

Remote vs In-Person Follow-up Programming After Subthalamic DBS for Parkinson Disease: A Multicentre Randomized Noninferiority Trial

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Abstract

Background and Objectives:

Remote programming of deep brain stimulation may improve access to specialized postoperative care for people with Parkinson disease, but prospective randomized evidence remains limited. We aimed to determine whether remote follow-up programming after standardized inpatient initiation is noninferior to conventional in-person follow-up programming for motor outcomes during the early postoperative period.

Methods

In this prospective, randomized, open-label, multicenter noninferiority trial, adults with idiopathic Parkinson disease who recently underwent bilateral subthalamic nucleus deep brain stimulation implantation at 6 German centers were randomized 1:1 to conventional in-person follow-up programming or remote follow-up programming through a secure telemedicine platform during the first 90 days after surgery. All participants underwent initial in-person postoperative programming before randomization. The primary outcome was the Movement Disorder Society–Unified Parkinson's Disease Rating Scale Part III score at 90 days in the medication-on and stimulation-on state. The prespecified noninferiority margin was 5 points.

Results

Fifty-two participants were randomized. The per-protocol population included 26 participants in the conventional care group and 22 in the remote programming group. The between-group median difference of the primary endpoint was – 2.5 points (95% confidence interval – 9.0 to 2.0), meeting the prespecified noninferiority criterion. Secondary clinical outcomes and patient-reported outcomes were broadly comparable between groups. Serious adverse events occurred at similar frequencies in both groups, and no deaths occurred.

Conclusions

Remote follow-up programming after standardized inpatient initiation was feasible, safe, and clinically effective, achieving motor outcomes noninferior to conventional in-person follow-up care during the first 3 months after surgery.

Trial Registration:

The trial was prospectively registered at ClinicalTrials.gov (NCT05193825; registered December 21, 2021)

Introduction

Deep brain stimulation (DBS) is an established therapy for patients with advanced Parkinson disease (PD) with motor fluctuations, but clinical outcomes depend on iterative postoperative programming to optimize stimulation parameters. This care is usually delivered in person at specialized centres, requiring frequent travel that may limit access for patients living at a distance or with mobility constraints.^{1–3} As digital health technologies increasingly enable remote delivery of specialized medical care, telemedicine-based approaches may offer new opportunities to decentralize DBS follow-up and improve access to expert management.

Telemedicine is increasingly used in movement disorders care, and remote DBS programming has emerged as a potential strategy to reduce travel burden while maintaining clinical effectiveness.^{4–8} Several retrospective or nonrandomized studies—predominantly from China—have reported high patient satisfaction, reduced costs, and motor outcomes comparable to standard in-person programming.^{9–15} However, these studies were limited by lack of randomization, heterogeneous outcome assessment, and incomplete safety reporting, restricting causal inference.

More recently, the first remote DBS programming platform was approved for clinical use outside China, enabling secure telemedical adjustment of stimulation parameters. A randomized trial suggested accelerated symptom improvement with internet-based DBS optimization, but the intervention combined in-person and remote care, and only a subset of participants relied exclusively on remote

programming.¹⁶ Consequently, prospective randomized evidence directly comparing remote DBS follow-up programming after standardized inpatient initiation with standard in-person care remains lacking.

We therefore conducted a prospective, randomized, multicentre noninferiority trial to evaluate whether remote DBS programming is noninferior to standard in-person programming for motor outcomes at 3 months after subthalamic nucleus DBS implantation in patients with PD, with additional assessment of safety and patient-reported outcomes.

Methods

Study Design and Oversight REMOTE was a prospective, multicenter, randomized, open-label, parallel-group noninferiority trial conducted at six centers in Germany. The trial compared the efficacy and safety of remote vs standard-of-care (SoC) programming of subthalamic nucleus deep brain stimulation (STN-DBS) in patients with PD. The coordinating ethics committee at LMU University Hospital approved the study (#21–0844), with local approval obtained at each participating center. The trial was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines. All participants provided written informed consent. The study was registered Dec. 21st, 2021, at ClinicalTrials.gov (NCT05193825). The full protocol is provided as **Appendix** in the **Supplemental Material**.

Participants Eligible participants were adults aged 35 years or older with idiopathic PD diagnosed according to Movement Disorder Society (MDS) criteria who had recently undergone bilateral STN-DBS implantation and were eligible for and willing to undergo remote DBS programming. Key exclusion criteria included dementia or unstable psychiatric conditions. Complete inclusion and exclusion criteria are provided in the **Appendix** of the **Supplemental Material**. Sex and gender were self-reported by participants.

