Abstract

Deep brain stimulation (DBS) is broadly applied for neuropsychiatric diseases and thus determining its mechanism is of interest, especially in terms of the neural structure surrounding the DBS probe and the volume of tissue activated (VTA) during DBS. For re-operations for battery replacement, a major issue is reducing treatment power consumption without compromising clinical benefits. To avoid side effects and to minimize power consumption, optimized adjustment of the stimulation parameters is required. This study thus proposes a scheme for determining the optimal stimulation parameters. An electromagnetic finite element model for a patient-specific physiological brain model is first established using magnetic resonance imaging (MRI) data. Using finite element analysis (FEA), varied stimulation parameters are applied to the electromagnetic model for VTA estimation. Optimal electrode contact(s) are selected based on the estimated VTA to avoid side effects. Moreover, a nonlinear programming method for optimizing the stimulation voltage and the pulse width is applied to minimize power consumption in DBS. The effectiveness of the model parameters was verified using five Parkinson’s disease patients. The results demonstrate that the estimates of the VTA are consistent with the observations within the desired region of the brain while avoiding side effects and reducing power consumption by 13% on average. The proposed method allows clinicians and researchers to efficiently select the optimal stimulation parameters. Moreover, it provides valuable information for closed-loop stimulation protocols in DBS.

Keywords: Deep brain stimulation (DBS), Volume of tissue activated (VTA), Side effects, Power consumption, Magnetic resonance imaging (MRI), Finite element analysis (FEA)

1. Introduction

Over the last decade, deep brain stimulation (DBS) has been adopted to treat various neuropsychiatric disorders, such as essential tremors, epilepsy, drug-resistant depression, and obsessive compulsive disorder [1]. In this approach, electrodes are implanted chronically into a selected brain target, such as the subthalamic nucleus (STN), to treat Parkinson’s disease (PD). A brain-electrode interface (BEI), which consists of the implanted electrode, a layer of peri-electrode space surrounding the electrode, and the surrounding brain tissue, is then formed [2-6]. Because the brain tissue content in the peri-electrode space varies with time, stimulation parameters should be adjusted during DBS to maintain the efficacy of therapy. To quantify the efficacy of DBS, the Unified Parkinson’s Disease Rating Scale (UPDRS) [7], based on a clinical evaluation of symptoms, has been established to assess the severity of PD symptoms. Among the problems that may be confronted during the adjustment of stimulation parameters in clinical practice, side effects and power consumption are considered to be the most serious [8-14]. Side effects could be induced when the stimulation region covers undesired parts of the brain, which commonly occurs in clinical practice. In addition, the stimulator’s battery might require frequent replacement because stimulation at constant amplitude consumes considerable power. On average, the mean lifetime of a stimulator’s battery in PD was found to be 47-83 months [15]. A battery replacement costs as much as twenty-five thousand US dollars [16].

The focus of the present study is preventing the neuropsychiatric side effects that can be induced when the DBS-stimulated region covers the limbic circuit on the antero-ventral part of the STN, which is related to emotion control [9,10]. Several methods have been proposed for reducing power consumption during DBS [11-13]; they can be classified into two main categories: (i) the development of new devices for DBS [11,12] and (ii) adjustment of DBS parameters [13]. In