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Comparison of 2-dimensional magnetic resonance imaging and 3-planar reconstruction methods for targeting the subthalamic nucleus in Parkinson disease

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Abstract

Objective: The study aims to compare 2-dimensional (2D) and 3-planar (3P) reconstruction magnetic resonance imaging (MRI) methods of targeting the optimal region of the subthalamic nucleus (STN) for chronic stimulation in patients with Parkinson disease.

Methods: We studied 14 patients with Parkinson disease treated with bilateral STN deep brain stimulation (DBS) (28 STN targets). Electrode implantation was based on direct and indirect targeting based upon the position of the anterior and posterior commissures using 2D MRI, with selection of the final target based on microelectrode recording. Optimal settings, including the contacts used, were determined during the clinical follow-up. The position of the best contact was defined with postoperative MRI. Optimal contact position was compared to targets calculated by the direct method from the preoperative 2D MRI and 3P reconstruction. Optimal contact position was also compared to the indirect targets calculated from the preoperative 2D MRI and 3P reconstruction. The distance between the targets and the position of the best contact were calculated.

Results: The mean improvement in OFF-period Unified Parkinson Disease Rating Scale III subscores with STN DBS was 52%. The mean distance between the optimal contact position and the direct target was 4.66 mm (SD = 1.33) using the 2D MRI and 3.49 mm (SD = 1.29) using the 3P reconstruction (t test, $P < .001$). The mean distance between the optimal contact and the indirect target was 3.42 mm (SD = 1.34) using the 2D MRI and 2.61 mm (SD = 0.97; t test, $P = .001$) using the 3P reconstruction. The variance of the direct target was less using the 3P reconstruction than using the 2D MRI (F test, $P = .002$), indicating greater precision. Similarly, the variance of the indirect target using the 3P reconstruction was less than using the 2D MRI (F test, $P = .012$).

Conclusion: Indirect and direct targets chosen using 3P reconstruction more closely approximate the position of the clinically optimal contact than targets chosen using 2D MRI.

Keywords: Deep brain stimulation; Subthalamic nucleus; Parkinson disease; Neurosurgery; Magnetic resonance imaging; Stereotactic surgery

1. Introduction

Despite the relatively small size, ovoid shape, and oblique disposition of the subthalamic nucleus (STN) [17,21], it can be targeted for the treatment of movement disorders with excellent results [9,11]. Ventriculography [2], computerized tomography [1,7,22], and magnetic resonance imaging (MRI) [16,19] have all been used for operative

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targeting. Several studies have demonstrated that MRI is as accurate as the other methods [1,3,10]. With the progress of the computer-assisted surgery, 3-planar (3P) reconstruction of the stereotactic images has been proposed as a way to increase the reliability and efficacy of this procedure [3,4,18] by correcting for frame placement and minimizing MRI-related distortion.

In this study, we compared conventional 2-dimensional (2D) MRI with 3P reconstruction methods of targeting the STN in patients with Parkinson disease. We compared modified direct targets (3 mm above the center of the nucleus), derived from either the 2D MRI or the 3P reconstruction, with the coordinates of the contact giving the optimal clinical result postoperatively. Indirect targets based on the coordinates of the anterior commissure (AC) and posterior commissure (PC), using either 2D MRI or 3P reconstruction, were also compared to the optimal contact position.

2. Patients and methods

We reviewed 14 patients with Parkinson disease treated with bilateral subthalamic deep brain stimulation (28 subthalamic targets). For inclusion in this study, a preoperative stereotactic MRI and a postoperative MRI (1-5 days postoperative) were required. The parameters used for both pre- and postoperative MRIs (1.5-T unit, Signa Model; General Electric Medical System, Milwaukee, WI) are shown in Table 1. The techniques used for deep brain stimulation electrode insertion are described elsewhere [8]. The x-coordinate was defined as the lateral-medial distance, the y-coordinate as the anterior-posterior distance, and the z-coordinate as the superior-inferior distance. The target of the first microelectrode track was based upon the 2D MRI–based indirect target for x- and z-coordinates and the mean of the y-coordinates from the 2D MRI–based direct and indirect targets. No correction was made for uneven frame placement before choosing the target for the first pass of the microelectrode.

The postoperative MRI was used to target the final position of the electrode tip (Model 3387 quadripolar lead) as well as the medial-lateral and anterior-posterior trajectory angles. The coordinates of the optimal contact were calculated as previously described, using the contact that gave the optimal clinical results at follow-up, the position of the tip, and the trajectory angles [16]. These coordinates were derived relative to the AC and PC in Talairach space. If the patient had better results using double monopolar stimulation, the midpoint between the 2 negative contacts was used as the final target. If bipolar stimulation was optimal, the negative contact was defined as the final target because this is the area of highest stimulation (charge is concentrated around the cathode).

Table 1
MRI specifications

Parameter	T2-weighted sequence
Image mode	2D
TR (ms)	4000.0
TE (ms)	90.0
Echo train	8
No. of slices	20
Matrix size	256 × 256
Slice thickness (mm)	2
Slice gap (mm)	0
Signal means	3
Bandwidth (kHz)	3.29
Field of view (mm)	270

2.1. Indirect and direct 2D targets

Both direct and indirect targeting from 2D MRI were used for surgical planning. A standard T2-weighted axial 2D MRI was used to target the posterior border of the AC and the anterior border of the PC. The indirect target was defined as a point 12 mm lateral, 3 mm posterior, and 3 mm inferior to the AC-PC midpoint (MCP). The 2D direct target was calculated using coronal sections from the 2D T2-weighted MRI. The STN was identified as a hypointense, ovoid structure, lateral to the most anterior part of the red nucleus and superior to the substantia nigra. The center of the STN was targeted and its coordinates calculated. Preliminary analysis (data not shown) revealed that this target was far from the position of the optimal contact. This was not unexpected because the optimal target for chronic stimulation within the STN appears to lie near the superior portion of the nucleus [6,13,16,23]. Therefore, the z-coordinate (superior-inferior) of the direct target was modified superiorly by 3 mm to obtain closer coordinates to the optimal region for stimulation. This modified direct target was closer to the optimal contact position than the direct target (data not shown).

For our post hoc analysis, frame-based coordinates were transformed into AC-PC coordinates as a way to correct for frame placement and to compare different patients. Uneven frame placement was measured in terms of the roll (displacement in the coronal plane), yaw (displacement in the axial plane), and pitch (displacement in the sagittal plane relative to the AC-PC line) to analyze its contribution to errors in targeting.

2.2. Indirect and direct 3P target

Axial T2-weighted fast-spin echo sequence images were transferred to the StealthStation. Using the FrameLink software (FrameLink 4.1, StealthStation Mach 4.1; Medtronic SNT, Minneapolis, MN), the fiducials of the frame (Leksell series G; Elekta Instruments, Atlanta, GA) were recognized, transforming the entire image volume into stereotactic coordinate space. During this procedure, the mean rod marking error was calculated by the software and registered. Coronal and sagittal images were reconstructed based on the information from the axial images. The AC and PC were targeted using the 3 planes. Two points in the