Improving surgical treatment for movement disorders

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Chapter 3

Postoperative displacement of deep brain stimulation
electrodes related to lead-anchoring technique

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Chapter 3

ABSTRACT

Background
Deep brain stimulation (DBS) electrodes displacement may occur after surgery, especially in patients with large subdural air collections, but other factors might also contribute.

Objective
We investigated the role of factors potentially contributing to postoperative electrode displacement, in particular different DBS lead anchoring techniques.

Methods
We analyzed 55 patients (106 electrodes) with Parkinson’s disease, dystonia, tremor, and obsessive-compulsive disorder, in whom early-postoperative and follow-up CT were performed. Electrodes were anchored with titanium micro-plates or with commercially-available plastic-cap systems (Stimloc™, Medtronic). Postoperative subdural air collections volumes were measured and two independent examiners determined the stereotactic coordinates of the deepest DBS contact on early-postoperative and follow-up CT. The influence of age, surgery duration, subdural air volume, use of microrecordings, fixation method, follow-up time, and side operated first was assessed.

Results
Subdural air collections measured on average 4.3 ± 6.2 cm³. Electrode displacement in the X (p = .026), Y (p =.009), and Z (p<.001) axes and the 3D displacement (p =.030) significantly correlated only with the electrode anchoring method (larger displacement for micro-plate-anchored electrodes). Fourteen percent of the electrodes showed ≥2-mm (potentially relevant) Z-coordinate displacement (28% of the micro-plate-anchored electrodes and 2% of the Stimloc™-anchored, p < .001).

Conclusion
Although titanium micro-plates are less expensive, the commercially-available plastic cap system (Medtronic Stimloc™) is more efficient in preventing postoperative DBS electrode displacement. A reliability analysis of the electrode fixation is warranted when alternative anchoring methods are used.
INTRODUCTION

Accurate stereotactic implantation of deep brain stimulation (DBS) electrodes is essential to maximize benefits from DBS surgery. It is assumed that anatomic structures do not move between preoperative image acquisition and stereotactic electrode implantation. However, several reports revealed erratic implantation of DBS electrodes caused by shifts of up to 5 mm of deep brain structures due to cerebrospinal fluid (CSF) loss and subdural air invasion.\(^1\)\(^4\) Another assumption is that implanted electrodes do not move postoperatively, while recently our group reported significant upward displacement of DBS leads in the months following surgery in 14 Parkinson’s disease (PD) patients undergoing DBS of the subthalamic nucleus (STN).\(^5\) This postoperative displacement significantly correlated with the amount of air invading the subdural space during surgery. A similar finding was also reported by Kim et al.,\(^6\) and led us to focus more on minimizing CSF leakage during surgery.

Other explanations for postoperative DBS electrode displacement should be considered, since we also observed such displacement in several patients with no or minimal subdural air.\(^5\) For example, our technique of anchoring the DBS electrode with a titanium micro-plate at the border of the burr hole could in theory allow upward migration when underneath bone erosion with subsequent loosening of the fixation and retraction of the lead occur in the months following surgery. In 2008, we therefore changed our anchoring technique and started using a commercially-available plastic lead anchoring device and burr-hole cover (Stimloc\textsuperscript{TM}, Medtronic, Minneapolis, MN).

The aim of the present study was to further define the role of subdural air invasion and to investigate other potential factors contributing to electrode shift, in particular different DBS lead anchoring techniques.

METHODS

Patients
We retrospectively analyzed data routinely obtained in all patients who underwent DBS at our center, and in whom we performed both an early postoperative and a follow-up computer tomography (CT) in the period between April 2005 and April 2010. Indications for surgery included PD, dystonia, obsessive-compulsive disorder (OCD) and tremor. Demographical data and clinical information were retrospectively collected from the patients’ files. The Medical Ethical Committee of the Academic Medical Center in Amsterdam was officially consulted and waived the need for official approval for this study.
Surgical Targeting and Procedure

Target localization was based on preoperative frame-based magnetic resonance imaging (MRI) and, in most patients, micro-electrode recordings (MER) and macro-stimulation. Details of the surgical technique and MER are described elsewhere. Whenever possible, surgery was performed with the patient awake. Bilateral procedures were always performed simultaneously and were started on the most affected side or on the side contralateral to the dominant hand. For MER, one to five parallel steel cannulas and microelectrodes, placed in a 2-mm interspace array, were inserted. All steel cannulas stayed in place throughout the surgical procedure, including during electrode implantation.

