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Directional Recording of Subthalamic Spectral Power Densities in Parkinson's Disease and the Effect of Steering Deep Brain Stimulation

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ABSTRACT

Background: A new 32-contacts deep brain stimulation (DBS) lead, capable of directionally steering stimulation, was tested intraoperatively.
Objective: The aim of this pilot study was to perform recordings from the multidirectional contacts and to investigate the effect of directional current steering on the local field potentials (LFPs).
Methods: In eight patients with Parkinson's disease, after standard microelectrode recording and clinical testing, the new lead was temporarily implanted. The 32-channel LFP recordings were measured simultaneously at different depths and directions before and after directional stimulation.
Results: The spatial distribution of LFPs power spectral densities across the contact array at baseline marked the borders of the subthalamic nucleus (STN) with a significant increase in beta power and with a mean accuracy of approximately 0.6 mm in four patients.The power in the 18.5–30 Hz frequency band varied across different directions in all patients. In the three cases that showed improvement of rigidity, this was higher when current was steered toward the direction with the highest LFP power in the beta band. Subthalamic LFPs in six patients showed a differential frequency-dependent suppression/enhancement of the oscillatory activity in the 10–45 Hz frequency band after four different 'steering' modes as compared to ring mode, suggesting a higher specificity.
Conclusions: Through a new 32-contact DBS lead it is possible to record simultaneous subthalamic LFPs at different depths and directions, providing confirmation of adequate lead placement and multidirectional spatial-temporal information potentially related to pathological subthalamic electrical activity and to the effect of stimulation. Although further research is needed, this may improve the efficiency of steering stimulation.

Introduction

The subthalamic nucleus (STN) is the predominantly chosen target for deep brain stimulation (DBS) in patients with Parkinson's disease [1–8]. Abnormal oscillatory electrical activity of ensembles of neurons in the STN, observable in the amplitude modulation of the firing patterns of these neurons in a frequency range from approximately 10–35 Hz, is related to the severity of the parkinsonian state [9–12]. The amount of spectral power is related to the clinical status of the patient and the level of anti-parkinsonian medication [1,10,13–22]. Furthermore, STN DBS is capable of modulating this oscillatory activity [22–25].

Oscillatory amplitude modulation is not only observed in the spiking patterns of STN neurons, but also can be recorded from the local field potentials (LFP), which are the low frequency (<500 Hz) fluctuations of electrical activity. LFPs reflect the linearly summed postsynaptic potential from local cell groups [14,20,26–28]. As such, LFPs show a relationship with the envelope of the neural

Abbreviations: STN, subthalamic nucleus; GPi, Globus Pallidus interna; DBS, deep brain stimulation; LFP, local field potential; MER, micro electrode recording.

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spiking pattern [20,29,30] and consequently are related to the on or off state of the patient or to motor tasks. Interaction between different frequency bands has been described [14,22,31–36].

Therefore, for intraoperative fine tuning of STN localization, LFPs could be used instead of the microelectrode recording (MER) [37–39]. This could give the advantage that electrophysiological localization of the STN is derived directly from the same DBS lead that is used for chronic stimulation. In addition, knowledge about the relationship between the frequency characteristics of LFPs and clinical status could be used to optimally adapt chronic DBS [36,40–42].

The current pilot study describes LFPs derived from a new 32-contact DBS lead. As compared with the currently available leads, in a first observation this new lead not only seems to provide higher resolution depth localization of neuronal activity, but also directional information which could be used to improve targeting and to support adaptive DBS.

Materials and methods

Participants and surgery

The study was approved by the Medical Ethical Committee of the Academic Medical Center of Amsterdam. All the subjects received oral and written information and signed an informed consent. The study was conducted in conformity to the Declaration of Helsinki, the Dutch Act on Medical Research Involving Human Subjects (WMO) and the Standard EN ISO 14155: 2011 on clinical investigation of medical devices for human subjects – Good Clinical Practice.

