TECHNICAL NOTE

Clinical Accuracy of Customized Stereotactic Fixtures for Stereoelectroencephalography

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■ BACKGROUND: **Stereoelectroencephalograpy (SEEG) is a diagnostic method involving 3-dimensional exploration of brain structures using depth electrodes for locating epileptogenic foci in patients with drug-resistant epilepsy. A variety of frame-based, frameless, and robotic stereotactic systems have been designed for the accurate placement of depth electrodes.**

■ OBJECTIVES: **Using the FHC microTargeting platform as a model, we introduce a fully customized design that has all the constructive elements positioned by a computer algorithm, according to the planned trajectories, anchoring points, and anatomic constraints. All the constructive elements form a single-body fixture, which allows for the efficient implantation of multiple depth electrodes following trajectories having a wide range of orientations. We aim at evaluating the safety and accuracy of this stereotactic system in a clinical setting.**

■ METHODS: **A total of 173 depth electrodes were implanted in 21 patients with drug-resistant epilepsy. Matlab and DEETO software packages were used to postoperatively evaluate the targeting accuracy. Automatic detection of electrode locations eliminated any subjectivity in calculating the targeting errors.**

■ RESULTS: **As a result of using custom geometry of the stereotactic platform, the new design is optimized for each patient and streamlines the surgical procedures. The most important results characterizing the platform's accuracy are the values of 1.22 mm for the median lateral target point localization error and 1.17 mm for the median lateral entry point localization error.**

■ CONCLUSIONS: **The patient-customized platforms are comparable in terms of safety, accuracy, and simplicity of use to the existing robotic devices for implantation of depth electrodes in patients undergoing SEEG investigations.**

INTRODUCTION

Stereoelectroencephalography (SEEG), a complex method used in patients with drug-resistant epilepsy, aims to delineate the epileptogenic network, along with the eloquent cortex, with the ultimate goal of defining the area to be surgically resected, ablated, or subjected to the application of neuromodulation.[1-5] SEEG investigations require the implantation of 5 to 18 depth electrodes[5] by use of 1 of the several stereotactic systems available.[6,7]

Several frame-based and frameless stereotactic systems can be used for the implantation of depth electrodes.[6,7] The traditional frame-based systems include the Leksell system (Elekta Instruments Inc., Stockholm, Sweden), the Zamorano-Dujovny system (Inomed Ltd., Emmendingen, Germany), the Riechert-Mundinger system (Inomed Ltd.), and the Cosman-Roberts-Wells system (Integra, Plainsboro, New Jersey, USA). The frameless systems have been gaining ground recently, and among them we can count the NexFrame (Medtronic Inc., Minneapolis, Minnesota, USA), the iMRI-guided ClearPoint SmartFrame (MRI Interventions Inc., Irvine, California, USA), the Varioguide system (BrainLab, Munich, Germany), and the StarFix

Key words
- 3-Dimensional printing
- Epilepsy
- Frameless stereotaxy
- Stereoelectroencephalography

Abbreviations and Acronyms
CT: Computed tomography
DEETO: seeg electroDE rEconstruction TOol
EPLE: Entry point localization error
IQR: Interquartile range
LEPLE: Lateral entry point localization error
LTPLE: Lateral target point localization error
SEEG: Stereoelectroencephalography
TPLE: Target point localization error

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microTargeting Platform (FHC Inc., Bowdoin, Maine, USA). Robotic devices like Neuromate (Renishaw Inc., Wotton-under-Edge, UK) and Rosa (Medtech, Montpellier, France), originally referred to as frameless devices, tend now to be considered in a class of their own; see, for instance, a recent metastudy by Vakharia et al.[8] describing the accuracy of SEEG implantation methods, performed on 15 patients.

Accuracy of electrode placement is important not only for reaching the desired targets and maximizing the gray matter sampling but also from a safety point of view, to avoid colliding with vascular structures.[9] Whereas all vascular structures represent a risk to the patient's safety when located in the proximity of the trajectories, the subdural vessels near the entry point are particularly important to avoid.

