Tactics: An Open-Source Platform for Planning Stereotactic Surgery

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Introduction

Framed stereotactic neurosurgery remains the most accurate and precise method of targeting deep brain electrodes. The technique is predominantly used for biopsies, deep-brain stimulation (DBS), and placement of temporary depth electrodes for epilepsy investigation. Surgeons use preoperative imaging data, typically T_1-weighted magnetic resonance images, to plan electrode and biopsy targets using methods ranging from pen-and-paper calculations to the use of commercial software packages. These methods have deficiencies: inability to plan multiple trajectories or visualize them in 3D, inability to robustly locate the stereotactic frame, and lack of incorporation of models of the specific implanted electrode to allow visualization of the location of individual contacts. Because of these deficiencies, an ongoing research study (CRIO-DBS) on the effects of DBS in patients with treatment-resistant depression required the development of an application that would improve on standard planning techniques and provide a unified tool to be used by investigators throughout the study. Our objective was to develop and validate a custom software application for CRIO-DBS that would overcome deficiencies in standard planning techniques and that would provide a unified workflow from planning of procedures through to their validation.

Methods

A novel software application (called Tactics) was developed in C++ using open-source libraries that would allow for rapid application development and thus rapid clinical and research use. The application was developed in partnership with neurosurgeons from the CRIO-DBS team. An iterative model of development was used to gather biweekly feedback from the surgeons to ensure that implemented features were useful, intuitive, and robust. The application was populated with DBS lead specifications from catalogues of popular manufacturers, providing surgeons the capability to plan their surgeries with leads available to them in the operating room and allowing for precise targeting of individual electrode contacts. The software was developed with the ability to register postoperative imaging with preoperative plans, to confirm that performed trajectories matched their planned counterparts. Usability of the software was evaluated through surgeons planning stereotactic biopsies with the software in parallel with their standard methods (Fig 1). The accuracy of the software was then systematically validated by attaching a stereotactic frame to an imaging phantom containing a grid of fiducial markers at varying depths. The phantom was imaged in a computed tomography scanner (HiSpeed, General Electric Hardware, Waukesha, WI, USA), providing 512×512 images with 1 mm slice thickness and 250 mm field of view. The images were loaded into the application and the positions of each fiducial marker were targeted and recorded (Fig 2). A neurosurgeon performed physical localization of the fiducial markers using the attached stereotactic frame and positions were compared against positions targeted with the software and a mean targeting accuracy was calculated.

Results and Discussion

The application was developed, from concept to clinical and research use, in 6 months. Initial usability testing demonstrated that the software has increased functionality and matching target coordinates in comparison to standard planning techniques. Validation of software accuracy using the imaging phantom showed a mean target localization error of 0.7 mm demonstrating a high degree of accuracy within the measurement granularity of the stereotactic frame. Tactics demonstrated a unified workflow for entire procedures from planning, placing, and validating positions of leads. The CRIO-DBS team has adopted the software as the standard tool for planning and validating their stereotactic surgeries. Given experimental validation of the accuracy of the application, and the adoption of the application among the CRIO-DBS clinicians and researchers, the application has shown to be robust and intuitive as well as an asset to DBS workflows.

Conclusion

Tactics has become an integral tool for clinicians and researchers both within CRIO-DBS and our hospital. Because of the ability to fuse postoperative and preoperative imaging, the application has enabled clinicians and researchers to compare performed trajectories against planned trajectories, providing additional resources for clinicians and researchers to validate treatment and outcomes. This postoperative validation has instigated further study by CRIO-DBS into the accuracy of placed versus planned lead trajectories and targets. Source code and binaries of the application are to be distributed online on www.atamai.com for free use and modification.

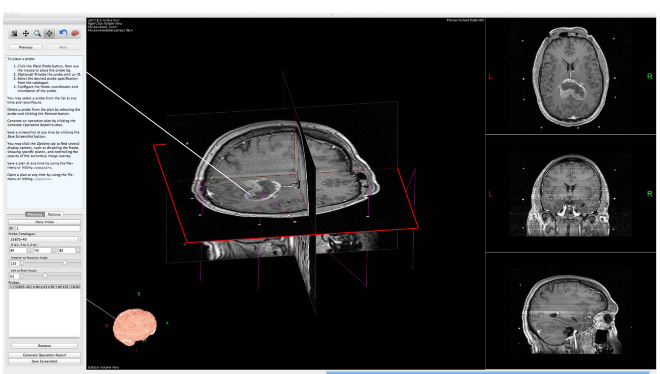

Fig 1. Initial validation of Tactics was performed through surgeons planning biopsies with Tactics alongside their standard techniques. Here, a neurosurgeon plans the target and trajectory for a brain tumor biopsy using Tactics.

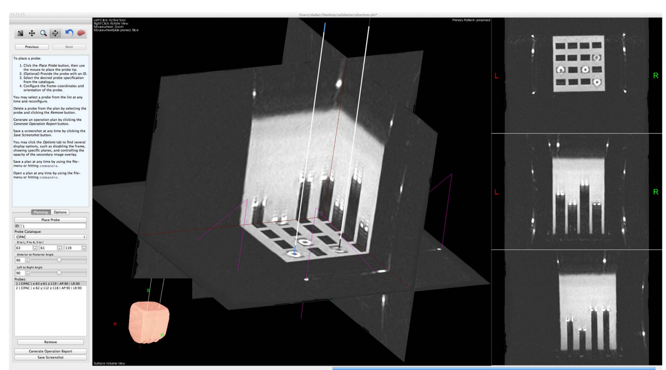

Fig 2. Targeting fiducial markers in a phantom using Tactics. The center of each circular fiducial marker was targeted by an expert and compared against known coordinates from the attached stereotactic frame. The expert was blind to the known coordinates.