Randomization and Masking Participants were randomly assigned in a 1:1 ratio to remote or SoC programming using a centralized web-based system with block randomization with allocation concealment stratified by study center. Owing to the nature of the intervention, participants and treating physicians were not blinded. Outcome assessments were performed by raters blinded to group allocation when feasible.

Procedures Baseline assessments were performed before surgery. All participants underwent bilateral STN-DBS implantation using standard stereotactic techniques. All participants underwent initial in-person programming at the hospital after electrode implantation before randomization. After randomization, participants assigned to the SoC group received conventional in-person DBS programming during the first 90 days after implantation. Participants assigned to the remote group received DBS programming exclusively via a secure telemedicine platform (Abbott NeuroSphere™ Virtual Clinic), which enabled video-based consultations and remote adjustment of stimulation parameters. Follow-up assessments were conducted 90 days after implantation in the medication-on/stimulation-on condition. Detailed study procedures are provided as **Supplementary Methods** in the **Supplementary Material**.

Outcomes The primary outcome was the Movement Disorder Society–Unified Parkinson's Disease Rating Scale (MDS-UPDRS) Part III score at 90 days in the medication-on/stimulation-on condition. Secondary outcomes included MDS-UPDRS Parts I, II, and IV; Parkinson's Disease Questionnaire-39 Summary Index (PDQ-39-SI); Beck Depression Inventory–II (BDI-II); Montreal Cognitive Assessment (MoCA); Hoehn and Yahr Scale (H&Y) Scale; Ardouin Scale; Scale for Suicidal Behavior (SSEV); number of programming sessions, and Levodopa Equivalent Daily Dose (LEDD). Exploratory outcomes included stimulation parameters and volumes of tissue activated (VTA). Overall treatment satisfaction was assessed using a 0–10 visual analogue scale (VAS), with 0 indicating very low and 10 indicating very high satisfaction. Safety outcomes included adverse events, serious adverse events, and device-related complications. Outcome definitions and assessment details are provided as **Supplementary Methods** in the **Supplementary Material**.

Statistical Analysis The trial was designed to test noninferiority of remote DBS programming compared with SoC. A non-inferiority margin of 5 points on the MDS-UPDRS Part III was prespecified, reflecting the lower bound of a clinically meaningful difference in motor function.¹⁷ The nonparametric analysis framework and bootstrap confidence interval approach were prespecified in the statistical analysis plan. Based on prior DBS studies (SD ≈ 6 points)¹⁸ and assuming a 10% dropout rate, 23 evaluable participants per group were required to achieve 80% power at a two-sided α of .05; accordingly, 52 patients were enrolled. The primary analysis followed a per-protocol (PP) estimand consistent with the ICH E9(R1) framework, estimating the treatment effect among participants adhering to the assigned programming strategy without major protocol deviations. A supportive intention-to-treat (ITT) analysis evaluated a treatment policy estimand. The primary outcome was analyzed using the Mann–Whitney U test, with between-group differences in median change from baseline and corresponding 95% confidence intervals (CIs) estimated using bootstrap resampling. Secondary outcomes were analyzed using nonparametric methods without adjustment for multiple comparisons. Safety outcomes were summarized descriptively. Additional exploratory and imaging analyses are reported in the **Supplementary Methods** of the **Supplementary Material**.

Role of the Funder The study was supported by Abbott Medical Inc., which had no role in the study design, data collection, data analysis, data interpretation, or manuscript preparation.

Trial Monitoring An independent clinical research organization (Invisio Clinical Studies Consulting GmbH) conducted on-site monitoring to ensure protocol adherence, data accuracy, and participant safety, in accordance with Good Clinical Practice (GCP) standards.

