenth of the time (1 minute to create lesions plus 1 minute for cooling would take a total of 2 minutes to produce 10 lesions instead of 1 lesion). Thus, the time required to produce 125 lesions would be only 25 minutes. Hence, the entire procedure could be completed within 1 hour. In addition, artificial intelligence could be integrated into the procedure, which is repetitive with a limited learning curve. Another option to decrease operative time is to combine thermocoagulation with open surgery.

The small cohort and short follow-up period are major shortcomings of this study. However, the primary purpose of this study was to demonstrate the safety, efficacy, and proof of concept of ROTCH.

Conclusions

In this pilot study, we performed a novel surgical technique, ROTCH, on 6 patients. After at least 1 year of follow-up, 5 patients had an ILAE class 1 outcome and 1 patient had an ILAE class 2 outcome. The procedure is mostly minimally invasive, and patients had negligible blood loss. Also, this study demonstrated the feasibility, safety, efficacy, and proof of concept of this procedure. The initial results seem to be good and promising.

Key Points

- We describe a new “bloodless” technique (≤ 5-ml es-

FIG. 8. Patient 6. A 5-month-old boy presented with seizures since the 3rd day of life. At the time of presentation to us, the child had 15–20 seizures per day. A and B: Axial (A) and coronal (B) MR images showing right hemispheric cortical dysplasia. C: The child was seizure free on the next day after radiofrequency thermocoagulation hemispherotomy. D and E: Various disconnections are shown, including anterior disconnection (upper arrow) and posterior disconnection (lower arrow). The lesions are between the amygdalar and temporal stem disconnections. F and G: Middle disconnections (arrow) are shown. H and I: The stitches were removed on day 7 after surgery, and healing was entirely satisfactory. Figure is available in color online only.
timated blood loss) used to perform hemispherotomy with robot-guided radiofrequency thermocoagulation.

• The technique, robotic thermocoagulative hemispherotomy (ROTCH), is performed with multiple twist-drill holes and a single stitch for each opening.

• ROTCH was used to perform corpus callosotomy and anterior, middle, posterior, and temporal stem–amygdala disconnections.

• The unique “X” technique allowed vertical planar disconnection with a minimal number of openings.

• Of 6 patients who underwent operations (2 patients with Rasmussen's encephalitis, 1 with posttraumatic encephalomalacia, 2 with hemispheric cortical dysplasia, and 1 with perinatal insult), 5 had an ILAE class 1 outcome and 1 had an ILAE class 2 outcome after at least 1 year of follow-up.

Acknowledgments
This study was partly funded by a grant from the Department of Biotechnology, Ministry of Science & Technology, Government of India (grant no. BT/MED/122/SP24580/2018).

References

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: Chandra, Manjari Tripathi. Acquisition of data: all authors. Analysis and interpretation of data: Chandra, Madhuvi Tripathi, Manjari Tripathi. Drafting the article: Chandra, Doddamani, Girishan, Samala, Agrawal, Manjari Tripathi. Critically revising the article: Chandra, Manjari Tripathi. Reviewed submitted version of manuscript: Chandra, Manjari Tripathi. Approved the final version of the manuscript on behalf of all authors: Chandra. Statistical analysis: Chandra. Administrative/technical/material support: Chandra, Manjari Tripathi. Study supervision: Chandra, Manjari Tripathi.

Supplemental Information
Videos

Previous Presentations
Parts of this paper were presented at the Asian Epilepsy Surgery Congress, Kobe, Japan, November 1–2, 2019.

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