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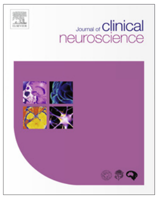

Microelectrode accuracy in deep brain stimulation surgery

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ABSTRACT

Microelectrode recording (MER) provides vital neurophysiological information about target nuclei during deep brain stimulation (DBS). There have been extensive studies looking at the accuracy of DBS lead placement; however, to date, no large series have assessed the accuracy of the microelectrode. In this study, we report the accuracy of microelectrode tip placement in comparison to preoperatively planned radiographic target. Patients who underwent DBS with MER from 2014 to 2016 were included in the study. At the authors' institution, intra-operative CT (iCT) is routinely performed after the first microelectrode track to confirm tip accuracy. Retrospective analysis of microelectrode track error was calculated between the planned trajectory and the microelectrode tip. The radial error was calculated on the same axial plane using the Euclidian distance formula, and multivariate analysis was performed to ascertain any directional bias of error. A total of 227 microelectrode tracks were analyzed, (150 STN, 50 ViM, 27 GPi) yielding a total radial error of 1.2 mm ± 0.2 SEM across all targets. Analysis of vector error distribution revealed lack of directional bias. MER is an accurate electrophysiological representation of the planned target.

1. Introduction

Deep brain stimulation (DBS) is an effective surgical option for patients with medically refractory Parkinson's disease (PD), essential tremor (ET) and dystonia with expanding applications extending into realm of psychiatric disorders such as treatment resistant depression and obsessive compulsive disorder [1–3]. Despite advancements in neuroimaging and stereotactic techniques emphasizing radiographic target optimization, microelectrode recording (MER) remains the gold standard for neurophysiological target optimization and refinement [4–6]. MER gives real-time neurophysiological localization and feedback of desired nuclei for targeting; however, there is a paucity of literature regarding the accuracy of the microelectrode, which in instances of MER-guided DBS surgery, guides and precedes final lead placement [7,8]. Although numerous publications have addressed the accuracy of final DBS lead placement, no studies have directly addressed microelectrode accuracy in a large series [4,5,8]. At our institution, intraoperative CT with volumetric merging to preoperative MRI is routinely performed following the first MER track. This allows for localization of the microelectrode tip in comparison to the desired radiographic target thus providing essential information that allows for correlation between neurophysiological recordings and radiographic location. Here we report on the accuracy of microelectrode in comparison to the preoperatively chosen radiographic target at a single institution where MER is routinely used for target optimization.

2. Methods

This study included patients who underwent DBS with MER for PD, dystonia and ET between 2014 and 2016 and was approved by the Institutional Review Board (IRB) at the authors' institution. Patients selected met the qualifications of DBS surgery as determined through a multidisciplinary evaluation and assessment by the neurosurgery, neurology and neuropsychology teams and had successfully completed the operation.

2.1. MER error calculation

To ascertain MER trajectory error, we retrospectively analyzed the radial error between the initial MER track and planned trajectory as determined by iCT (O-arm, Medtronic, Minneapolis, MN) in all patients who underwent DBS with MER between 2014 and 2016. The MER trajectory was planned using targeting software (Framelink 5.1, Medtronic, Minneapolis, MN) utilizing the computationally merged images from preoperative MRI and CT. Per our institutional protocol, MRI is typically completed 1–2 weeks prior

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to the surgical date, whereas the CT is performed on the day of surgery after stereotactic head frame placement. Initial targeting was performed using direct visualization on T2-weighted and susceptibility weighted imaging (SWI) in instances of subthalamic nucleus (STN) or globus pallidus pars interna (GPi) targeting and atlas-based coordinates of the ventral intermediate thalamic nucleus (VIM) described within the literature [9]. After completion of the first MER track, with the electrode tip at target depth, an iCT was performed and computationally merged with the preoperative CT. The final microelectrode coordinates were subsequently determined.

The radial error was defined as the vector difference between the intended and actual trajectories, measured on the axial plane as seen in Fig. 1A and Fig. 1B. Using this plane is the most clinically relevant measurement intra-operatively allowing easier determination of whether repositioning with adjustments in the x or y directions are necessary [4,10]. The z coordinate is modifiable in real-time without the need for repositioning the microelectrode. The radial error between the planned trajectory and the final microelectrode coordinates were calculated using the Euclidean distance formula: $\sqrt{(\Delta X^2) + (\Delta Y^2) + (\Delta Z^2)}$. Although this formula is used to calculate three-dimensional vector error, it can be used to calculate the radial distance between two points on the same axial plane since the value of Δz is essentially zero. The mean error ± standard error of the mean (SEM) was also calculated.

