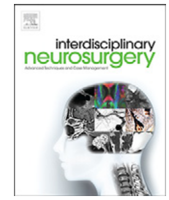
Interdisciplinary Neurosurgery: Advanced Techniques and Case Management 6 (2016) 38–41

Contents lists available at ScienceDirect

Interdisciplinary Neurosurgery: Advanced Techniques and Case Management

journal homepage: www.inat-journal.com



Technical Note & Surgical Technique

Robot-assisted placement of depth electrodes along the long Axis of the amygdalohippocampal complex

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ARTICLE INFO

Article history:
Received 4 April 2016
Revised 9 April 2016
Accepted 17 April 2016

Keywords:
Depth electrodes
Mesial temporal
Robotic assistance
Stereotactic cannulation

ABSTRACT

Background: Classically, transoccipital hippocampal depth electrode implantation requires a stereotactic headframe and arc and the patient to be placed in a seated or prone position, which can be cumbersome to position and uncomfortable for the surgeon. Robotic intracranial devices are increasingly being utilized for stereotactic procedures such as stereolectroencephalography (SEEG) but commonly require patients be placed in head-neutral position to perform facial registration.
Objective: Here we describe a novel robotic implantation technique where a stereotactic intracranial robot is used to place bilateral hippocampal depth electrodes in the lateral position.
Methods: Four patients underwent SEEG depth electrode placement, which included placement of bilateral hippocampal depth electrodes. Each patient was positioned in the lateral position and registered to the robot with laser facial registration. Trajectories were planned with the robotic navigation software, which then identified the appropriate entry points and trajectories needed to reach the targets. After electrode implantation, target localization was confirmed using computed tomography (CT).
Results: Electrodes targeting the amygdalohippocampal complex were accurate and there were no complications in this group. An average of seven electrodes were placed per patient. Ictal onset was localized for each patient. All patients subsequently underwent temporal lobectomy and 75% have been seizure free since surgery.
Conclusions: We have developed the Robot-Assisted Lateral Transoccipital Approach (RALTA), which is an advantageous technique for placing bilateral amygdalohippocampal depth electrodes using robotic guidance. Benefits of this technique include fewer electrodes required per patient and ease of positioning compared with seated or prone positioning.

1. Introduction

Stereoelectroencephalography (SEEG) is used to localize ictal onset zones in patients with medically refractory focal epilepsy and is becoming a popular technique for invasive electrode monitoring [1]. In adults, temporal lobe epilepsy is the most common type of focal medically refractory epilepsy [2,3] and this region is a common target for depth electrode implantation [4]. There are two techniques for implanting depth electrodes within the temporal lobe: 1)- insert two or three depth electrodes targeting the amygdala and head and tail of the hippocampus orthogonal to the mesial structures, and 2)- implant a single electrode along the entire length of the hippocampus from a transoccipital approach [5–7]. In terms of monitoring efficacy, complications, and outcomes, there is no evidence showing a major difference between the two methods [6].

Both methods have their benefits and drawbacks. For example, an orthogonal approach is considered to be more accurate than an occipital approach because there is a shorter distance between the entry point and target [8]. The orthogonal approach also provides lateral temporal lobe coverage, which may be important based upon the patient's clinical presentation, but also requires more electrodes and thus more trajectories, potentially increasing procedural costs and the risk of vascular injury [8]. An orthogonal approach also samples less of the mesial structures than the transoccipital approach [6]. Conversely, a disadvantage of the occipital approach is that the patient must lie prone or in a seated position, which can be cumbersome or uncomfortable for the surgeon.

Use of an intracranial stereotactic robotic assistance device has become more popular in placing depth electrodes, including placing SEEG depth electrodes with high accuracy [9]. Robots excel at handling spatial information, which is essential to accurate placement of depth electrodes [10]. However, robotic assistance cannot be used easily to place depth electrodes from an occipital approach because the robot performs laser registration of the patient's face, which is difficult to do via conventional methods for a transoccipital approach (i.e., when the

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http://dx.doi.org/10.1016/j.inat.2016.04.004

Table 1
Preoperative patient demographics.

