Contact Location and Neuropsychological Outcomes in Subthalamic Deep Brain Stimulation

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BACKGROUND: A host of influences contribute to cognitive and behavioral changes following deep brain stimulation. The location of the active cathode is likely an important variable but it has received little attention.

OBJECTIVE: To determine whether active contact location relative to the subthalamic nucleus and other neighboring structures is related to nonmotor outcomes.

METHODS: We identified a retrospective, cross-sectional sample of 46 patients who underwent subthalamic nucleus deep brain stimulation for treatment of idiopathic Parkinson's disease. T-tests or nonparametric equivalents were used to detect baseline differences between unilateral left, unilateral right, and bilateral surgical groups. Correlation and partial correlational analyses identified relationships between contact location variables and alterations in cognitive, mood, quality of life, motor, and disease variables.

RESULTS: Medial contact locations within the left subthalamic nucleus were correlated with improvements in self-reported mood ($r_{12} = -0.78$, $P = .001$; 95% confidence interval [CI] = -0.43 to -0.93) but worsening semantic fluency ($r_{26} = -0.38$, $P = .048$; 95% CI = -0.01 to -0.66). Phonemic fluency worsened with more posterior left placement ($r_{34} = 0.35$, $P = .036$; 95% CI = 0.03 to 0.61). Memory outcome was related to right hemisphere stimulation voltage ($r_{29} = -0.40$, $P = .022$; 95% CI = -0.05 to -0.66), which is likely a proxy for variable electrode location.

CONCLUSION: Location of the active contact is related to nonmotor outcomes, even in electrodes that are adequately placed. This is relevant to clinical care as there appears to be a trade-off between mood and fluency abilities that should be considered during surgical planning according to preoperative patient characteristics.

KEY WORDS: Outcome research, Neuropsychology/behavior, Parkinson's disease, Surgery/stimulation

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Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is an effective treatment for the motor symptoms of Parkinson's disease. However, the behavioral and cognitive side effects that can

accompany this procedure are poorly understood. Outcome studies commonly demonstrate small but reliable group changes on tests of fluency, verbal memory, and depression¹ with significant variability across individual patients. For example, while mild improvements in depressive symptoms are observed at the group level, other data indicate that up to 25% of patients experience marked, though often transient, worsening of depression symptoms.^{2–5} Identifying the factors that contribute to this individual variability is important for understanding and avoiding nonmotor side effects in individual patients.

As with capsular side effects, cognitive and behavioral side effects are often hypothesized to arise from current spread to areas outside the surgical target location such as the associative and limbic divisions of the STN. The few studies

ABBREVIATIONS: AC, Anterior Commissure; BDI-II, Beck Depression Inventory-2nd Edition; CI, confidence interval; DBS, deep brain stimulation; IC, Internal Capsule; LEDD, levodopa equivalent daily dosage; MCP, Mid-commissural Point; PC, Posterior Commissure; QoL, quality of life; RN, Red Nucleus; SD, standard deviation; STN, subthalamic nucleus; STROBE, Strengthening the Reporting of Observational studies in Epidemiology; UPDRS-III, Unified Parkinson's Disease Rating Scale-III

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that have examined this relationship have done so in relatively small samples of patients and there is little consistency in the measurement methods or findings.⁶⁻¹⁰ Here, we considered the positioning of the active contacts relative to the STN and neighboring structures as a potential contributor to cognitive and behavioral side effects and systematically examined both unilateral and bilateral STN patients to observe potential laterality differences. Understanding associations between active contact location and nonmotor outcomes would have significant clinical relevance and inform lead placement for efficacy *and* for cognitive and behavioral safety.

METHODS

Standard Protocol Approvals, Registrations, and Patient Consents

The study was approved by the institutional review board. Informed consent requirements were waived due to the retrospective study design. Strengthening the Reporting of Observational studies in Epidemiology (STROBE) reporting guidelines were followed for this manuscript.