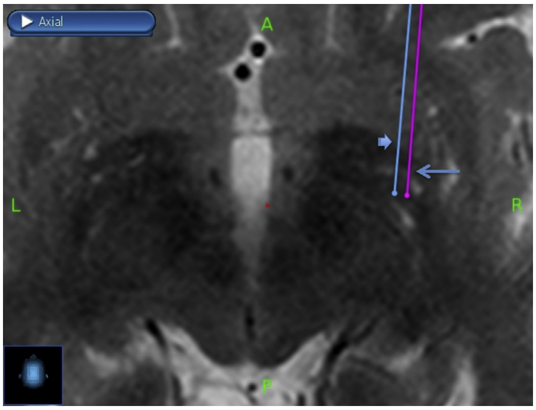

Fig. 1A. Axial MRI showing the planned trajectory target (small arrow head), and the microelectrode tract (long arrow) during a right GPi DBS implantation surgery. The difference in the axial plane is the basis for the calculation of radial error.

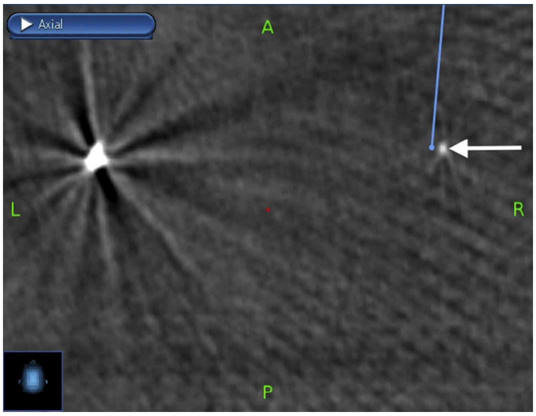

Fig. 1B. Intraoperative CT showing the visualized location of the microelectrode tip (long arrow) in relation to the planned trajectory (line). The DBS lead implanted into the left GPi can also be seen at the left of the figure.

Measurement and error calculations were performed using Excel software (Microsoft, Seattle, WA). Multivariate directional vector analysis was performed using R (Vienna, Austria) [11].

3. Results

A total of 227 microelectrode tracks were analyzed (150 STN, 50 ViM, 27 GPi) in 171 patients. Average patient age was 62.6 years old. The most common pathology was Parkinson's disease followed by tremor and dystonia at 27% and 10% respectively. Full demographics shown in Table 1. Average x, y, z coordinates of initial radiographic target in comparison to the average x, y, z coordinates of the microelectrode tip amongst each and all targets are shown in Table 2. The total average radial error amongst all nuclei ± standard error of the mean (SEM) between the planned radiographic target and the final microelectrode tip was 1.2 ± 0.02 mm. The average error of the planned versus actual track coordinates was 0.62 mm in x and 0.73 in the y coordinate amongst all targets. Results further stratified by target and directional coordinates are shown in Table 2. Vector analysis demonstrated random error directionality and is shown graphically amongst all targets in Fig. 2.

4. Discussion

We report the accuracy of the microelectrode in comparison to the preoperative radiographically chosen nucleus in a large series of DBS cases performed with MER. Prior studies comparing neurophysiological data obtained from MER to radiographic target have been reported under the assumption that the microelectrode accurately resides within the intended target/follows the same trajectory (as defined by either atlas coordinates or preoperative imaging) [12–14]. The use of iCT not only provides the opportunity to confirm accuracy of the microelectrode within the desired nucleus but also can assess for aberrant trajectories when MER data is suboptimal. We found that amongst all targets, radial error between the planned radiographic target and the final microelectrode tip was 1.2 mm. Although there are no other reported studies regarding microelectrode accuracy by which to compare this error, we are ultimately limited to comparisons with published reports of DBS lead placement error. Our results compare favorably with previous literature regarding DBS lead radial error which ranges from 1.59 to 3.2 mm [4,15,16]. Admittedly, this is not a homogenous comparison as the structural properties of the microelectrode and DBS lead vary significantly, with microelectrode being more rigid and thinner in comparison to a DBS leads.

Inherent sources of error such as imprecisions in stereotactic equipment (i.e. headstage, guide tube, arc or frame) or targeting soft-

Table 1
Demographic information of patients included in current study. GPi = Globus pallidus interna, STN = Subthalamic nucleus, ViM = Ventral intermediate thalamic nucleus.

Demographics	
Patients	171
Age (avg)	62.6
Male/Female	105/66
Diagnosis (%)	
Parkinson's Disease	63%
Dystonia	10%
Essential Tremor	27%
Target (# Hemispheres)	
Total	227
STN	150
Gpi	27
ViM	50

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