In order to minimize CSF loss and subdural air invasion, we applied the following operative technique: first, paths were planned with entry on top of a pre-coronal gyrus, at a 15-20° anterior angulation to the inter-commissural line and a 20-30° lateral angulation from the midline, avoiding sulci, vascular structures, and ventricles. Second, patients were operated in a semi-sitting supine position with the head elevated at 20-30°. Third, we closed burr holes with fibrin glue after introduction of the microelectrodes or macro-stimulation electrode. After test stimulation, a quadripolar DBS electrode (model 3389®; Medtronic, Minneapolis, MN) was implanted under fluoroscopic guidance. Two electrode anchoring methods were used: until November 2008, electrodes were fixed at the border of the burr hole with a standard titanium micro-plate (MatrixNEURO™, DePuySynthes Zuchwil, Switzerland) and underneath plastic covering (to prevent electrode damaging), similar to the technique reported by Favre et al. From November 2008 onwards, electrodes were anchored to the skull using a commercially-available plastic lead anchoring device and burr hole cover (Stimloc™, Medtronic, Minneapolis, MN, Figure 1C-D). Implantable pulse generators were implanted in a subcutaneous pocket in the infraclavicular region and connected with the electrodes under general anesthesia.

CT Measurements of subdural air collection and electrode location

A CT (MX 8000 multi-slice CT; Philips, Eindhoven, The Netherlands) with 2-mm slices was performed in the early postoperative period and at long-term follow-up. Both CT scans were co-registered with the preoperative stereotactic MR using Leksell Surgiplan® software version 10.0 (Elekta Instruments AB, Stockholm, Sweden). The co-registration procedure implied an automatic run and successive manual fine tuning of the co-registration performed by the examiner.

Subdural air collections were delineated on both sides of the brain independently in all patients on three-dimensional reconstruction of the early postoperative CT and measured volumes using BrainLAB iPlan® software version 2.5 (BrainLAB, Feldkirchen, Germany). To define the outcome measures, stereotactic coordinates of the metallic artifact of the deepest contact of the DBS electrodes were determined on the early postoperative and follow-up CT. The difference in X, Y, and Z stereotactic coordinates in the follow-up scan
with respect to the early postoperative scan, as well as the total 3D electrode displacement (calculated as the vector derived from the square root of $\partial X^2 + \partial Y^2 + \partial Z^2$) were used as measures of electrode displacement. In order to minimize inaccuracy due to the co-registration procedure and to the identification of electrodes tips, all co-registrations and electrode markings were performed independently by two examiners (MFC and MB), and average values were used for analysis.

Figure 1. Electrode fixation methods used in this series. A-B) Micro-plate fixation system based on a custom made slightly concave titanium micro-plate, which is fixated to the skull with two screws. Between the plate and the electrode, a small silicone plate is inserted to prevent electrode damage. C-D) Commercially available fixation system (Medtronic Stimloc™) made of a plastic ring filling the burr hole, a plastic inlay with a lead clip, and a cap/burr hole cover. The electrode is fixated by a clamp in the inner inlay.
Statistical Analysis

Multiple linear regression analysis was used to assess the influence of several factors on directional postoperative DBS electrodes displacement along the X, Y, and Z axes, and on the absolute 3D displacement. Factors included in the analysis were: age at surgery, duration of surgery, volume of postoperative subdural air collections, use of MER, electrode fixation method, follow-up time (time between early postoperative CT and follow-up CT), and whether the side was operated first or second. Pearson correlation analysis was conducted to assess the correlations among the variables. Paired-samples t-test and Chi-square test were used to compare groups where appropriate. Statistical analysis was performed using PASW Statistics 18. A p value < .05 was considered significant. Mean values are presented ± standard deviation (SD).

