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Magnetic resonance and computed tomography image fusion technology in patients with Parkinson's disease after deep brain stimulation

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ABSTRACT

Electrode position after deep brain stimulation (DBS) for Parkinson's disease (PD) needs to be confirmed, but there are concerns about the risk of postoperative magnetic resonance imaging (MRI) after DBS. These issues could be avoided by fusion images obtained from preoperative MRI and postoperative computed tomography (CT). This study aimed to investigate image fusion technology for displaying the position of the electrodes compared with postoperative MRI. This was a retrospective study of 32 patients with PD treated with bilateral subthalamic nucleus (STN) DBS between April 2015 and March 2016. The postoperative (same day) CT and preoperative MRI were fused using the Elekta Leksell 10.1 planning workstation (Elekta Instruments, Stockholm, Sweden). The position of the electrodes was compared between the fusion images and postoperative 1–2-week MRI. The position of the electrodes was highly correlated between the fusion and postoperative MRI (all r between 0.865 and 0.996; all $P < 0.001$). The differences of the left electrode position in the lateral and vertical planes was significantly different between the two methods (0.30 and 0.24 mm, respectively, both $P < 0.05$), but there were no significant differences for the other electrode and planes (all $P > 0.05$). The position of the electrodes was highly correlated between the fusion and postoperative MRI. The CT-MRI fusion images could be used to avoid the potential risks of MRI after DBS in patients with PD.

1. Introduction

Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is considered as a safe, minimally invasive, and effective surgical treatment for Parkinson's disease (PD), improving quality of life in about 70% of the patients within five years [1,2]. DBS of the subthalamic nucleus (STN) is an effective treatment for PD [3,4] and the dorsolateral STN border is the most effective target [3,5]. Because the dorsolateral part of the STN (the sensorimotor area) is associated with the movement of the skeletal muscles [3]. In addition, the STN plays an essential role in the cortex-basal ganglia-thalamus circuit, which is one of the major targets for the treatment of dyskinetic disorders [3,6]. Therefore, the precise identification of the position of the DBS electrodes relative to the dorsolateral part of the STN will help improving the clinical effectiveness of DBS [7,8].

MRI is an ideal technique for evaluating the structure and function of the brain in patients with PD. Although pre-operative imaging studies and intra-operative microelectrode recordings have been used to guide the position of the electrode to the appropriate target nucleus [9], post-operative imaging is a crucial aspect to assess eventual complications and to evaluate the exact electrode position [10,11]. Post-operative confirmation of the electrode placement is desirable in order to verify the location and to rule out surgical complications. This information is also useful to optimize subsequent programming and to investigate long-term complications. Unfortunately, there are barriers to the use of MRI in the post-DBS setting. MRI examination after DBS is associated with risks such as electrode heating and dislocation, electrical stimulation, and equipment damage. In addition, MRI after electrode implantation can induce severe injury such as transient myodystony, paralysis, coma, and even death [12–16], but recent studies have demonstrated that this procedure can be performed safely without causing any adverse effects, especially for ≤ 1.5 T field strength [17]. It is important to keep in mind that not all currently available DBS stimulating systems on the market are validated for post-operative MRI. Baker et al. [18] suggested that some using a lead management device would allow for a wider range of clinical scanning sequences at 1.5 and 3 T in patients with DBS implants. Nevertheless, the clinical approach to MRI in patients with DBS remains controversial due to lack of extensive safety data and research when MRI is used with neurological implants.

The use of CT could overcome some of the limitations of MRI after

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DBS, but CT is limited by poor contrast for soft tissues and by image artifacts due to the metallic electrodes [19]. CT-MRI fusion imaging is a concept that combines a preoperative/intraoperative MRI and a post-implantation CT [20–22]. This approach has been validated [22,23].

Therefore, the aim of this study was to investigate the value of image fusion technology (using preoperative MRI with postoperative thin-layer CT) to display the position of the electrodes compared with postoperative MRI. A prospective trial comparing postoperative CT to MRI is currently underway (ClinicalTrials.org #NCT01997398), but the present retrospective study will nevertheless provide additional data regarding the postoperative use of the fusion technology, as well as determining the exact benefits from the procedure.

2. Patients and methods

2.1. Study design and subjects

This was a retrospective study of 32 consecutive patients with PD who underwent bilateral electrode implantation for STN DBS between April 2015 and March 2016 at the Shenzhen Second People's Hospital. There were 12 females and 20 males, with a mean age of 56.8 ± 12.0 (range, 32–76) years. Disease duration was 8.1 ± 3.8 (range, 3–19) years. The mean Hoehn and Yahr stage score was 3.0 ± 0.9 (range, 2–5). All PD patients who underwent bilateral electrode placement for subthalamic nucleus (STN) DBS were included. No adverse effects were found in the included patients. All patients underwent preoperative MRI, postoperative CT (about 12 h after operation to rule out intracranial bleeding), and MRI 1–2 weeks after operation (to observe the position of electrodes). The exclusion criteria were: 1) poor image quality (such as artifacts or blurred edges); 2) no intraoperative microelectrode recording; 3) postoperative bleeding; or 4) complications such as infection.

This study was approved by the Ethics Committee of the Shenzhen Second People's Hospital. The need for individual consent was waived by the committee because of the retrospective nature of the study.

