A Frameless Stereotactic Implantation Technique for Depth Electrodes in Refractory Epilepsy Using Intraoperative Magnetic Resonance Imaging

Karl Roessler[1], Björn Sommer[1], Andreas Merkel[1], Stefan Rampp[1], Stephanie Gollwitzer[2], Hajo M. Hamer[2], Michael Buchfelder[1]

■ OBJECTIVE: **Various complex techniques for depth electrode insertion in refractory epilepsy using preoperative imaging have been investigated. We evaluated a simple, accurate, cost-effective, and timesaving method using intraoperative magnetic resonance imaging (MRI).**

■ METHODS: **A neuronavigation-guided insertion tube attached to bone facilitated the placement of stereotactic percutaneous drill holes, bolt implantation, and frameless stereotactic insertion of depth electrodes. Image registration was carried out by head coil fiducials with trajectory planning and intraoperative electrode correction.**

■ RESULTS: **In 6 patients with refractory epilepsy (3 women and 3 men; mean age, 30.0 years; range, 20–37 years), 58 depth electrodes (9–11 per patient) were placed. The mean length of the inserted electrodes was 37.3 mm ± 8.8 (mean ± SD) (range, 22.1–84.4 mm). The overall target point accuracy was 3.2 mm ± 2.2 (range, 0–8.6 mm), which was significantly different from the overall entry point accuracy of 1.4 mm ± 1.2 ($P < 0.0001$). All electrodes functioned perfectly, enabling high-quality stereo-electroencephalography recordings over a period of 7.3 days ± 0.5 (range, 7–8 days). The mean implantation time for 9–11 electrodes per patient was 115 minutes ± 36.3 (range, 75–160 minutes; 12 minutes for 1 electrode on average) including the intraoperative MRI (T1 three-dimensional magnetization-prepared rapid acquisition gradient echo, T2, and diffusion tensor imaging). There was no hemorrhage, infection, or neurologic deficit related to the procedure.**

■ CONCLUSIONS: **Our frameless technique of depth electrode insertion using intraoperative MRI guidance is an accurate, reliable, cost-effective, and timesaving method for stereo-electroencephalography.**

INTRODUCTION

Because of the cumbersome and time-consuming method of frame-based stereotactic implantation of depth electrodes for stereo-electroencephalography (SEEG) described by Bancaud and Talairach,[1-3] depth electrodes were used routinely in only a few epilepsy centers. However, since the development of frameless stereotactic neurosurgical devices, image guidance, and frameless stereotactic drilling methods, SEEG electrode implantation has become more popular during the last few years.[2,4-7] This popularity is also due to the low complication rates reported for SEEG compared with invasive monitoring using large craniotomies for grid and strip electrode implantation. Additionally, more complex cases of epilepsy often with negative magnetic resonance imaging (MRI) findings and already surgically treated epilepsy cases requiring monitoring have contributed to the number of patients needing SEEG diagnostics. Thus, straightforward cost-effective and timesaving implantation techniques are needed. Various tools, including robotic-assisted devices, have been investigated for feasibility and accuracy in depth electrode implantation.[5,7,8] Although intraoperative MRI was proposed for frameless stereotactic depth electrode implantation many years ago, appropriate publications are missing. Therefore, we investigated a simple, accurate, and timesaving implantation technique supported by intraoperative high-field MRI.

Key words
- Depth electrode placement
- Epilepsy surgery
- Frameless stereotactic technique
- Intraoperative MRI
- Stereo-electroencephalography

Abbreviations and Acronyms
3-D: Three-dimensional
MPRAGE: Magnetization-prepared rapid acquisition gradient echo
MRI: Magnetic resonance imaging
SEEG: Stereo-electroencephalography

From the Departments of [1]Neurosurgery and [2]Neurology, Epilepsy Centre, University Hospital Erlangen, Erlangen, Germany

To whom correspondence should be addressed: Karl Roessler, M.D., Ph.D. [E-mail: karl.roessler@uk-erlangen.de]

Karl Roessler and Björn Sommer are co–first authors.

Citation: World Neurosurg. (2016) 94:206-210.
http://dx.doi.org/10.1016/j.wneu.2016.06.114

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

MATERIALS AND METHODS

Patients and Electrodes

Six patients (3 women and 3 men; mean age, 30 years; range, 20–37 years) with medically refractory epilepsy were selected for invasive monitoring using depth electrodes for SEEG (Table 1). All patients were investigated clinically by video electroencephalography monitoring, structural and functional 3-T MRI, and single-photon emission computed tomography and magnetoencephalography imaging and underwent neurologic and neuropsychologic assessment in the Epilepsy Centre at University Hospital Erlangen according to a board-certified investigation protocol. Two patients presented with frontal lobe epilepsy, 2 patients presented with parietal lobe epilepsy, and 2 patients presented with temporal lobe epilepsy. MRI revealed suspicious temporal contusions in 1 patient (left temporal lobe), remained negative in 3 patients (2 frontal lobes, 1 temporal lobe), and revealed suspicious parietal lobe focal cortical dysplasia in the 2 remaining patients. In these 6 patients, 58 electrodes (9–11 per patient) were placed based on suspected seizure-onset zone (Table 1).