Subjects

We retrospectively identified all patients in our Neuropsychology Registry who underwent unilateral or bilateral STN DBS in a 5-yr period (2009-2014) at our center who had (1) available pre- and postoperative neuropsychological and neurological evaluations, and (2) postoperative neuroimaging sufficient for contact localization. This produced a sample size of 46 patients who were eligible for the study. An additional 143 patients with Parkinson's disease who were implanted with STN DBS electrodes in this period were not included in this study. The majority of these patients were missing postoperative neuropsychological data either due to nonreferral, refusal to return for testing or data not entered into the database at the time of subject identification. These patients were 63.9 yr old (standard deviation [SD] = 8.3) which is similar to the age of our sample. The proportion of patients with unilateral/bilateral implantation was also similar in the included and excluded patients, with approximately 52% of excluded patients undergoing unilateral STN electrode implantation. Selection criteria for DBS candidacy and surgical technique have been published previously.¹¹⁻¹³

Neuropsychological, Medication, and Motor Variables

All patients underwent full neuropsychological evaluations before and after surgery (average time postsurgery was 6.9 mo, SD = 4.0, range = 3-29). Select cognitive, mood, and quality of life (QoL) variables (phonemic and semantic fluency; Rey Auditory Verbal Learning Test—single trial learning score; Wisconsin Card Sorting Test—number of perseverative errors), mood (Beck Depression Inventory-Second Edition; Beck Anxiety Inventory), and QoL (Parkinson's Disease Questionnaire-39) were chosen for analysis based on frequency of reported postoperative changes in the literature¹ and/or sensitivity to acute STN stimulation.¹⁴⁻¹⁶ Fluency tasks reflect strategic retrieval under speeded conditions. Single trial learning on the Rey Auditory Verbal Learning task reflects the automaticity of verbal memory encoding. Perseverative errors on the Wisconsin Card Sorting test is a measure of executive dysfunction reflected in a failure to adjust behavioral strategies based on negative feedback.

Levodopa equivalent daily dosage (LEDD) and medication type (none, levodopa only, or levodopa + agonist) were determined for all

patients at the time of neuropsychological testing. Unified Parkinson's Disease Rating Scale-III (UPDRS-III) scores were used to evaluate motor characteristics. See Table for clinical characteristics before and after DBS.

Location of the Cathode

Details of the methodology to assess localization of leads and individual electrode contacts have been published previously.¹⁷ Briefly, location of anatomical landmarks and lead placement were established in relation to the midcommissural point after co-registering postoperative CT scans to preoperative MRIs. Postoperative CTs were acquired more than 1 mo after brain lead implantation in order to allow for resolution of pneumocephalus and brain shift. Images were normalized to anterior commissure and posterior commissure and a reference point was designated at the Mid-commissural Point (MCP) (X = 0; Y = 0; Z = 0). Values of X, Y, and Z followed convention (positive = right, anterior, and superior, respectively). Anatomical landmark coordinates were acquired from preoperative coronal T2-weighted images. We used 5 anatomical landmarks: third ventricle dimensions—Anterior Commissure (AC)-Posterior Commissure (PC) distance for length (AC-PC) and AC to third ventricle floor for height (AC height); variance in location of the red nucleus (measured 7 mm posterior to MCP)—lateral edge of the red nucleus (Red Nucleus (RN) lat) and inferior margin of the red nucleus (RN inf); and angle of the posterior limb of the internal capsule and midline (Internal Capsule [IC] angle).

We identified contacts and stimulation parameters that were employed clinically (based on optimal motor response without sensorimotor side effects) at the time of postoperative neuropsychological evaluation. Coordinates of 69 active cathodal contacts (31 right; 38 left) were calculated based on the Cartesian coordinates of the centroid of contact zero, the known center-to-center contact distances in the 3389 model lead (Medtronic Inc, Dublin, Ireland), and sagittal and coronal angles of the electrode. The shortest distance between the active contact and the internal capsule was directly measured on T2-weighted images. The distance between the active contact and the lateral and inferior edges of the red nucleus was determined by calculating the Euclidian distance between them.

Statistical Analysis

Medication, Motor, and Cognitive/Mood/QoL

Two-tailed independent samples t-tests and Mann-Whitney U-tests (with Cohen's d for independent samples) were used to examine baseline differences between surgical groups: unilateral vs bilateral and unilateral left vs unilateral right. For the entire sample and separately within each group (bilateral, unilateral left, and unilateral right), preoperative to postoperative change in all variables of interest was assessed using paired samples t-tests and Wilcoxon signed-rank tests. For repeated measures analyses, effect sizes were calculated using Cohen's d for dependent samples. Preoperative to postoperative change scores were calculated for each medication, motor, and cognitive/mood/QoL variable; across the entire sample, correlation analyses (Pearson's or Spearman's where appropriate) were used to explore the relationships among them.