RESULTS

A total of 178 patients underwent bilateral or unilateral DBS at our center in 2005-2008. In 55 patients both an early postoperative CT scan (within 3 days) and a follow-up CT scan were performed. Forty patients (73%) received both scans as part of a clinical trial (“NSTAPS” trial, randomly comparing STN DBS and GPI DBS for Parkinson’s disease, or a trial assessing the efficacy of nucleus accumbens DBS for OCD). The remaining 15 patients (27%) received the early postoperative scan as part of our routine procedure, and the late follow-up scan to check the electrode position for optimization of stimulation parameters. Their clinical and demographical characteristics are presented in Table 1. Fifty-two patients underwent bilateral DBS, three unilateral DBS. One patient with bilateral implantation had one electrode explanted early after implantation due to infection. Thus, a total of 106 electrodes were used for analysis.

Subdural Air Volume

Measurement of postoperative subdural air collections revealed air volumes between 0 and 32.8 cm³, with a mean of 4.3 ± 6.2 cm³. The amount of air did not correlate with the age, length of surgery, use of MER, or electrode fixation method. In bilateral cases, the amount of subdural air on the side operated first (mean 4.4 ± 6.1 cm³) and second (mean 4.0 ± 6.2 cm³) was comparable (paired-samples t-test, p = .51). On all follow-up CTs, air collections had resolved.
Table 1. Clinical characteristics of the patients included in the study.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (women/men)</td>
<td>22/33</td>
</tr>
<tr>
<td>Age at surgery (years)</td>
<td>55.1 ± 11.6 (range 26-72)</td>
</tr>
<tr>
<td>Diagnosis (No. electrodes/No. patients)</td>
<td></td>
</tr>
<tr>
<td>Parkinson’s disease</td>
<td>63/32</td>
</tr>
<tr>
<td>Dystonia</td>
<td>15/8</td>
</tr>
<tr>
<td>OCD</td>
<td>24/12</td>
</tr>
<tr>
<td>Tremor</td>
<td>4/3</td>
</tr>
<tr>
<td>Total</td>
<td>106/55</td>
</tr>
<tr>
<td>Surgical target</td>
<td></td>
</tr>
<tr>
<td>STN</td>
<td>33</td>
</tr>
<tr>
<td>GPi</td>
<td>44</td>
</tr>
<tr>
<td>Accumbens</td>
<td>24</td>
</tr>
<tr>
<td>Thalamus</td>
<td>5</td>
</tr>
<tr>
<td>Surgery duration (minutes)</td>
<td>208.7 ± 70.4 (range 80-357)</td>
</tr>
<tr>
<td>No. microelectrodes per side</td>
<td>2.8 ± 1.8 (range 0-5)</td>
</tr>
<tr>
<td>No. sides with MER (%)</td>
<td>83 (78.3%)</td>
</tr>
<tr>
<td>No. side with fixation method = plate</td>
<td>50 (47.2%)</td>
</tr>
<tr>
<td>Early CT time (days after surgery)</td>
<td>1.2 ± 0.7 (range 0-3)</td>
</tr>
<tr>
<td>Follow-up CT time (months)</td>
<td>12.3 ± 6.3 (range 2-35)</td>
</tr>
<tr>
<td>Volume subdural air (cm$^3$)</td>
<td>4.3 ± 6.2 (range 0-32.8)</td>
</tr>
</tbody>
</table>

OCD, Obsessive compulsive disorder; STN, Subthalamic nucleus; GPi, Globus pallidus pars interna; MER, microelectrode recordings; Ct, computed tomography. Data are presented as average ± standard deviation.

Postoperative DBS Electrode Displacement

None of the electrodes penetrated the lateral ventricle. The displacement in stereotactic X-coordinate of the metallic artifact of the deepest contact of DBS leads from early postoperative (on average one day following implantation) to follow-up CT (on average, one year) varied between 0.7 mm more medial and 3.3 mm more lateral, with a mean absolute displacement of 0.8 ± 0.6 mm. The displacement in stereotactic Y-coordinate varied between 1.3 mm more posterior and 3.3 mm more anterior (mean absolute displacement 0.8 ± 0.7 mm). The displacement in stereotactic Z-coordinate varied between 14.3 mm more dorsal and 2.2 mm more ventral (mean absolute displacement 1.2 ± 1.5 mm). Total absolute electrode displacement along the electrode trajectory (3D), as defined by the vector derived from the square root of $\Delta X^2 + \Delta Y^2 + \Delta Z^2$, was on average 1.9 ± 1.5 mm (range 0.5-14.7 mm). There were no differences in electrode displacement between the patients participating in the trials and the other patients.

