Journal of Neuroscience Methods 198 (2011) 280–286

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Kinematic optimization of deep brain stimulation across multiple motor symptoms in Parkinson's disease

Thomas Mera[a,*], Jerrold L. Vitek[b,d], Jay L. Alberts[c,d,e], Joseph P. Giuffrida[a]

[a] Division of Movement Disorders, Cleveland Medical Devices, Inc., 4415 Euclid Ave Suite 400, Cleveland, OH 44103, USA
[b] Department of Neuroscience, Cleveland Clinic, 9500 Euclid Ave, Cleveland, OH 44195, USA
[c] Department of Biomedical Engineering, Cleveland Clinic, 9500 Euclid Ave, Cleveland, OH 44195, USA
[d] Center for Neurological Restoration, Cleveland Clinic, 9500 Euclid Ave, Cleveland, OH 44195, USA
[e] Louis Stokes Department of Veteran Affairs, FES Center, 10701 East Blvd, Cleveland, OH 44106, USA

ARTICLE INFO

Article history:
Received 15 October 2010
Received in revised form 23 March 2011
Accepted 24 March 2011

Keywords:
Parkinson's disease
Deep brain stimulation
Outpatient programming
Tremor
Bradykinesia
Kinesia

ABSTRACT

Parkinson's disease (PD) is a neurodegenerative disorder characterized by motor symptoms including tremor and bradykinesia (slowness of movement). Drug treatment, although capable of controlling these symptoms over a number of years, becomes less effective as the disease progresses and leads to motor complications such as drug-induced dyskinesia (involuntary abnormal movements). Deep brain stimulation (DBS) provides an alternative means of controlling motor symptoms in these patients, and while DBS has been effective in improving motor symptoms, these improvements are largely based on accurate placement of the lead and the ability of medical personnel to adequately program the DBS device following implantation. While guidelines exist for DBS programming, selection of stimulation parameters and patient outcome is greatly dependent on subjective clinical assessments and the experience of the medical personnel performing the programming. The aim of this project was to assess the feasibility of using a quantitative and objective approach to programming. Two subjects underwent standard procedures for DBS programming while wearing a small, compact motion sensor. Kinematic data were collected from subjects as they completed motor tasks to evaluate DBS efficacy. Quantitative variables characterizing tremor and bradykinesia were related to stimulation parameters. Results indicated different stimulation settings might be required for optimal improvement of different motor symptoms. A standardized method of programming DBS parameters utilizing motion analysis may provide an objective method of assessment that the programmer can use to better identify stimulation parameters to achieve optimal improvement across multiple motor symptoms.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder characterized by the varied combination of motor symptoms including tremor and bradykinesia (slowness of movement). As the disease progresses, motor symptoms worsen and medication side effects become more prevalent. As quality of life becomes increasingly compromised, patients may consider deep brain stimulation (DBS) surgery. Numerous studies show benefits of DBS of the subthalamic nucleus (STN) and the globus pallidus internus (GPi) in PD (Katayama et al., 2001; Obeso et al., 2001; Deuschl et al., 2006). Following DBS surgery, stimulation parameters are chosen to optimize patient motor symptoms while minimizing any side effects (Kumar, 2002; Hunka et al., 2005). Stimulation parameters include choice of contacts and polarity (cathodal versus anodal), voltage, pulse width, and frequency (Volkmann et al., 2006). Depending on the institution, DBS programming may be performed by a variety of healthcare professionals, including movement disorder neurologists, neurosurgeons, fellows, occupational and physical therapists, and nurses (Hunka et al., 2005). Clinical rating scales, most commonly the Unified Parkinson's Disease Rating Scale (UPDRS) (Goetz et al., 2007), are used to evaluate PD symptom improvement in response to different stimulation settings. Symptoms are rated on a 0–4 integer scale corresponding to normal, slight, mild, moderate, and severe. The UPDRS ratings are used to evaluate and adjust stimulation parameters (Lukhanina et al., 2000; Goetz et al., 2007). This subjective assessment can be highly dependent on the observer's assessment and skill in evaluating these motor symptoms. Stimulation programming that utilizes an objective assessment method across multiple motor symptoms would allow for the selection of parameters based on clear quantitative measures rather than subjective assessments. Greater reliance on objective measures has

* Corresponding author. Tel.: +1 216 619 5897; fax: +1 216 791 6739.
E-mail address: tmera@clevemed.com (T. Mera).

0165-0270/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jneumeth.2011.03.019

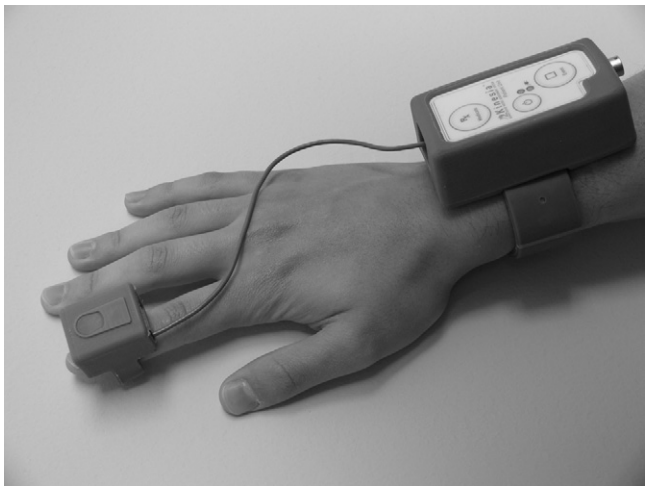

Fig. 1. Kinesia motion capture device. The unit consists of a finger-worn motion sensor and wrist-worn command module for data acquisition and wireless data transmission.

the potential to improve motor outcomes while side effects are minimized.