Contact Location

To evaluate lateralized relationships between the location of the active contact/stimulation parameters and cognitive/mood/QoL changes, correlation analyses were conducted separately for each unilateral DBS group. Bilateral patients were then added and correlations were recalculated for each side separately. Partial correlations were executed where relevant in order to evaluate the contribution of potentially influential

variables such as medication changes. Nonparametric Spearman's rho was employed for associations involving nonnormal distributions, while parametric Pearson's r was used for analyses where data approach normal distributions. 95% confidence intervals (CIs) were obtained for all correlations. All analyses were conducted on complete cases using SPSS v.17 (IBM Inc, Armonk, New York), with alpha set to 0.05.

RESULTS

Subject Characteristics

The sample included 46 patients: 8 patients had unilateral right electrodes, 15 had unilateral left electrodes, and 23 patients had bilateral electrodes. On average, at the time of surgery, patients were 60.9 yr of age ($SD = 8.1$) with 13.4 yr education ($SD = 2.9$). Thirty-eight patients were male and 38 patients were right-hand dominant (left = 7; ambidextrous = 1). Average disease duration was 9.0 yr ($SD = 4.0$). See Table for baseline and postoperative clinical, cognitive, and psychological characteristics. When compared to unilateral left patients, unilateral right patients exhibited poorer on-medication motor scores ($t_{20} = 2.6$, $P = .018$, $d = 1.15$), fluency performance (phonemic $t_{20} = -2.7$, $P = .015$, $d = 1.18$; semantic $t_{20} = -2.9$, $P = .009$, $d = 1.29$), and single trial learning ($t_{20} = -4.1$, $P = .001$, $d = 1.84$) at baseline. As expected, bilateral patients were on higher levodopa equivalent doses ($t_{44} = -2.7$, $P = .010$, $d = 0.79$) and had poorer motor scores off medications ($t_{42} = -2.3$, $P = .028$, $d = 0.68$) than unilateral patients; unilateral and bilateral patients were not significantly different at baseline for any cognitive or psychological variable.

Changes from Baseline to Follow-up

The Table demonstrates that, across the entire sample, there were significant improvements in motor scores both on-medication/on-stimulation ($t_{39} = 2.5$, $P = .019$, $d = 0.39$) and off-medication/on-stimulation ($t_{33} = 10.7$, $P < .001$, $d = 1.87$), as well as significant reductions in medication burden ($t_{45} = 3.6$, $P = .001$, $d = 0.55$). This suggests that, from a motor outcome standpoint, the electrodes were well placed for this sample. Self-reported QoL (Parkinson's disease Questionnaire-39 [PDQ-39]) improved after surgery ($t_{44} = 5.8$, $P < .001$, $d = 0.9$). There was significant worsening of both semantic ($t_{44} = 5.6$, $P < .001$, $d = 0.84$) and phonemic ($t_{44} = 5.1$, $P < .001$, $d = 0.75$) fluency scores, and improvements in anxiety ($t_{45} = 3.7$, $P < .001$, $d = 0.56$) which were due to changes in the left unilateral and bilateral groups. Unilateral and bilateral patients did not differ with respect to postsurgical change on any motor, QoL, or cognitive variable.

Reductions in dopamine equivalent daily dosage were associated with improved QoL ($r_{43} = 0.40$, $P = .006$; 95% CI = 0.12 to 0.62), improved depression ($r_{44} = 0.37$, $P = .012$; 95% CI = 0.09 to 0.6), and improved verbal attention span ($r_{41} = 0.55$, $P < .001$; 95% CI = 0.3 to 0.73). Motor outcome was not related to any cognitive/mood/QoL outcome (r values ranged between 0.27 and -0.24 , all $P > .1$).

Contact Location

Significant relationships with contact location were identified for 3 measures that demonstrated changes after surgery: depression, semantic fluency, and phonemic fluency (see **Table, Supplemental Digital Content 1** for exact values). There were no significant associations between contact location and any other mood or cognitive measures.