The directional DBS electrodes displacement in the X, Y, and Z axes, and the absolute 3D displacement significantly correlated only with electrode fixation method (p = .026 for X-coordinate, p = .009 for Y-coordinate, p<.001 for Z-coordinate, and p = .030 for total displacement).
No correlation was observed with any of the other factors (age at surgery, duration of surgery, volume of postoperative subdural air collections, use of MER, follow-up time (time between early postoperative CT and follow-up CT), and whether the side was operated first or second).

Z-coordinate displacement for electrodes anchored with the titanium micro-plate ranged from 0.6 mm more ventral to 14.3 mm more dorsal (mean absolute displacement 1.6 ± 2.0 mm), while for electrodes anchored with Stimloc™ it ranged from 2.2 mm more ventral to 1.8 mm more dorsal (absolute average displacement 0.8 ± 0.5 mm). Table 2, Figure 2

The direction of displacement was dorsally for 82 DBS electrodes (77%) and ventrally for 24 electrodes. There was a higher percentage of electrodes which moved dorsally among those anchored with titanium micro-plates (45 electrodes, 90%; 5 electrodes which moved ventrally, 10%) than with Stimloc™ (37 electrodes, 66%; 19 electrodes moved ventrally, 34%; p = .005).

Displacements of ≤ 2 mm falls under the maximal limit of accuracy of the CT-imaging and co-registration technique and thus could be regarded as clinically not relevant. In the current series, a total of 15 electrodes (14%) showed ≥ 2mm Z-coordinate displacement (potentially relevant; Figure 2). It occurred significantly more often in titanium micro-plate- (14 electrodes, 28%) than in Stimloc™-anchored electrodes (1 electrode, 2%; p < .001). Interestingly, all >2mm displaced micro-plate-anchored electrodes moved upward (mean Z-coordinate displacement of 3.4 ± 3.2 mm), whereas the only >2mm displaced Stimloc™-anchored electrode moved downward (2.2 mm). Only one micro-plate-anchored electrode of this series (0.9%) was repositioned due to clinical consequences of displacement (14.3 mm dorsal Z-coordinate displacement in a patient with cervical dystonia, presenting with lack of effect).

Table 2. Range of displacement along the stereotactic coordinates

<table>
<thead>
<tr>
<th></th>
<th>Range X coordinate</th>
<th>Range Y coordinate</th>
<th>Range Z coordinate</th>
<th>Range absolute 3D displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medial</td>
<td>Lateral</td>
<td>Posterior</td>
<td>Anterior</td>
</tr>
<tr>
<td>Microplate</td>
<td>-0.7</td>
<td>3.3</td>
<td>-1.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Stimloc™</td>
<td>-0.5</td>
<td>2.0</td>
<td>-1.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>
DISCUSSION

Postoperative DBS electrode displacement
We demonstrated that DBS leads can show displacement after surgery even after minimization of CSF loss. The only factor correlating with postoperative directional displacement along all stereotactic coordinates, and with the absolute 3D displacement, was the method of anchoring DBS electrodes: displacement was larger for DBS leads anchored with a titanium micro-plate.

The present study of 106 DBS electrodes in 55 patients, implanted for various diseases at various deep brain targets, confirms that DBS leads have not always reached their final position on early postoperative imaging, as previously reported in our analysis of 26 leads in 14 PD patients undergoing STN DBS (not included in the present series). In this previous study, postoperative displacement was significantly correlated with the amount of air invading the subdural space and the subsequent posterior shift of the frontal cortex during surgery. In the patients operated thereafter, we therefore changed our operative technique in order to minimize CSF loss during surgery. These changes involved planning the burr holes on top of a gyrus, performing surgery with patients in a semi-sitting position and, in particular, effective sealing of the burr hole with fibrin glue immediately after introduction of the microelectrodes and macro-stimulation electrode. For the patients presented here, this resulted in much smaller postoperative subdural air volumes than in our previous series (on...
average $4.3 \pm 6.2$ cm$^3$ vs $17 \pm 24$ cm$^3$). Similarly small postoperative intracranial air volumes were also reported by others who employed special operative techniques to minimize CSF loss. As a consequence of the smaller subdural air volumes, total postoperative displacement along the electrode trajectory of the currently analyzed DBS leads was much smaller than in our previous study (3D displacement $1.9 \pm 1.5$ mm versus $3.3 \pm 2.5$ mm; absolute Z-coordinate displacement $1.2 \pm 1.5$ mm versus $2.6 \pm 2$ mm). The minimization of CSF leakage is also reflected by the fact that the amount of air in the present series did not statistically influence the amount of displacement. None of the other explored factors (age at surgery, length of surgery, use of MER, follow-up time, or whether it was the side operated first or second) significantly correlated with displacement either.