Although all of the modern stereotactic devices have comparable accuracy,[8] it is important for the workflow associated with their use to be as simple as possible, with a small number of preoperative and intraoperative steps. Traditional stereotactic devices require mounting onto the patient's head a base frame, followed by the preoperative imaging for identifying rods or fiducial markers to perform the frame-to-patient coregistration. These steps are typically performed on the same day as the depth electrode implantation, putting a toll on the time and focus dedicated to the main step of electrode implantation. Because of the large number of electrodes implanted in each patient, reconfiguration and repositioning of the frame for each electrode trajectory can become cumbersome. In particular, the robotic devices reduce this time to a minimum, with just a few seconds required to reposition the toolguide to be aligned with the next trajectory. In this study, we introduce a patient-customized stereotactic device, referred to as the stereotactic platform, that incorporates all trajectories in its construction and allows a similarly fast transition from trajectory to trajectory. Such a fixture, just like the robotic devices, requires no adjustments or coordinates to be manually entered by the neurosurgeon, therefore minimizing human error.

Reaching epilepsy targets may require trajectories having a large variety of approaches, covering wide areas of the skull. Therefore, the attachment points of some stereotactic frames may interfere with the ideal trajectories, forcing the neurosurgeon to choose alternative, less optimal approaches. Our fixture is based on a computer-generated 3-dimensional (3D) model, allowing full flexibility in choosing the attachment points. Once a preoperative plan is defined, the neurosurgeon can plan the insertion of the bone anchors for the platform in the available areas without having to make any compromise in the choice of the trajectories.

Designed with these speed and flexibility characteristics in mind, the platform has to meet essential safety and accuracy requirements, which we further analyze in this study.

PATIENTS AND METHODS

The participants in this study were 21 adult patients with drug-resistant epilepsy who underwent presurgical evaluation with the use of SEEG. A total of 173 depth electrodes were placed in these patients by use of the microTargeting Epilepsy Platform (FHC Inc.). All implantation procedures were performed at Vanderbilt University Medical Center in Nashville, Tennessee.

The microTargeting Epilepsy Platform is a patient-customized stereotactic device designed with the use of Waypoint Navigator surgical planning software (FHC Inc.) and manufactured by the use of 3D printing technology. Medical-grade PA12 polyamide powder was the material used to build the platform through a selective-laser sintering process. The design is conformed to the patient's anatomy and can accommodate more than 20 trajectories. This platform requires several small bone anchors, serving the role of fiducial markers as well, to be implanted several days before the surgery, as described previously.[10,11] The location of the bone anchors is fully customizable to provide the widest anchoring base for maximum mechanical stability while avoiding conflicts with the planned trajectories and following the anatomic constraints. For instance, we advise avoiding the placement of fiducials into areas with very thin skull, such as lower in the temporal bone. Typically, the anchors are distributed evenly around the area to be implanted, at a minimum distance of 4 cm from the nearest entry point. The fiducial implantation procedure is simple, such that the neurosurgeon can always place extra fiducials based on the draft implantation template, having the option to discard those that interfere with future entry points. Alternatively, the trajectories can be preplanned ahead of the fiducial implantation, and virtual anchors can be manually placed in the planning software, providing guidance on their optimal location. In the series of 21 patients we have implanted between 4 and 8 anchors per patient (mean, 6.14 anchors) in non-stereotyped locations. After the implantation of the fiducials, a computed tomographic (CT) scan of the patient is performed. The location of the anchors is found on the CT by use of an automatic detection algorithm implemented in the Waypoint Navigator planning software.[12]

The coordinates of the bone anchor locations, together with the planned trajectories, are used by a computer algorithm to design a platform that is mounted to the bone anchors and contains "hubs" for guiding the insertion tools and electrodes along the planned trajectories (**Figure 1**). The algorithm uses fixed-shape tool guides, called "hubs," that are instantiated at spatial locations that are aligned with each trajectory, at a specified distance from the target. The distance from the target is calculated by use of a constant value for the clearance between each hub base and the skull, such that the location of the hubs conforms to the actual skull anatomy. This is made possible by the implementation of an algorithm in the planning software that detects the bone (including its thickness) in the preoperative CTs and uses this information for creating the platform. The user-selectable clearance value is set to 35 mm for most of the surgical procedures—a value representing a good compromise between minimizing the drill skiving and the ability to perform surgical electrode implantation steps, as described in the next paragraph. The set of distances to the target and the bone thicknesses for all trajectories are provided by the planning software in form of a table that is used at the time of surgery for positioning the depth stops on the drill bit, cannula, and electrode for each trajectory. To allow the attachment of the platform to the skull, using thumb knobs, fixed-geometry elements, called