Eight patients with a diagnosis of idiopathic Parkinson's disease who were candidate for STN DBS were included in the study. Details of the surgical procedure have been described in detail elsewhere [43]. Lead implant was performed with patients being awake, without sedatives, and in the practically defined off medication

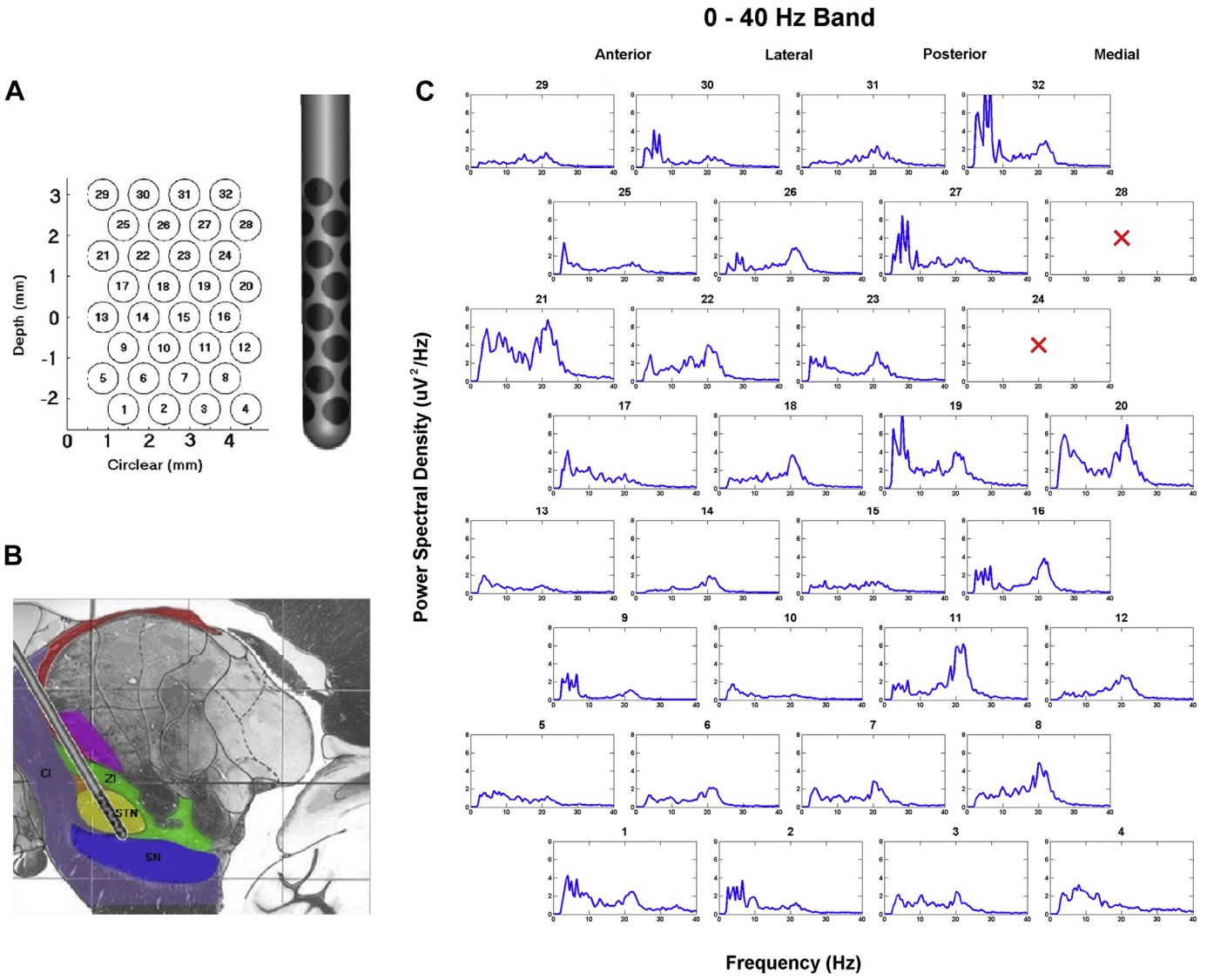

Figure 1. A) Shows a schematic two-dimensional display of the multi array lead. B) Shows schematically the position of the lead inside the STN (yellow) in a stereotactic atlas in a sagittal view at 12 mm from AC-PC. C) Shows for each contact point the power spectral density of the LFPs between 0 and 40 Hz at baseline in the unfolded 2D array display in patient 6. Based on the MER recordings in this case all 32 contacts were completely inside the STN. On top of the array, the direction towards which each contact is heading is indicated (For instance, contact 1,9,17 and 25 are heading into the anterior direction). The contact points 24 and 28 boxes are filled with a red cross because here pre-amplifiers went into saturation due to a too high DC offset, and therefore LFP recordings were not possible. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)