Neuronavigation and Intraoperative MRI

All procedures were performed using a commercially available neuronavigation system (Bainlab AG, Feldkirchen, Germany). MRI scans for intraoperative imaging were performed using a 1.5-T clinical whole-body MRI scanner with echo planar imaging (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany) equipped with a head coil integrated in the automatic head fixation (NORAS MRI Products GmbH, Hoechberg, Germany).

Surgery was performed with the patient in a supine position under deep general anesthesia (Figure 1). The patient's head was immobilized in the automatic head fixation device of the NORAS head coil in a position allowing the targeting of all preplanned electrode entry points, followed by scanning for registration and image fusion in 1.5-T intraoperative MRI (T1 three-dimensional [3-D] magnetization-prepared rapid acquisition gradient echo [MPRAGE], T2 axial scans, and diffusion tensor imaging scans for reconstruction of fiber tracts when necessary). The intraoperative images were fused with preoperative 3-T MRI and cranial computed tomography images containing the preplanned electrode positions and registered on the patient's head (registration accuracy <2 mm in all cases).

Surgical Procedure

The insertion tube (Ad-Tech Medical, Racine, Wisconsin, USA) for drilling and electrode placement was equipped with a tracking device with registration of its length and the axis using the Brainlab registration matrix and subsequently immobilized by 2 fixation arms (LEYLA retractor system; Hermann Müller Chirurgie- und Dentalinstrumente GmbH, Tuttlingen, Germany). After skin incision at the site of the precalculated entry point, the insertion tube was inserted into the wound until the sharp crown tip could be fixed on the skull surface. In that position, the trajectory of the electrode was calibrated, and a twist drill hole was performed by using an electric driver (Colibri battery driver; Synthes GmbH, Umkirch bei Freiburg, Germany). The dura mater was opened with a dura perforator and coagulated with a monopolar cautery (Ad-Tech Medical) (Figure 1C), and the fixation bolt (Ad-Tech Medical) was screwed into the skull. A thin stylet (Ad-Tech Medical) was introduced to the preplanned target point followed by implantation of the depth electrode, the dimensions of which were determined beforehand based on preoperative planning (Ad-Tech) (Figure 1A). Finally, the electrode was fixed in the preplanned position by a screw and a plastic cap at the bolt (Figure 1B). After insertion, intraoperative MRI was performed to visualize the electrode positions and allow intraoperative correction if necessary.

Data Analysis

The locations of the implanted electrodes were immediately analyzed under sterile operative conditions. Entry and target point accuracy was obtained by comparing the preplanned trajectories with the postoperative electrode position using the navigation system software (iPlan 2.6; Brainlab AG) by comparing preoperative and postoperative T1 3-D MPRAGE imaging (1 mm thickness). The entry and target point error was calculated using the Euclidean distances between the virtual and the in vivo target point position in 3 dimensions. The entry point accuracy was also calculated using the same method. GraphPad Prism 5.03 software (GraphPad Software, Inc, La Jolla, California, USA) using Student t-test was used for statistical analysis.

RESULTS

The mean length of the inserted electrodes was 37.3 mm ± 8.8 (mean ± SD) (range, 22.1–84.4 mm; Table 1). The overall target point accuracy was 3.2 mm ± 2.2 (range, 0–8.6 mm), which was significantly different from the overall entry point accuracy of 1.4

Table 1. Patient Demographics

Patient	Age (Years)	Expected Epi-Type	Number of Electrodes	Entry Point Accuracy (mm)	Target Point Accuracy (mm)	Length of Electrodes (mm)
1	29	PLE left	11	1.5 (0–3)	2.2 (0–6.7)	47.7 (27.7–84.4)
2	39	FLE right	9	1.2 (0–2.5)	1.3 (0–4.4)	32.5 (26.4–45.5)
3	20	PLE right	9	1.2 (0–4)	5.0 (3.5–7.2)	54.5 (42.3–67.1)
4	20	FLE right	11	1.2 (0–2.5)	3.6 (0–7.9)	49.8 (22.1–67.1)
5	33	TLE right	9	0.9 (0–1.8)	3.0 (0–5.1)	45.2 (33.4–67.6)
6	37	TLE left	9	2.7 (0–5)	4.3 (2.2–8.6)	41.8 (28.5–56.8)
Mean	29.7		10	1.4	3.2	37.3

Epi-Type, type of epileptic seizures; PLE, parietal lobe epilepsy; FLE, frontal lobe epilepsy; TLE, temporal lobe epilepsy.