Depression

Postoperatively, depression improved in patients with unilateral left electrodes with more medial contact locations (closer to the lateral edge of the red nucleus; see Figure 1; $r_{12} = -0.78$, $P = .001$; 95% CI = -0.43 to -0.93); this relationship remained even after controlling for LEDD reduction ($r_{10} = -0.71$, $P = .006$; 95% CI = -0.23 to -0.91). The association between more medial left-sided contacts and depression improvement remained when bilateral patients were included and LEDD reduction was controlled for ($r_{33} = -0.36$, $P = .032$; 95% CI = -0.03 to -0.62). Among unilateral right patients, more anterior contacts (y-coordinates) were associated with postoperative improvements in depression ($\rho_{05} = 0.75$, $P = .05$; 95% CI = -0.01 to 0.97; see **Figure, Supplemental Digital Content 2**). However, due to the small sample size and the restricted range of depression change scores, the reliability and utility of the latter relationship are somewhat suspect.

Semantic Fluency

Semantic fluency worsened with more medial contact placement on the left (increasing distance between the active contact and the internal capsule; see Figure 2) in all patients with left electrodes, including those with bilateral leads ($r_{26} = -0.38$, $P = .048$; 95% CI = -0.01 to -0.66). All other location comparisons were nonsignificant.

Phonemic Fluency

Among all patients with left-sided electrodes (including those bilaterally implanted), phonemic fluency worsened with more posterior left-sided contacts (y-coordinate; see Figure 3; $r_{34} = 0.35$, $P = .036$; 95% CI = 0.03 to 0.61). All other location comparisons were nonsignificant.

Stimulation Amplitude

For all patients with right-sided electrodes, increasing stimulation voltage was associated with worsened single trial learning (see Figure 4; $r_{29} = -0.40$, $P = .022$; 95% CI = -0.05 to -0.66). Analysis of stimulation parameters was limited to voltage settings due to minimal variability in pulse width or stimulation frequency settings in the sample.

DISCUSSION

Depression

We observed a robust relationship between improved mood and more medial contact locations in patients with left-sided electrodes. The relationship between depression and left-sided contacts was significant but less robust when patients with bilateral electrodes were included. This may simply reflect the fact

that patients with bilateral electrodes did not demonstrate a high degree of variability in depression change after surgery (see Table). Alternatively, there may be a moderating effect of a contralateral electrode.

Our finding is at least partially consistent with earlier work reporting that left-side electrode tips that were more laterally placed in the subthalamic area were associated with worsened mood after bilateral STN DBS.⁶ However, our finding is

novel and intriguing as medial placement was associated with depression improvement rather than “less worsening,” suggesting that current spread to the “limbic” division of the left STN can positively affect mood. This could be akin to the observations of mania/euphoria induction with left-sided stimulation at more ventral contact sites.¹⁸⁻²⁰ It is important to note, as illustrated in Figure 1, that the more medially placed contacts were still largely within dorsal and posterior regions of the nucleus, indicating that the location-related depression-alleviating effect is present

even when DBS contacts are well placed within the sensorimotor division.

Improvements in depression were not simply a product of improved motor function (which was unrelated to depression change in this sample) or higher dopaminergic doses. In fact, it was interesting to note that depression *improved* with reductions in LEDD. While this appears to run counter to the “dopamine withdrawal” phenomenon that is often a concern after STN DBS, it is also possible that some form of “withdrawal” may have

TABLE. Baseline and Postoperative Characteristics

	Baseline				Postoperative			
	N	Mean	SD	Range	N	Mean	SD	Range
LEDD*	46	1014	569	0–3130	46	688	375	0–1750
Medication								
None	3				3			
Ldopa only	17				24			
Ldopa + agonist	26				19			
UPDRSIII								
						(On stimulation)		
On meds*	42	20.4	8.2	4–35	43	16.0	10.0	2–39
Off meds**	44	38.2	9.7	18–62	37	20.4	7.7	4–39
Stimulation								
R Frequency					31	139.8	25.9	80–185
R Voltage					31	3.2	0.6	2.1–4.8
R Pulse width					31	67.7	13.3	60–90
L Frequency					38	140.2	28.3	80–185
L Voltage					38	3.4	0.7	1.8–4.5
L Pulse width					38	70.4	17.2	60–120
PDQ-39**	45	25.8	13.5	0–53	46	16.3	10.7	1–42
DRS-II	44	132.8	8.9	104–143	40	133.9	8.8	98–144
Digit span	44	9.7	2.9	4–19	45	9.7	2.5	4–17
Phonemic FI**	45	34.8	10.9	3–55	45	29.3	10.7	9–60
Semantic FI**	45	40.8	10.4	13–67	46	35.4	11.0	14–60
WCSTper	46	24.9	15.1	4–56	45	24.2	17.7	4–83
RAVLT1	45	4.7	1.8	1–9	46	4.8	2.0	0–10
BAI*	46	10.8	7.3	0–34	46	7.1	5.8	0–28
BDI-II	46	10.2	6.6	1–30	46	8.9	6.7	0–27

LEDD, levodopa equivalent daily dosage (mg).

