Frameless Stereotactic Drilling for Placement of Depth Electrodes in Refractory Epilepsy: Operative Technique and Initial Experience

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BACKGROUND: For stereotactic implantation of depth electrodes in refractory epilepsy, both frame-based and frameless techniques have been developed. The higher versatility of current frameless techniques compared with framed-based methods is paid by the need of a standard burr hole for the implantation of 1 electrode.
OBJECTIVE: To develop a frameless method that allows convenient implantation of the electrode via a percutaneous bolt as used in frame-based methods, thereby avoiding the need for a standard burr hole.
METHODS: We adopted our technique from frameless stereotactic biopsy and designed the GIDE, a bone-fixated Guide for Implantation of Depth Electrodes. This reducing sleeve works as a stabilizer of the neuronavigation arm through bony contact and allows percutaneous stereotactic drilling, screwing of an implantation bolt, and placement of the depth electrode.
RESULTS: Twenty-six electrodes in 7 patients (5 male and 2 female patients; median age, 19.6 years; range, 5.5-39.1 years) were successfully implanted. The overall accuracy was comparable to that of frameless stereotactic biopsy with a target deviation of 3.0 ± 1.9 mm (mean ± SD). All electrodes were within or touched the targeted anatomic structure with an adequate quality of the recordings. We encountered no hemorrhage or neurological deficit related to the depth electrode.
CONCLUSION: Our technique combines the high versatility of frameless stereotaxy with the convenient implantation and fixation of the depth electrode via a percutaneous bolt used in frame-based stereotactic methods. Thus, our technique allows fast, efficient implantation of depth electrodes for intracranial electroencephalography recordings.

KEY WORDS: Depth electrode placement, Frameless stereotaxy, Stereotactic drilling

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Stereotactic placement of depth electrodes to study epilepsy was reported in the 1950s by Bancaud and Talairach and has been mostly used in France and Italy as the method of choice for invasive monitoring in cases of refractory focal epilepsy.[1,2]

The Talairach technique, although accurate and safe, was originally described as a multiphase and complex time-consuming method that uses the Talairach stereotactic frame in conjunction with angiography studies.[1-3] Electrode placement was limited to lateral orthogonal trajectories with minimal working space at the implantation site.

Abbreviations: **EEG,** electroencephalography; **GIDE,** Guide for Implantation of Depth Electrodes

The development of different stereotactic frames then allowed a greater variability in entry sites and trajectory angles and more working space at the implantation site. The advancement in neuroimaging has further led to a wide adaption of such frame-based stereotactic techniques for electrode placement today.[4-6]

Although frame-based methodologies are highly accurate and safe, they have a number of drawbacks: a significant amount of time for frame placement and image acquisition for coregistration, potential patient discomfort, restricted access to the surgical field with limitations when combined with craniotomy or burr holes for placing subdural grid and strip electrodes, limitations in possible trajectories, and a limited ability to redefine and adjust trajectories intraoperatively.

Although frameless stereotaxy potentially avoids these constraints and has been shown to be an accurate and safe alternative for intracranial biopsies comparable to frame-based systems, it has not yet been widely adopted for depth electrode placement.[7-14] One possible reason might be that with current frameless methods, a 3-cm skin incision along with a standard burr hole is necessary for the implantation of 1 single electrode. Subcutaneous tunneling and inconvenient electrode fixation further complicate the procedure. This potentially limits its use and practicability for comprehensive intracranial electroencephalography (EEG) recordings with multiple depth electrodes.

We adopted our technique from frameless stereotactic biopsy procedures and developed a frameless stereotactic drilling method for depth electrode placement that avoids a standard skin incision and burr hole and simultaneously uses the advantageous fixation of the electrode via a percutaneous bolt used in frame-based techniques.[6] Here, we describe this new operative technique and our initial experience with its use.

METHODS

Patient Population

Seven patients (5 male and 2 female patients; median age, 19.6 years; range, 5.5-39.1 years) undergoing presurgical evaluation at the Vienna Epilepsy Center (Epilepsy Monitoring Units, Department of Pediatrics and Adolescence Medicine and Department of Neurology, Medical University of Vienna, 2nd Neurological Department, General Hospital Hietzing, Vienna) underwent depth electrode placement with the technique described in this report between October 2013 and February 2014. All patients had refractory epilepsy and underwent extensive preoperative evaluation by a standardized protocol including thorough neurological, ophthalmologic, neuropsychological, and psychiatric assessment, as well as intensive video-EEG monitoring. Imaging included high-resolution magnetic resonance (MR) imaging and functional MR imaging, Tc-hexamethylpropyleneamine oxime single-photon emission computed tomography (CT), and fludeoxyglucose and methionin positron emission tomographic imaging, when indicated.