Patient	Age at procedure	Epilepsy onset	Refractory AEDs	Pre-op vagal nerve stimulator	Pre-op MRI findings	Pre-op video EEG findings
1	69Y	34Y	Lacosamide; Levetiracetam; Clonazepam	Yes (ineffective)	Nonlesional	Poor lateralization pattern; onset was suggestive on the right hemisphere
2	47Y	16Y	Lacosamide; Levetiracetam; Phenytoin	Yes	Right-sided mesial temporal sclerosis	Temporal interictal epileptiform abnormalities with electroclinical seizures; unclear laterality regarding onset
3	44Y	5Y	Lacosamide; Levetiracetam; Topiramate; Phenytoin; Valproate; Lamotrigine; Phenobarbital; Zonisamide; Pregabalin; Carbamazepine	Yes (ineffective)	Right-sided cortical dysplasia	Bilateral independent onset seizures, but predominantly right hemispheric
4	50Y	NA	Levetiracetam; Phenytoin	None	Possible right mesial temporal atrophy	Epileptiform discharges in T2 region but also independent discharges in T1. These discharges are rarely bisynchronous.

patient is lying prone or sitting upright). Here we describe a novel technique to place electrodes within the amygdalohippocampal complex via a transoccipital approach using robotic assistance by placing the patient in a lateral position. To our knowledge, this is the first instance where electrodes were placed via a transoccipital approach into the amygdalohippocampal complex using a robot.

2. Methods

All patients undergoing stereoelectroencephalography (SEEG) at our institution have been implanted with robot assistance since the ROSA was obtained in January of 2015. Altogether, approximately 35 patients have been implanted during this time and these four patients were the first to have occipital placement of bilateral hippocampal electrodes as they were deemed good candidates for this variation on the procedure.

2.1. Presurgical workup

Four patients with medically refractory focal epilepsy were discussed in Epilepsy Management Conference after undergoing a preoperative workup that included inpatient video electroencephalography (vEEG), proton emission tomography (PET), and high-resolution magnetic-resonance imaging (MRI). The decision was made to implant SEEG depth electrodes for ictal onset localization (Table 1). Robotic assistance SEEG has been used regularly at our facility since January 2015. While mesial temporal lobe onset was suspected in each of these patients, bilateral frontotemporal implantations were planned for each patient based upon the patient's clinical findings (Fig. 1). Each patient underwent a volumetric MRI for stereotactic navigational purposes. One surgeon (SV) performed all the procedures.

2.2. Procedure

Each patient underwent general anesthesia and was then placed in the lateral position. A Leksell stereotactic head frame (Elekta, Crawley, United Kingdon), was placed and the patient was fixed to the robot. This was done solely to connect patient to the robot and not for stereotactic navigation purposes. ROSA robot (Medtech Surgical, Inc., Montpellier France), was used to place depth electrodes for SEEG [11,12]. Laser facial registration was performed in the lateral position (Fig. 2). Bilateral frontal and temporal trajectories were planned with the ROSA navigation software including entry points and trajectories needed to reach the desired targets. Percutaneous burr holes were made at these marked locations on the scalp, skull bolts were placed and electrodes were placed to predetermined length (Fig. 1). Placement of the electrodes in the correct location was then confirmed via post-operative CT scan, an effective method for confirming location [1]. Patients were then admitted to the epilepsy-monitoring unit for monitoring. On average, patients are monitored in the epilepsy monitoring unit for 7–10 days during which time they are continuously monitoring for seizures. After localization of the ictal onset zone, patients are brought back to the operating room for removal of electrodes and then discharged home to allow for wound healing. They are then brought back for the definitive procedure (lobectomy, RNS, etc.) within two weeks.