2.2. Preoperative imaging

A 1.5 T MRI system (Avanto, Siemens, Erlangen, Germany) was used to scan the brain on the day before surgery. On the day of surgery, a Leksell stereotactic frame was placed before using a 1.0-T system (Magnet Harmony, Siemens, Erlangen, Germany) MRI. MR images were used to identify the anterior commissure (AC), posterior commissure (PC), midcommissural point, and target coordinates. Then, burr holes were made bilaterally in the skull in front of the coronal suture. The coordinates of the STN were determined by direct visualization on a T2-weighted intraoperative MR image in the axial plane and by indirect targeting based on the midpoint of the AC-PC line, with the target determined as 4 mm below and 12 mm lateral to the midline and 2–3 mm posterior to the midpoint of the AC-PC. Coronal images orthogonal to these coordinates were obtained. The entry points were determined for the electrode trajectory to be parallel to the long axis of the STN, and avoiding blood vessels. The final target coordinates were determined based on intraoperative electrophysiology study.

2.3. Electrode implantation

DBS was performed as previously described [24]. The medication was stopped for at least 12 h before surgery. After local anesthesia with Lidocaine, the directional arc of the Leksell frame was placed according to the planned coordinate. The scalp was incised under local Lidocaine anesthesia. After confirmation of the skull access point, a 14-cm drill was used to drill the skull, a fistula was made at the cortex, and a microelectrode recording device was installed (G102R, PINS Medical Equipment Co., Ltd., Beijing, China). The coordinates of the STN were confirmed by electrophysiology. On the left side, the middle channel was chosen for the left microelectrode recording using a semi-microelectrode (G102R, PINS Medical Equipment Co., Ltd., Beijing, China) with the active pole consisting of the exposed tip of the needle. The microelectrode was inserted through the hole down to 10 mm above the theoretical target and was advanced by 1-mm increments using a microdrive device. Along the track, the passage into the STN resulted in a frank increase in signal amplitude. The tracks were repeated until signal amplitude higher than two fold the basal noise was obtained. If electric signals were not detected for three times during the operation, the head holder was used again during the operation for MRI re-examination. The signals matching the movements of the right upper and lower limbs were induced, and the microelectrode was removed. The mean number of microelectrode recording for each side was generally 1-2. The electrode (3389S, Medtronic, Fridley, MN, USA; made of titanium alloy) was implanted into the deep brain on the left side. The electrode was implanted on the right side in the same manner. The electrodes were tested to ensure that no obvious side effects were induced when the voltage was higher than 5 V. A permanent pacemaker was implanted [24]. During the weeks after implantation, the stimulation parameters (electrode montage, pulse width, frequency, and voltage) were adjusted for optimal results. All operations were performed by the same surgeon, who is a chief surgeon at the Department of Functional Neurosurgery, as well as the second co-author of this article.

2.4. Magnetic resonance imaging

Intraoperative MRI was performed using a Siemens 1.0-T MRI (Magnet Harmony, Siemens, Erlangen, Germany) using a 8-channel head coil. The protocol included high-resolution PD + T2-weighted tra (spin-echo, TR = 6500 ms, TE1 = 14 ms, TE2 = 85 m, FOV = 280 mm, matrix = 256 × 256, NEX = 3, slice thickness of 2 mm).

Preoperative MRI was performed using a Siemens 1.5 T MRI (Avanto, Siemens, Erlangen, Germany) using a 32-channel head coil. The protocol included T1-weighted tra (spin-echo, TR = 388 ms, TE = 133 ms, FOV = 20, slice thickness of 2 mm) and high-resolution PD + T2-weighted tra (spin-echo, TR = 3460 ms, TE1 = 11 ms, TE2 = 90 ms FA = 1500, FOV = 250 mm, matrix = 256 × 256, NEX = 2, slice thickness of 2 mm).

Postoperative MRI was performed on a Siemens 1.5 T scanner and included a T2-TSE tra (spin-echo sequence TE = 90 ms, TR = 4320 ms, FOV = 230 mm2, matrix = 256 × 256, voxel size 0.9 × 0.9 × 2.0 mm, NEX = 2, slice thickness of 2 mm) and a T2-TSE cor (spin-echo, TR = 3090 ms, TE = 84 ms, FA = 1500, FOV = 220 mm, matrix = 384 × 288, NEX = 1, slice thickness of 2 mm).

2.5. Computed tomography

Postoperative CT was performed using a 40-row spiral CT (Somatom definition, AS; Siemens, Erlangen, Germany). Scanning parameters were: 140 keV, 286 mA, and slice thickness of 0.6 mm.

2.6. Image fusion

The postoperative CT images were registered to the preoperative T2- or proton density-weighted FSE MR images used for stereotactic targeting. The CT/MR registration was performed with the Merge algorithm included in the Elekta Leksell 10.1 software (Elekta Instruments, Stockholm, Sweden). The registration process is automatic. For quality control, several fiducial makers were used on the cranium and in the brain.

The spatial position of the electrodes was then observed (Fig. 1A). The electrode tips on the fused images and postoperative MRI images were measured on the Elekta Leksell 10.1 operation planning workstation (Elekta Instruments, Stockholm, Sweden) (Fig. 1B).