Equipment

All procedures were performed with the commercially available neuronavigational system S7 (Medtronic, Louisville, Colorado) with Synergy Cranial version 2.2 software and the Vertek articulating arm designed for frameless stereotactic biopsy. We developed the GIDE, a bone-fixated Guide for Implantation of Depth Electrodes. This adapter tube (length, 10 cm; outer diameter, 7.9 mm; inner diameter, 4 mm) designed by AD-Tech (Racine, Wisconsin) acted as a reducing sleeve and stabilizer of the precision aiming device of the Vertek arm through bony contact (Figure 1). Through this GIDE stereotactic drilling, screwing of the fixation bolt, calculation of the correct depth distance, and placement of the depth electrode were accomplished. For monopolar coagulation of the dura, another reducing sleeve was designed. Stereotactic drilling was performed with the DeMartel system in the first 3 cases. To reduce possible deviations from the planned trajectory by a leverage effect resulting from the length of the DeMartel system and to enhance working comfort, we used the COLIBRI battery-driven Power Tool system (Johnson & Johnson, Synthes, New Brunswick, New Jersey) in the last 4 cases.

Image Acquisition

All image data were acquired on a 3.0-T MR system (Siemens Magnetom Trio, Siemens Medical Systems, Erlangen, Germany). The

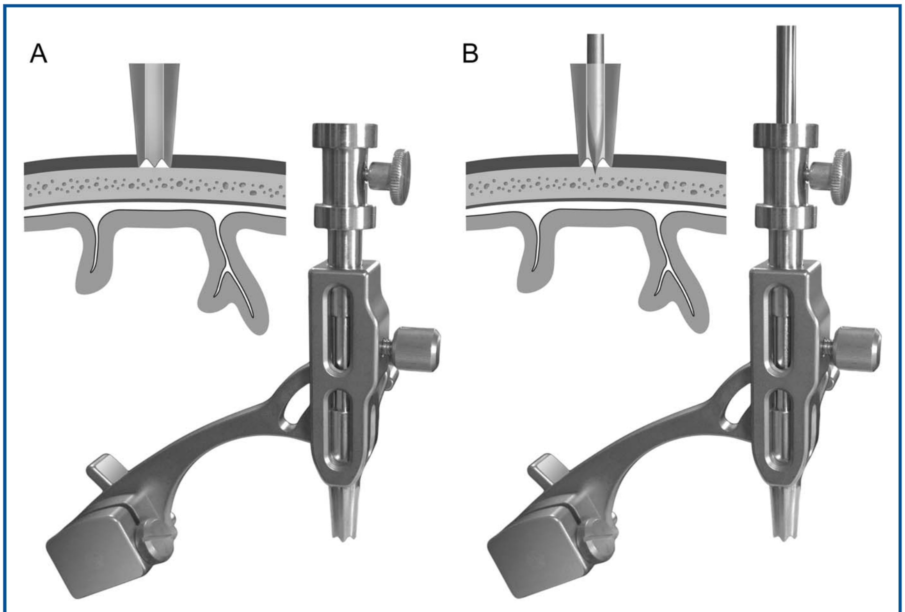

FIGURE 1. **A**, *the reducing sleeve is introduced through the precision aiming device. Its shark-teeth design guarantees stable bony contact.* **B**, *center punching with a K wire prepares stereotactic drilling.*

standard images required for neuronavigation included T1-weighted MR images in the axial orientation with and without contrast enhancement (T1 3-dimensional [3-D] gradient-echo sequence; acquisition time, 5.34 minutes; repetition time, 1800 milliseconds; echo time, 3.79 milliseconds; matrix size, 256 × 256; field of view, 220 mm; flip angle, 12°; slice thickness, 1 mm; number of slices, 192) to accurately visualize the anatomy of the gyral and sulcal pattern, the targeted brain regions, and the vasculature. Three-dimensional surface rendering was used for planning and intraoperatively. For brain volume extraction to create the 3-D model, the semiautomated brain volume extraction tool included in the Synergy Cranial navigation software version 2.2 was used. It is based on a watershed algorithm that builds a brain volume based on the signal threshold between cortex and cancellous bone on MR images.[15] Depending on the individual MR scanner and acquisition, threshold values have to be adjusted manually (our settings: lower threshold, 200; upper threshold, 1200; filter, medium). The direct volume-rendering module of the navigation software was used for intraoperative display of the 3-D brain model. For transparency of the 3-D brain surface, we selected the predefined transfer function basic volume rendering.

A CT scan (2-mm sequential axial images) is required to enhance the accuracy of the surface registration[11] and to calculate the thickness of the bone along each trajectory, which is important for later drilling and calculation of the correct depth distance of each electrode.

Preoperative Planning Phase

Images were loaded from the PACS workstation to the navigational planning station. MR and CT images were merged by use of the automated Stealth Merge application. The CT scan was set to color map bone in the examination settings. Each electrode trajectory was planned from the outer bone surface to the target, avoiding vessels and crossing of sulci. Along each trajectory, the thickness of the skin and bone and the total trajectory length were noted on a printed standardized protocol sheet for later calculations. Data were then sent to the neuronavigation unit that was going to be used intraoperatively.