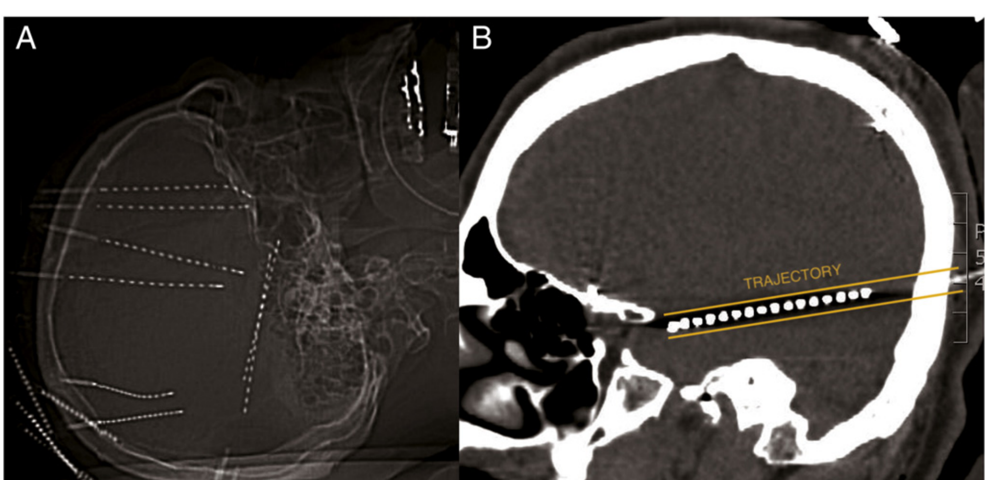

Fig. 1. Panel A—Radiograph showing typical SEEG implantation including bilateral transoccipital electrodes; Panel B— Representative SEEG map showing electrode implantation targets and placement.

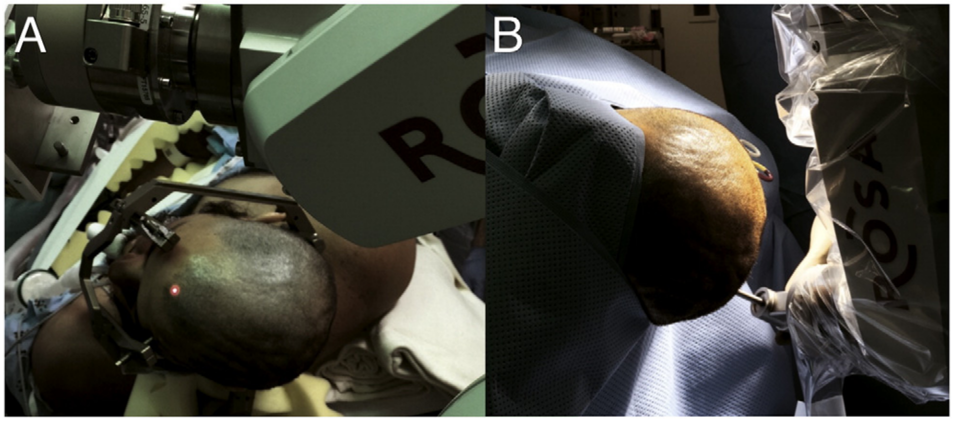

Fig. 2. Panel 1 A—Laser facial registration is being performed on patient in lateral position; Panel 1B—The robotic guidance is assisting with electrode implantation of the left transoccipital hippocampal approach.

2.3. Data collection

All charts were retrospectively reviewed. Data pertaining to technique of insertion, electrode localization, complications, number of electrodes, and seizure-free outcomes were recorded. This study was approved by the University of California, Irvine, Institutional Review Board.

3. Results

The results are summarized in Table 2. For all four patients, the ictal onset zone was localized to the right hippocampus and the subsequent procedure was resection of the right temporal lobectomy. Pathology for each patient returned as hippocampal sclerosis, with one patient having dual pathology (hippocampal sclerosis and cortical dysplasia). There were no immediate or unexpected complications following implantation or resection for any of the patients and three of the four patients experienced complete cessation of their seizures at six-month follow-up. The fourth patient experienced a 50% reduction in the frequency and severity of seizures.