Anchoring by means of a titanium micro-plate proved to be less efficacious than the Stimloc$^\text{TM}$ system in keeping electrodes in place during long term follow-up. Different types of custom-made fixation methods (similar to the one we used before) are still preferred at some centers due to the lower costs. Moreover the Stimloc$^\text{TM}$ does not fit in smaller craniostomies – e.g. when twist drill is used.

We hypothesize that anchoring DBS electrodes directly on the bone of the skull might allow for upward migration when underneath bone erosion and subsequent loosening of the anchoring occur. (Figure 3) These phenomena were in fact observed in several other patients that underwent stereotactic repositioning of their displaced leads (personal observations by PvdM and PRS).

Figure 3. Illustrative drawing of the possible cause of electrode displacement in patients in whom the micro-plate system was used. A) trans-skeletal cut showing the situation just after fixation with the micro-plate. B) trans-skeletal cut showing underneath bone erosion with subsequent loosening of the fixation.
Upward displacement seems to be much alleviated by the use of a plastic cap system such as the Stimloc™, in which the anchoring does not rely on direct contact between the DBS electrode and the bone of the skull. Although downward displacement was observed with the Stimloc™, this was > 2mm in only one case (2.2 mm). Our results suggest that the anchoring method with Stimloc™ provides a reliable fixation of the electrode in the great majority of cases. This could be considered a valid reason to face the relatively high costs of this device (about 600 Euros for a bilateral procedure at our center, as compared to about 200 Euros for the titanium micro-plate and screws (MatrixNEURO™, DePuySynthes Zuchwil, Switzerland)).

Impact of postoperative DBS electrode displacement on treatment success of DBS
The mean Z-coordinate lead displacement in the present series was 1.6 ± 2.0 mm (range 0.6 downward to 14.3 mm upward) for electrodes anchored with the titanium micro-plate and 0.8 ± 0.5 mm (range 2.2 downward to 1.8 upward) for electrodes anchored with Stimloc™. It is important to consider that the co-registration technique implies some inaccuracy — although in this study we tried to reduce it to a minimum by using the average scores of two independent raters — and that CT scan acquisition was performed with 2mm-thick slices. Moreover, the currently used quadripolar DBS lead (model 3389®; Medtronic, Minneapolis, MN) has four 1.5-mm contacts with three 0.5 mm interspaces, spanning 7.5 mm in total. For these reasons, in our current clinical practice we only consider electrodes displacements ≥2 mm as potentially clinically meaningful. In the present series, ≥ 2mm migration was only observed in a total of 15 electrodes (14% of the total), the majority of these (14 electrodes, 93%) being anchored with the micro-plate.

The effect of the observed lead displacements on clinical symptoms for this group of patients cannot be determined retrospectively. However, it is of notice that only one electrode out of 106 electrodes (0.9%) in 55 patients needed to be repositioned due to unsatisfactory clinical effect (dorsal Z-coordinate displacement of 14.3 mm). It is reasonable to believe that effects deriving from minor electrode displacement could be corrected for by adaptation of the stimulation parameters used for chronic stimulation.

CONCLUSION

DBS electrodes are subject to postoperative displacement, which can be clinically relevant in some cases. The most important factors determining postoperative electrode displacement are likely related to CSF loss and subdural air invasion. Once these factors are minimized, a potential relevant factor is the electrode anchoring method. Although custom made metallic micro-plates are less expensive and widely used, the commercially-available plastic cap system (Medtronic Stimloc™) proved to be more efficient than micro-plates in preventing post-operative electrode displacement. Based on our data, we suggest that an analysis of
reliability of the electrode anchoring should be performed in all cases in which alternative anchoring methods are used.

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