Stereotactic Drilling and Electrode Implantation

After general endotracheal anesthesia had been induced, patients were fixed in the Mayfield clamp (Cincinnati, Ohio), and the navigation arm was mounted to the Mayfield apparatus. Registration of the navigation was performed with surface registration.[16] Under sterile conditions, the Vertek articulation arm of the navigation with the precision aiming device on its top was then fixed to the Mayfield clamp with the dual Mayfield attachment, and the Vertek probe pointer was registered (Figure 2). This was followed by the alignment of the Vertek articulating arm with the predefined trajectory. Because loss of cerebrospinal fluid after opening of the dura potentially causes brain shift, the longest trajectory was aligned first in case of a multiple depth electrode placement procedure. For the same reason, all depth electrodes were finished before strip and grid electrode placement was performed. During the alignment of the Vertek articulating arm, a target error of <0.3 mm was assumed to be acceptable. A learning curve was needed to achieve such a high accuracy in a reasonable time.

Then, the GIDE with the tip colored with a sterile felt pen was introduced through the precision aiming device to mark the skin incision. The precision aiming device could then be dismounted to allow the precise stab incision without deviating the trajectory. The stab incision was about 5 mm, depending on the thickness of the scalp or muscle. After mobilizing the periosteal layer with a dissector, the GIDE could be introduced over

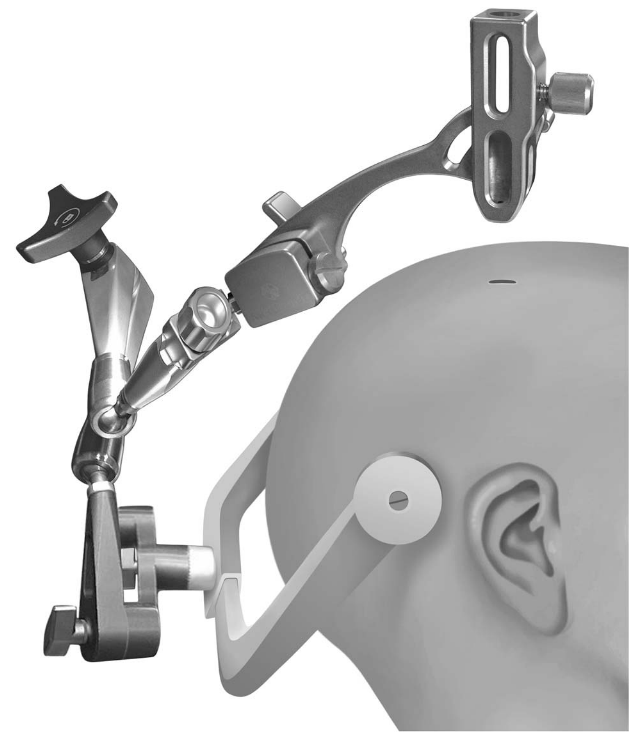

FIGURE 2. *The Vertek articulation arm with the precision aiming device on its top is mounted on the Mayfield clamp with the dual attachment.*

the remounted precision aiming device and positioned on the bone. Stable bony contact was guaranteed by slightly pounding the GIDE into the bone with its shark-teeth design on the tip (Figure 1A).

As a next step, after center punching the drill hole with a K wire, stereotactic drilling along the trajectory was performed (Figure 1B). To avoid inadvertent sliding of the drill into the brain, a stop device was positioned on the drill (Figure 3A). The correct position of the stop device on the drill was easily calculated: Because the reducing sleeve with a length of 10 cm had bony contact and the thickness of the bone along the trajectory had been calculated, the stop device was positioned on the drill at 10 cm plus the distance of the bone thickness (Figure 3B).

After stereotactic drilling, a reducing sleeve for the monopolar coagulation was introduced, and the dura was coagulated and perforated (Figure 4). The implantation bolt could then be screwed into the skull with the screwdriver, which had a stop device mounted (Figure 5A). This stop device served as a length measuring tool for calculating the final depth distance for the electrode. It marked the length of the screwdriver after the implantation bolt was fixed sufficiently (Figure 5B).

The calculation of the depth distance of the electrode was calculated as follows: The planned trajectory length from the entry point at the outer bone surface plus the length of the reducing sleeve (10 cm) minus the measured length of the screwdriver gives the final depth distance (Figure 5B).

Before the precision aiming device arm could be dismounted again for the implantation of the electrode, possible deviation caused by the drilling procedure could be ruled out by putting the Vertek probe in place again.