Current methods of optimizing programming parameters require a continuous process that takes a significant amount of time and effort by both the clinician and patient. Programming sessions of DBS require more than twice the time of a typical PD evaluation by a movement disorder neurologist (Okun et al., 2005). Extended programming sessions result in patient fatigue and worsening symptoms, making programming even more difficult (Kumar, 2002; Hunka et al., 2005). It is estimated that programming a patient for the first year following implantation requires approximately 30 h of clinical time (Hunka et al., 2005). Multiple visits lead to additional travel expenses for patients and can be particularly difficult for those who live in rural areas without adequate access to clinics specialized in DBS programming (Okun et al., 2005). While DBS has been effective in treating advanced PD, a more quantitative approach of programming could reduce the frequency and duration of programming sessions, reducing health care costs while improving patient outcomes.

The objective of this preliminary study was to evaluate the feasibility of an automated system to assist with motor symptom assessment during DBS programming. Two subjects diagnosed with PD underwent standard procedures for DBS outpatient programming while wearing a small, compact motion sensor. Data were collected as subjects completed motor tasks typically performed during DBS assessment. Quantitative variables of tremor and bradykinesia were used to create tuning maps, which correlated the severity of these motor symptoms as a function of stimulation parameters. A stimulation parameter estimation algorithm was developed to output optimal settings for individual symptoms and overall motor response across multiple symptoms.

2. Material and methods

Case studies were performed at the Center for Neurological Restoration at the Cleveland Clinic under the purview of both Cleveland Medical Devices Inc. and Cleveland Clinic Institutional Review Boards. All subjects provided informed consent.

2.1. Technology overview

Kinesia™ (CleveMed, Cleveland, OH), a Food and Drug Administration cleared-to-market device, captures three dimensional motion data (Fig. 1). The finger-worn motion sensor contains three orthogonal accelerometers and three orthogonal gyroscopes to capture linear accelerations and angular velocities, respectively. Sensor data are sampled at 128 Hz and wirelessly transmitted to a computer in real time. A prototype software interface designed using LabVIEW 8.6 (National Instruments, Austin, TX) collects and saves to disk motion sensor, UPDRS-based motor task, and stimulation parameter data. Recorded DBS settings consisted of the positive and negative electrode contacts used for stimulation and stimulation voltage (V), frequency (Hz), and pulse width (μs).

2.2. Data collection protocol

Two subjects were evaluated during their first outpatient programming session one month following DBS surgery. Both subjects presented primarily with moderate tremor (UPDRS rest tremor score 3) and with moderate bradykinesia (UPDRS finger tapping score 2 (subject 1) and 3 (subject 2)) during baseline assessment (off medication and off stimulation). Both received an electrode implant targeting the right STN and the contralateral upper extremity was assessed. Subjects were off antiparkinsonian medication overnight prior to the DBS programming session.

A trained nurse practitioner performed the programming procedure while Kinesia wirelessly transmitted kinematic data to the computer without obstructing hand movement or interfering with the standard DBS programming protocol. The sensor unit was placed over the most distal phalanx of the index finger (Fig. 1). Each subject was instructed to perform two tasks from the UPDRS-III motor examination per stimulation setting combination. The tasks were determined by the clinician based on existing motor symptoms. Rest tremor (item #20) and finger tapping (item #23) were performed for 20 s each and used to evaluate symptom response to stimulation parameters during programming.

Each of the four monopolar electrode contact settings was assessed individually by incrementing stimulation voltage from 0 V until stimulation-induced side effects were elicited as determined by the programmer. These effects manifested as blurry vision, slurred speech, muscle contractions, etc. and subsided when the stimulator was turned off. To evaluate each contact, frequency was fixed at 130 Hz and pulse width at 60 μs. Voltage was typically increased in 0.5–1.0 V increments and then reduced to 0.2–0.3 V once transient side effects occurred. On average, 2–3 min were given after each voltage increment before UPDRS motor tasks were performed. Subjects were given a rest period approximately 20 min before starting the next series of measurements along the subsequent contact.

2.3. Motor symptom features

Motion data collected during the DBS programming sessions were processed into quantitative variables that described motor symptom features. These features were plotted versus stimulation contact and voltage to provide a tuning map for assessing motor symptom severity in response to DBS settings.

2.3.1. Tremor

Kinematic data collected during rest tremor assessment were band pass filtered (2nd order Butterworth, 3–10 Hz). In a previous clinical study (Giuffrida et al., 2009), the log peak power of Kinesia motion sensor data demonstrated a high correlation to clinician scores for tremor tasks. This kinematic variable was processed from the motion sensor channel that exhibited the largest average signal amplitude.

2.3.2. Bradykinesia

While tremor improvement can be effectively characterized with a single variable, more complex analysis was required