4. Discussion

The Robot-Assisted Lateral Transoccipital Approach (RALTA) is a novel technique that has several advantages over orthogonal implantation techniques. The use of the robot results in high accuracy, precision, and consistency by removing the potential human elements that may create errors. As previously mentioned, an argument against depth electrode implantation across the entire long axis of the amygdalohippocampal complex is that it is not as accurate as electrodes implanted via an orthogonal approach, as there is a farther distance between the entry point and the final location [8]. However, robotic assistance may result in higher accuracy and precision that could make implanting long axis electrodes adequately effective.

Research has shown that using transoccipital hippocampal depth electrodes can 1)- result in a favorable risk profile, 2)- provide sole evidence for epileptogenic foci resection in some cases, and 3)- prevent likely unsuccessful resection in a subset of epileptic patients [7]. Previous work has shown that ROSA robotic assistance resulted in lower target error and axial deviation, and a higher ability to obtain the planned target, in SEEG depth electrode implantation when compared to traditional manual implantation [13].

There are several practical advantages to the RALTA from a surgical standpoint. Currently, if the surgeon deems the best option for accessing the amygdalohippocampal complex is with an occipital approach, the patient would have to either lie prone or sit upright, with the latter being cumbersome and leading to poor operating conditions. In these positions, laser facial registration is impossible because of the mechanical restrictions of the robot. By placing the patient in a lateral position, the facial structures are accessible and laser registration can be obtained. This allows for accuracy and precision of robotic assistance and the superior operating conditions of having the patient oriented in a surgically accessible position. In addition, this position does not preclude placement of other electrodes such as insular and orbitofrontal electrodes. Furthermore, robotic assistance has been shown to reduce OR time in some MRI-guided stereotactic procedures, which could increase efficiency and be more cost-effective in the long run [14]. The cost of the procedure is reduced because one electrode is able to sample the entire amygdalohippocampal complex compared with three electrodes which are commonly used to sample the amygdala, head and tail of the hippocampus. The average number of electrodes for this group was seven, which is a reduction from the fourteen electrodes we normally utilize for SEEG. Thus, RALTA allows for these benefits while also allowing for the accuracy and precision of robotic assistance.

Finally, the authors have found that this method is beneficial during the subsequent resections as there is less scarring of the temporal lobe when electrodes are placed via the transoccipital approach rather than placed along the temporal lobe.

There are however potential drawbacks and uncertainties to RALTA. If there is a concern for neocortical temporal lobe epilepsy, then orthogonal electrode implantation is likely a better option as this can sample the lateral temporal lobe and mesial structures.

Also, placing the patient in lateral position does take additional time compared with neutral positioning. This does add a small amount of

Table 2
Post-operative outcome.

Patient	SEEG localization	Number of electrodes	Resective treatment	Pathology	Complications	Six-month post-op seizure outcomes
1	Right hippocampus	6	Right temporal lobectomy	Hippocampal sclerosis	None	50% reduction in seizure burden
2	Right hippocampus	6	Right temporal lobectomy	Hippocampal sclerosis	None	Complete cessation of seizures
3	Right hippocampus	8	Right temporal lobectomy	Hippocampal sclerosis, cortical dysplasia	None	Complete cessation of seizures
4	Right hippocampus	8	Right temporal lobectomy	Hippocampal sclerosis	None	Complete cessation of seizures

additional time to the procedure, although this may be mitigated by the fact that fewer electrodes are placed. Bone fiducials may also be used to decrease registration time and is an alternative to facial registration in these patients.

5. Conclusion

RALTA is a novel technique that combines the advantages of an occipital approach to implanting hippocampal depth electrodes with the accuracy, efficiency, and precision of robotic assistance. In addition, it creates superior operating conditions for the surgeon, and could be an improvement on current manual procedures.

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