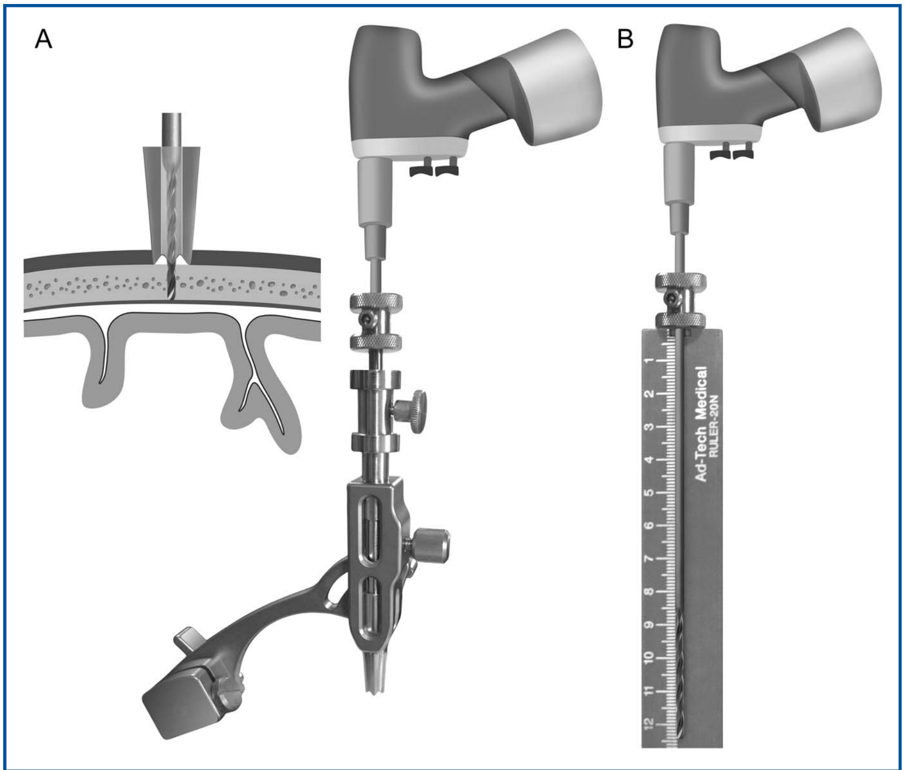

FIGURE 3. **A**, *stereotactic drilling is performed with a stop device mounted to avoid inadvertent sliding into the brain.* **B**, *the position of the stop device is adjusted with the ruler by the following calculation: the length of the reducing sleeve (100 mm) plus the distance of the bone thickness along the trajectory measured previously on the neuronavigation.*

Thus, a final check of the correct trajectory could be easily performed. For implantation of the electrode, the implantation bolt itself served as the guidance. The electrode fixation device of the bolt was put on the electrode, and the correct depth distance was adjusted on a specially designed ruler (Figure 6A). In case of a long depth distance, a stylet to avoid electrode deviation within the brain was introduced along the trajectory before the electrode was finally implanted and fixed on the implantation bolt (Figure 6B). One skin suture (3.0, Ethilon, Ethicon, Kiel, Germany) adapted the skin.

Assessment of Electrode Placement

Postoperatively, a standard CT scan was performed. This CT scan was merged with the preoperative MR images including the planned trajectories. Measurements of the electrode position were performed in the probe view setting of the user interface. This way, electrode deviation was visualized and could be measured in all planes simultaneously. We measured both the distance from the intended target to the center of the actual tip of the electrode and the distance from the intended entry point to the center of the implanted bolt.

To visualize the implanted electrodes, we performed snapshot pictures of the user interface in the axial, coronal, and sagittal planes and 3-D reconstructions with the same software.

The physiological quality of the recordings was assessed by the epileptologists as either adequate or inadequate.

RESULTS

Twenty-six electrodes in 7 patients (2-7 per patient) were implanted (Table). Fifteen electrodes were implanted in or around a suspected lesion (frontal, n = 10; parietal, n = 2; occipital, n = 1; temporal, n = 2). Seven electrodes were implanted in the amygdalohippocampal region: 5 of them via an orthogonal temporal trajectory and 2 via a longitudinal occipital trajectory. Four electrodes were implanted in the insula via a frontal trajectory in 3 patients and a parietal trajectory in the remaining patient. The mean $\pm$ SD length of the trajectories was 47.0 $\pm$ 20.9 mm.

In 6 of 7 patients, depth electrode placement was combined with subdural electrodes: 5 of the 6 with subdural strip electrodes implanted via a standard burr hole and 1 with a grid electrode implanted via a craniotomy. In 1 patient, who had multiple skin scars caused by previous surgeries, a percutaneous bolt would have hindered retraction of the skin incision for the burr hole needed for subdural strip electrode placement. The electrode was implanted with the guidance of a stereotactically drilled burr hole and the GIDE. The electrode was fixed via a miniplate on the bone and tunneled subcutaneously.

The procedure was well tolerated in all patients. We experienced no case of hemorrhage or neurological deficit related to the electrode placement.

