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Advanced Methods for Target Navigation using Microelectrode Recordings in Stereotactic Neurosurgery for Deep Brain Stimulation

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Abstract

This study describes novel methods for navigating and placing of electrodes into specific structures in the basal ganglia for deep brain stimulation (DBS), as it is common in the treatment of Parkinson's disease. Critical to these procedures in neurosurgery is the localization and identification of different target structures such as subthalamic nucleus (STN) along the electrode's trajectory and finding the best position for the stimulating electrode.

Typically, microelectrode recordings (MER) of local neural activity along up to five parallel trajectories are used by neurosurgeons for detecting the target region and creating the anatomic positions of the electrodes by imagination. We developed a method for automatic classification of the MER signals, which provides an electrode model with patient specific borders of the STN. In addition, a method is provided for finding the best matching of the electrode model with a 3D model of the STN. As a result, a 2.5D visualization of the target region is produced with the most probable positions of the electrodes and their intersections.

1. Introduction

Stereotactic deep brain stimulation (DBS) is a widespread treatment option for different kinds of neurological diseases, especially movement disorders, such as Parkinson´s disease (PD), Dystonia, different kinds of tremors, or chronic pain also [1]. In the treatment of advanced PD the subthalamic nucleus (STN) is considered the most promising target. The STN is a small, almond-shaped structure of approx. $0.6\,ml$, which is located in the midbrain, adjacent to the Substantia Nigra and the red nucleus [2].

The anatomical localization of the STN as target for stimulation is the primary task in the stereotactic planning phase. T1-weighted magnetic resonance images (MRI) are used for extracting the target points and planning of safe trajectories for moving the electrodes to these targets. This task can be performed automatically using image processing algorithms [3]. However, the STN cannot be identified in T1-MRI which are actually available. And because T2-weighted MRI bear geometric inhomogeneities, the target points are determined indirectly from the positions of the anatomical landmarks anterior (AC) and posterior (PC) commissure of the 3rd ventricle which can be well detected in T1-MRI. The initial target coordinates for the STN are approximated by a fixed and commonly used 3D distance from the midcommisural point [4]. Obviously, these coordinates deviate from the patient's real STN coordinates.

In the surgery phase a stereotactic frame is used for pushing the stimulating electrodes – one per each hemisphere – towards the target points. However, MRI distortions, limited mechanical precision, shifting of the brain within the cranium, and the aforementioned coordinate approximation prevent from reaching precisely the real target structure with the electrode's stimulation poles. It must not be stressed extra, that a procedure with highest placing precision should ensure better therapy results and reduce side effects. For this reason, two measures can be taken interoperatively to assure therapy success. First, up to five electrodes are inserted on parallel trajectories for finding the best hit with the target structure. Second, most surgeons use microelectrode recordings (MER) to locate the target structure. MER signals measure the local activity within a small area proximal to the tip of the electrode as it is moved stepwise through the patients's brain. The MER of different brain structures can be distinguished by experienced neurophysiologists considering commonly known features such as background activity, spike or burst rates [5, 6].

Classification of the MERs is sometimes ambiguous even for experienced neurosurgeons. There are different approaches for automatic analysis and classification of