Higher scores indicated better performance for: Mattis Dementia Rating Scale-2nd Edition raw score (DRS-II),¹⁴ and measures of Digit Span, Phonemic and Semantic fluency raw scores, single trial learning raw score (RAVLT1).¹⁹ Lower scores indicated better performance for number of perseverative errors on the Wisconsin Card Sorting Test²¹ (WCSTper). Lower scores on the Parkinson's disease Questionnaire-39 (PDQ-39), Beck Anxiety Inventory (BAI), and Beck Depression Inventory-2nd Edition (BDI-II) reflect better quality of life, less anxiety, and less depression.

Postoperative score differs from preoperative baseline, paired samples t-test * $P < .01$, ** $P < .001$.

occurred in the early postoperative period and resolved by the 6-mo follow-up assessment.

The strong left-sided association with depression change is consistent with prior work indicating that left STN DBS improves mood more than right²¹ as well as with clinical research indicating that the left hemisphere and subcortical structures play a special role in negative emotion.^{22–23} The weaker finding of improved depression with more anterior placement of unilateral right-sided electrodes is interesting but requires confirmation in a larger sample with a broader range of change scores on the Beck Depression Inventory-2nd Edition (BDI-II). Such confirmation may not be achievable given the paucity of patients with right-sided unilateral DBS due to the prevalence of left hemispheric dominance in the population and the tendency to treat the dominant side in unilateral procedures.

Fluency

Similarly, it is not surprising that changes in fluency performance were also related to contact location in the left hemisphere. Fluency declines in DBS are generally thought to be related to

worsening of linguistic processing¹ rather than articulatory/motor processes, given that these declines occur in patients with improved motor function. Our finding that left-sided contact locations are related to fluency changes is in line with an influence on a linguistic process in the dominant hemisphere of most patients.

An early meta-analysis showed that the largest change in cognition after STN DBS occurs in semantic fluency.¹ In our sample of patients with a left-sided electrode, semantic fluency worsened with contacts farther from the internal capsule (more medial). At first pass, this appears to contrast with Witt and colleagues⁸ demonstration that many of the patients who showed worse semantic fluency had active left-sided contacts more ventral to patients with stable fluency scores. However, their measurements were not anchored to anatomical locations and therefore the location of the “ventral” electrodes relative to STN cannot be determined. York et al⁶ was the only study to point to a role for the right hemisphere. They found that more superior positioning (shorter track length) on the right was related to worsening semantic fluency. These few findings reveal that there

is no consensus on the relevant aspects of electrode placement for semantic fluency. However, our data seem to be consistent with the notion that proximity to the associative division of the STN leads to cognitive worsening on the semantic fluency task.

Our finding of worsened phonemic fluency with contacts placed more posteriorly (negative y-coordinates) is partially consistent with the work of Ehlen and colleagues.⁹ They found that higher amplitude stimulation and more posterior contacts in bilateral patients led to greater reductions in phonemic fluency. However, York and colleagues⁶ found that postsurgical changes in phonemic fluency were associated with more lateral/superior electrode placement in the left hemisphere. Their patients had bilateral placements and there was an additional relationship between phonemic fluency change and more superior/posterior electrodes in the right hemisphere. Smith et al,¹⁰ on the other hand, did not find any association of electrode/contact location and phonemic fluency.

Memory

Finally, we found a relationship between stimulation voltage on the right and single trial learning. To our knowledge, contact location/stimulation effects on single trial learning on the Rey Auditory Verbal Learning Test have not been previously reported. York and colleagues⁶ did investigate relationships with 5 trial learning, short-term, and long-term recall and reported a variety of correlations with left-sided location variables. However, single trial learning is perhaps more dependent on right hemisphere circuits mediating attention control than these other memory measures, which could account for the right-sided effects. Moreover, the association with voltage rather than location could imply that this effect may arise from stimulation effects on more distributed circuits. Visual inspection of the contact locations in the right hemisphere revealed that many of the patients who performed poorly on single trial learning had clinically effective active contacts in the subthalamic area that were adjacent to the boundaries of the STN. This suggests that the clinically beneficial increased voltage used in these patients likely activates a larger volume of tissue and may have also affected fibers of passage.