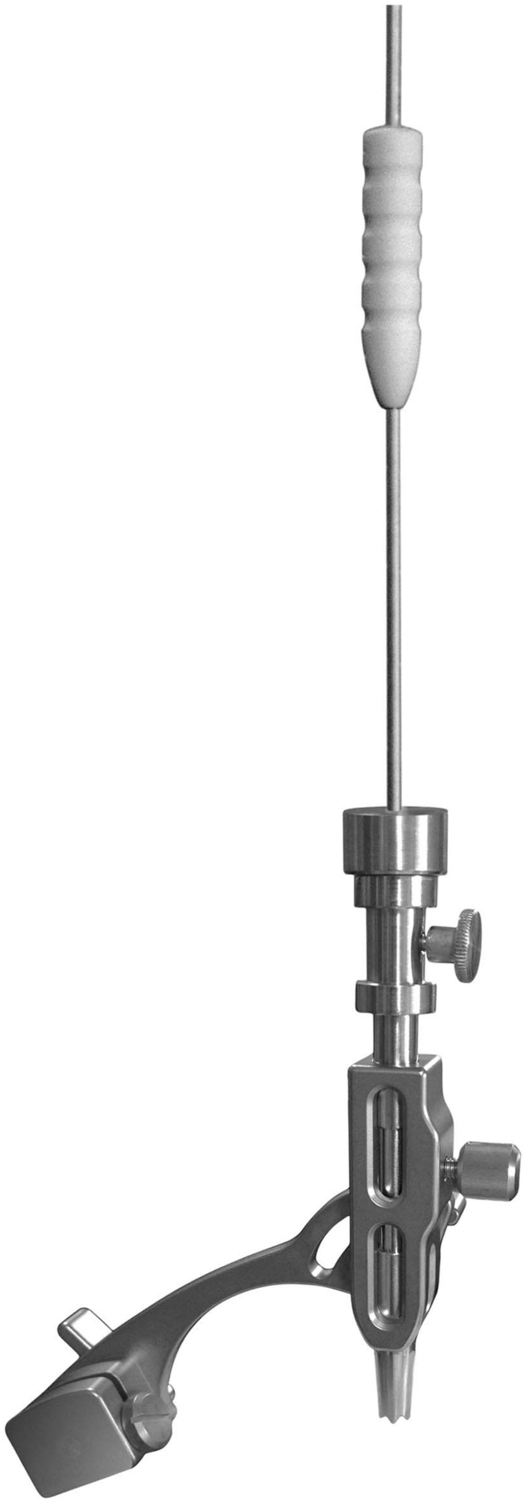

FIGURE 4. *Another reducing sleeve is introduced to allow monopolar coagulation and perforation of the dura.*

Adequate physiological recordings were obtained from all electrodes. No additional electrodes had to be implanted because of misplacement.

Accuracy

The mean ± SD distance from the center of the bolt to the intended entry point was 3.5 ± 1.4 mm (median, 3.7 mm; range, 1.0-6.7 mm). Because the exact alignment of the Vertek articulating arm and precision aiming device to the intended entry point is sometimes difficult and time-consuming, small deviations from the entry point were sometimes assumed acceptable intraoperatively by the neurosurgeon, if the newly defined entry point and trajectory followed the general principles of trajectory planning.

The mean ± SD distance of the electrode tip from the intended target was 3.0 ± 1.9 mm (median, 2.4 mm; range, 0.8-9.4 mm). The 9.4-mm deviation was seen in patient 4. In this case, an entry point deviation of 3.2 mm led to the deviation of the electrode within the brain by a deep sulcus; thus, the target was missed by 9.4 mm after 75-mm total trajectory length.

Procedure Duration

The mean duration of depth electrode placement from the start of trajectory alignment to fixation of the electrode was 19.1 minutes (range, 13-35 minutes). All procedures were performed by the same neurosurgeon (C.D.) who was familiar with the Vertek arm through his experience with intracranial biopsies. The most time-consuming part of the procedure was the correct alignment of the Vertek articulating arm and precision aiming device to the intended trajectory.

DISCUSSION

We developed a new technique of frameless stereotactic drilling for the placement of depth electrodes that is superior to the current standard frame-based methods for the following reasons: Our technique uses one of the commercially available neuronavigation system (S7) that is standard in neurosurgical units today.[17] In contrast to frame-based methods, our frameless technique has the advantage that imaging for registration can be performed without a frame in place long before surgery. No time for additional image acquisition is required on the day of surgery. Furthermore, although in experienced centers frames can be positioned on the patient's head quickly, fixing the head in a standard head clamp is easier. Therefore, the procedure can start very quickly right after patient positioning and a standard navigation registration.

As with other frameless techniques, our technique is highly flexible. All possible trajectories for electrode placement can be performed with virtually no limitations. In advanced frame-based methods, modifications of the standard frame position on the head also allow a great variety of possible trajectories; however, there are limitations of possible trajectories in each frame position. Furthermore, frameless techniques have the advantage that

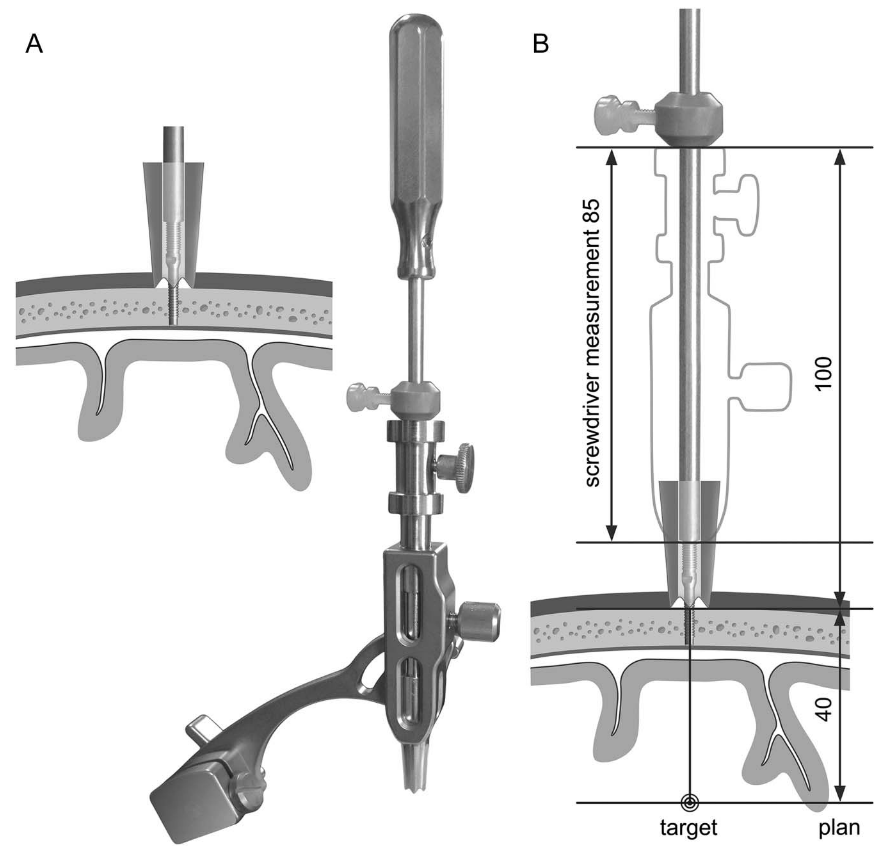

FIGURE 5. **A**, *the implantation bolt is screwed into the skull with a screwdriver, which has a stop device mounted.* **B**, *this stop device serves as a length measuring tool for the calculation of the correct depth distance of the electrode: The planned trajectory length (40 mm) plus the length of the reducing sleeve (100 mm) minus the measured length of the screwdriver (85 mm) gives the final depth distance (55 mm).*

intraoperative modifications of the planned trajectories can be accomplished easily and fast. This further enhances the flexibility of the procedure. If problems with the implantation of electrodes occur, it is sometimes necessary to modify the number or trajectories of the intended electrodes. With the head fixed in a standard head clamp, virtually all modifications, including craniotomies, are possible. With a stereotactic head frame, modifications and combinations with a craniotomy can become cumbersome and time-consuming.[10]

In previously described frameless techniques, the aforementioned advantages over frame-based methods are paid by the need for a 2- to 3-cm skin incision and a standard burr hole. In addition, inconvenient electrode fixation and subcutaneous tunneling further complicate the procedure.[10] A comprehensive stereo-electroencephalography procedure with 10 to 15 electrodes does not seem practicable to us. In frame-based methods, a small stab incision for a stereotactic drill burr hole and the implantation and simultaneous fixation of the electrode via a percutaneous implantation bolt obviate these difficulties.[6]

The aim of our novel technique was to combine this convenient percutaneous implantation with the flexibility of the neuronavigation arm, thereby being fast, flexible, and straightforward.

In procedures combined with the placement of subdural strip and grid electrodes, our technique offers additional versatility. The skin incision and bone flap necessary for subdural electrodes can sometimes hinder a percutaneous bolt fixation. If the bone at the planned entry point is exposed but not cut, the electrode can be implanted without the implantation bolt via a stereotactically drilled burr hole (patient 6). In cases when the entry point lies within the craniotomy, we place depth electrodes via a navigated stylet as described by Mehta et al.[10] For the skin incision and the craniotomy, the Vertek articulating arm can easily be completely moved out of the surgical field.

Even though the versatility of our technique allows a combination with strip and grid electrodes in virtually all variations, one has to keep in mind the potential risks of this combination of methods. Brain shift resulting from subdural electrodes can potentially lead