Interpretation

Our data indicate that there may be a trade-off to consider when placing left-sided electrodes. Specifically, electrodes that are placed in a more medial or anterior position *within the sensorimotor division of the STN* may be beneficial for mood or phonemic fluency but this may occur at the expense of semantic fluency performance. One could argue that this trade-off is a reasonable one to accept, given that depression has enormous influence on postoperative QoL while reduced semantic fluency is far less salient in patients' everyday activities. Alternatively, this may suggest strategies for taking advantage of steerable current or directional electrodes. The opportunity to direct stimulation in the more medial or lateral direction will allow for

more refined and selective postoperative programming that may permit more advantageous and less restrictive trade-offs between motor and nonmotor outcomes as well as between different cognitive functions. We note that these technologies are still in the beginning of their clinical use and the magnitude of their benefit toward better clinical outcomes remains to be seen.

In addition, our results indicate that patients who require greater stimulation voltage on the right may be at greater risk for less efficient memory function. This may be an important consideration during intraoperative stimulation as well as during clinical programming sessions following implantation of DBS devices to minimize cognitive morbidity. Unlike fluency changes after DBS, patients and families are often very aware of changes in memory function and this contributes to the patient's functional status in the real world.

Limitations

An important limitation of our study is that our analyses are correlational and causality cannot be completely determined. Cognitive and mood outcome is undoubtedly multifaceted, and any relationships between location and outcome should be regarded as one of many influences, rather than a full explanation of outcome. Additionally, our location measurements were derived using anatomical landmarks that are fairly well visualized and useful for surgical planning. However, coregistration techniques onto a common framework are still rudimentary and individual anatomical variation is not well accounted for. Our sample comprised approximately one-quarter of all STN DBS implantations completed at our institution over the study time frame. While age and surgical laterality were similar between included and excluded patients, it remains possible that there were systematic differences between the groups in terms of surgical outcomes. As such, we would stress that the current findings can be generalized only to STN DBS patients similar to those included in the study—with accurate STN DBS placement resulting in good motor outcomes, reduced medication burden, and improved QoL.

Generalizability

In considering the procedural implications of this work, it is important to discuss the scope of our data. As noted above, our sample consisted of patients with excellent surgical outcomes in terms of motor function. In other words, most electrodes were optimally placed in the subthalamic area and there were relatively few patients with striking cognitive/mood changes. Therefore, our findings may be less useful for understanding outcome in patients with misplaced electrodes.

CONCLUSION

We investigated the relationship between subthalamic cathode location and cognitive and behavioral changes in 46 patients

following unilateral or bilateral DBS. Our data suggest that contact location and stimulation parameters are relevant to the 3 most commonly nonmotor changes reported after STN DBS surgery: mood, fluency, and memory. The findings are very relevant for informing improvement opportunities in DBS targeting practices. One such opportunity is to develop tailored targeting techniques that will take into account patient-specific preoperative functional profiles. For example, patients affected by more severe preoperative depression may benefit from more medially targeted leads, despite expected changes in semantic fluency. On the contrary, such trade-offs may not be necessary in patients who present with severe motor symptoms but are less affected by behavioral problems.

Disclosures

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COMMENT

The authors studied 46 patients who had electrodes placed in the subthalamic nucleus for the treatment of Parkinson's disease. Their goal was to analyze the relationship between active contact location and nonmotor outcomes. They tested patients for mood, speech, and memory. The key results can be summarized as follows:

- Depression was improved with a more medial placement of the left electrode, more so in patients with a unilateral left electrode.
- Semantic fluency, however, was worse with a more medial left electrode.
- Phonemic fluency was worse with a more posterior left electrode.

As the authors indicate, their results point to a possible treatment approach for patients with depression (not a unique observation, as the STN has in fact been proposed as a target for that condition), specifically the medial portion of the nucleus. They point out that STN DBS often involves a “tradeoff” between the desirable motor effects and the side effects of worsened speech.

This study serves as a reminder of the potential side effects of STN DBS. Neurosurgeons placing DBS implants for movement disorders in

general, and Parkinson’s disease in particular, should take heed of these results and prepare patients for possible changes in mood and speech. They should consider how these slight changes in electrode location can affect their patients and plan accordingly.

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