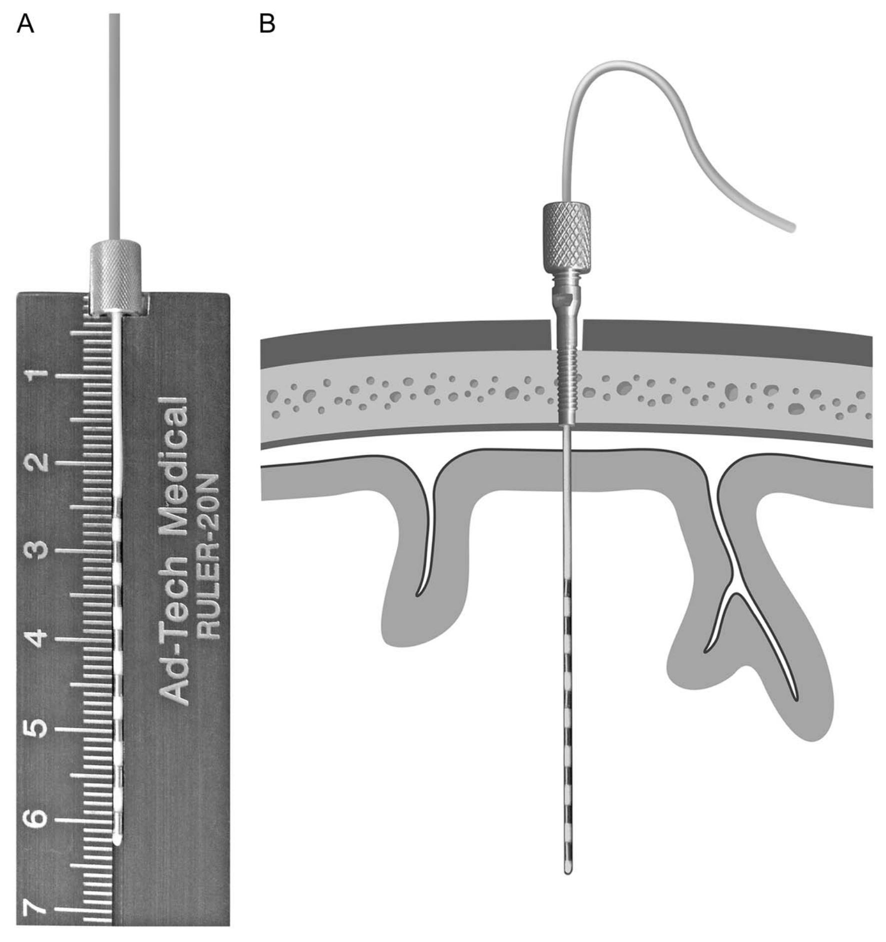

FIGURE 6. **A**, *the fixation screw of the implantation bolt is put on the electrode. The calculated depth distance is adjusted with the help of the ruler.* **B**, *the electrode is implanted and fixed on the bolt.*

to brain injury caused by the distortion of the depth electrodes. Furthermore, axial brain shift along the trajectory of the electrode can cause inaccuracy in depth. For these reasons, depending on the number and implantation sites of depth electrodes, we combine them with subdural strip electrodes alone, using additional small (eg, 4 × 5 cm) subdural plates in very selected cases only.

Because of the limited number of patients so far, definite conclusions about the safety of our technique have to be made with caution. However, we had no incidence of hemorrhage in this series of 26 depth electrodes. Our system allows real-time evaluation of each electrode trajectory before its final implantation to minimize crossing of sulci or the ependymal lining. Furthermore, no patient experienced infection or wound problems.

The overall accuracy was comparable to that in frameless stereotactic biopsy studies with a mean target deviation of 3.0 mm.[8,11,13] Thus, our stereotactic drilling technique does not deviate the neuronavigation arm that was designed for the performance of frameless stereotactic biopsies. It was sufficient to gain physiological recordings from all electrodes and to be within or touch the intended target in all cases.

Compared with frame-based methods, the accuracy of frameless stereotaxy is limited by the registration method of the neuronavigation and must be taken into account when planning trajectories.[11,18-24] However, in our series, even those as far as 4 to 5 mm from the intended target touched the edge of the anatomic structure and were adequate. As stated by previous authors, the requirements for accuracy in the placement of depth electrodes for epilepsy are not as stringent as those for other indications like deep brain stimulation.[10] The anatomic structures to be targeted for intracranial EEG recordings are less defined and more superficial; thus, the targeting trajectories are shorter.[5,6] The median length of electrode trajectories is 4 to 5 cm, which is about half the trajectory length in deep brain stimulation targeting the subthalamic nucleus or globus pallidus internus.[5,6] However, deflection results must be interpreted in the context of depth of trajectories. Thus, the accuracy of our

TABLE. Patient Characteristics and Electrode Accuracy[a]

Patient/ Age, y/Sex	Epilepsy	Magnetic Resonance Imaging	Target Location	Trajectory	Trajectory Length, mm	Entry Deviation, mm	Target Deviation, mm	Subdural Electrodes
1/29/F	FLE	Dysplasia	Perilesional	Oblique	41.4	3.2	2.6	No
			Perilesional	Oblique	30.8	4.3	1.9	
			Insular	Frontal, anterior insular	71.8	3.2	6.1	
			Insular	Frontal, posterior insular	60.0	2.6	4.9	
			Perilesional	Oblique	44.5	4.5	2.9	
			Amygdala	T2, orthogonal	37.9	4.8	2.1	
			Hippocampus mid	T2, orthogonal	39.3	3.5	2.4	
2/39/M	FLE	No lesion	Insular	Frontal, anterior insular	75.1	3.2	9.4	1 Strip frontobasal
			Frontal lobe	Oblique	45.4	4.6	2.1	1 Strip frontotemporal
			Amygdala	T2, orthogonal	48.0	2.1	2.3	
			Hippocampus mid	T2, orthogonal	45.2	4.3	2.1	
			Hippocampus post	T2, orthogonal	39.1	6.7	1.9	
3/26/M	TLE	No lesion	Hippocampus left	Occipital, longitudinal	90.0	4.2	2.9	2 Strips frontotemporal
			Hippocampus right	Occipital, longitudinal	91.2	2.2	2.4	
4/34/F	PLE	No lesion	Insular	Parietal, posterior insular	95.3	3.6	6.9	1 Strip central
			Occipital lobe	Oblique	21.1	4	2.5	1 Strip interhemispheric-parieto-occipital
			Parietal lobe	Oblique	34.1	3.1	2.6	
			Temporal lobe	Oblique	36	4.8	0.8	
			Parietal lobe	Oblique	35.8	4.1	1.4	
			Temporal lobe	Oblique	32.6	5.1	3.1	
5/10/M	FLE	Dysplasia	Perilesional	Oblique	45.5	3.9	1.9	2 Strips frontotemporal
			Perilesional	Oblique	41.3	4.5	2.3	
6/5/M	FLE	Dysplasia	Perilesional	Oblique	34.0	1.2	1.9	2 Strips frontotemporal
			Perilesional	Oblique	19.6	1.0	3.5	
7/13/M	FLE	Dysplasia	Perilesional	Oblique	38.2	1.1	2.4	1 Grid centroparietal
			Perilesional	Oblique	29.0	1.9	1.7	
					47.0 ± 20.9; (mean ± SD); 40.3 (median)	3.5 ± 1.4; (mean ± SD); 3.7 (median)	3.0 ± 1.9; (mean ± SD); 2.4 (median)	

[a]FLE, frontal lobe epilepsy; PLE, parietal lobe epilepsy; TLE, temporal lobe epilepsy; T2, middle temporal gyrus.

method (mean deviation, 3.0 mm; mean trajectory length, 47.0 mm) cannot be extrapolated to longer trajectories.

Most important for a safe placement of depth electrodes is the neurosurgeon's ability to sense resistance potentially caused by a sulcus or vessel when moving the electrode forward and not to rigorously push the electrode against it. Our technique allows smooth, easy placement of the electrode and guarantees good sensory feedback, thereby reducing the risk of a potential vascular injury.

CONCLUSION

We developed a novel technique of frameless stereotactic drilling for depth electrode placement that combines the advantages of 2 techniques: a high variability and flexibility of possible trajectories from the frameless technique and the convenient implantation and fixation of the electrode used in frame-based methods. According to our initial experience, depth electrode implantation for intracranial EEG recordings can be performed in a fast, efficient, and straightforward way with this technique.

Disclosures

Dr Wolfsberger is currently an educational consultant and a technological advisory board member of Medtronic surgical technologies. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

Epilepsy surgery often depends on electroencephalographic localization with intracranial electrodes. Placement of stereotactic depth electrodes by twist drill holes and anchor bolts provides a minimally invasive alternative to subdural strip/grid electrode arrays inserted via bur holes or extensive craniotomies. Notably, an approach based on depth electrodes pairs well with minimally invasive stereotactic thermocoagulation for epilepsy.[1-3] Depth electrodes may be placed with the use of stereotactic frames or robots or via image-guided frameless stereotaxis (IGS). Previous experience has shown IGS to generally be the least accurate, in part owing to the imprecision and limited rigidity of current articulating neuronavigation arms (reviewed by Cardinale et al[4]). Cranial exposures larger than twist holes also increase inaccuracy from cerebrospinal fluid loss and resulting brain shifts.

This report describes a modification of existing technique whereby frameless IGS is used to place depth electrodes. It is notable in 2 respects. First, the modification uses a novel reducing sleeve that directly engages bone, giving an additional point of fixation to skull to improve the rigidity of a standard IGS neuronavigation articulating arm. Second, the reducing sleeve accommodates placement of anchor bolts via small incisions.

The mean accuracies (deviations) at target and entry were reported as 3.0 and 3.5 mm, respectively, with a mean trajectory length of 47 mm. As expected, accuracies for longer trajectories were generally less precise. In general, these reported target accuracies are intermediate between those previously reported for IGS with articulating arms (approximately 6 mm) and slightly less precise than standard frame-based or robotic techniques (approximately 2-3 mm), as recently reviewed by Cardinale et al.[4] The authors rightly point out that such accuracies are sufficient for most epilepsy applications, and their technique may avoid the inconvenience of traditional frames and the expense of robotic assistance. Whichever the technique, the surgeon should take the anticipated error margins into account when planning trajectories, especially in more vascular regions such as insula.

As a report of accuracy for a new technique, this is a small study with no direct comparison with other approaches. Although no hemorrhages were reported, the purported safety and advantages of this technique must be weighed carefully in a larger study. Overall, this is an excellent description of what may well prove to be a worthwhile incremental improvement over an existing technique but with very preliminary results available.

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This article describes an effective method to place multiple depth electrodes with a simple frameless technique with an adequate precision. The error in placement is higher than for the frame-based method but acceptable. I have used a similar frameless technique using the biopsy arm for the Medtronic Stealth Station, with adaptation to place Dixi electrodes for 1 year. I learned it from Dr Didier Scavarda in Marseille, who has at least 4 years' experience with the method, even if it is not yet published. I also find it a very valuable and effective method, and it is important for patients undergoing epilepsy surgery that this method is now described and can be used at more places than the more time-consuming frame-based methods. My concern is that the combination described with subdural strips and grids may be dangerous, but this fact is adequately stressed in the article. Finally, with adequate precautions taken into account when a new method is implemented, this method should be valuable for many neurosurgeons and patients.

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