Results

Study Population Between March 2022 and December 2024, 54 patients with PD were screened across multiple centers in Germany (Munich, n = 28; Duesseldorf, n = 5; Hamburg, n = 4; Erlangen, n = 5; Leipzig, n = 4; Muenster, n = 6); 52 met eligibility criteria and were randomized to SoC programming (n = 26) or remote DBS programming (n = 26) (Fig. 1). Two patients were excluded during screening because of protocol-defined criteria. Baseline demographic and clinical characteristics were broadly comparable between groups (Table 1). Participants in the remote group were younger than those in the SoC group (median age, 60 years [IQR, 52–66] vs 66 years [IQR, 62.75–70.25]; P = .014) and had a numerically shorter disease duration (10.0 years [IQR, 6.75–13.5] vs 12.5 years [IQR, 9.25–14.0]; P = .17). Sex distribution was similar (SoC, 21 [80.7%] male; remote, 22 [84.6%] male), as was language background, with most participants reporting German as their first language. Motor symptom phenotype at disease onset, including tremor, rigidity, and bradykinesia, was comparable between groups, although rest tremor was slightly more prevalent in the SoC group. General anesthesia was used more frequently in the SoC group (11 [42.3%]) than in the remote group (9 [34.6%]). During follow-up, 4 participants in the remote group were excluded from the PP analysis. One participant underwent revision surgery because of insufficient tremor control due to unilateral electrode misplacement. Two participants with persistent gait impairment and suboptimal response to remote programming required crossover to in-person programming. One participant developed an implantable pulse generator infection requiring surgical intervention and replacement. The PP population therefore included 26 participants in the SoC group and 22 in the remote group.

Table 1. Baseline Characteristics of the Intention-to-Treat Population

	SoC (n = 26)	Remote (n = 26)
Age	66 (62.75-70.25)	60 (52-66)
Sex		
Male	21 (80.7%)	22 (84.6%)
Female	5 (19.3%)	4 (15.3%)
German as the first language	24 (92%)	26 (100%)
Disease Duration	12.5 (9.25-14)	10 (6.75-13.5)
First Motor Symptom		
Tremor	14 (53.8%)	8 (30.7%)
Rigor	2 (7.6%)	4 (15.3%)
Bradykinesia	11 (42.3%)	12 (46.1%)
Other	2 (7.6%)	2 (7.6%)
Surgery		
General Anaesthesia	11 (42.3%)	9 (34.6%)

Baseline demographic and clinical characteristics of all randomized participants. Data are presented as median (interquartile range) or number (percentage), unless otherwise indicated. Disease duration reflects time since clinical diagnosis of Parkinson disease. Categories for first motor symptom are not mutually exclusive. General anesthesia refers to the anesthetic strategy used during DBS surgery.

Primary Outcome The primary outcome was the MDS-UPDRS Part III score at 3 months after DBS implantation in the stimulation-on/medication-on condition (Fig. 2A; Table 2). Both groups demonstrated significant motor improvement. In the SoC group, median MDS-UPDRS Part III scores improved from 38.0 (IQR, 26.0–52.0) at baseline to 13.0 (IQR, 8.0–20.0) at 3 months, corresponding to a median change of – 23.0 points (IQR, 15 to 34.3). In the remote group, scores improved from 30.5 (IQR, 23.75–41.25) to 10.5 (IQR, 7.5–17.0), corresponding to a median change of – 20.5 points (IQR, 10.0 to 30.0). The between-group difference in MDS-UPDRS Part III at 3 months

was not statistically significant ($P = .36$). The unpaired median difference between groups for the primary endpoint was -2.5 points (95% CI, -9.0 to 2.0), meeting the prespecified noninferiority margin of 5 points (Fig. 2B). In a supportive ITT analysis including all randomized participants, missing 3-month outcomes were conservatively imputed using the worst observed 3-month MDS-UPDRS Part III score in the remote group (28 pts) and the best score in the SoC group (0 pts). Under this approach, median MDS-UPDRS Part III scores at 3 months were 13 in the SoC group and 12 in the remote group, corresponding to a median between-group difference of -1 point (95% CI, -4.5 to 4.0). The estimated treatment effect remained within the prespecified noninferiority margin and was consistent with the PP analysis. In multivariable analyses of the ITT cohort, baseline MDS-UPDRS Part III score (medication-off) and age were examined as predictors of 3-month MDS-UPDRS Part III score (medication-on/stimulation-on). Neither baseline motor severity nor age was significantly associated with motor outcome (model $R^2 \approx 0.10$; $P \approx .45$). There were no significant main effect of treatment group and no interaction between treatment group and baseline MDS-UPDRS Part III score or age. Analyses performed separately within each treatment group yielded similar results. In sensitivity analyses using an ANCOVA framework with adjustment for age and baseline MDS-UPDRS Part III score, treatment group assignment was not significantly associated with 3-month motor outcome ($\beta \approx -1.5$ points for remote vs SoC; $P = .58$). Adjustment for baseline covariates did not materially alter treatment effect estimates. Comparable findings were observed in adjusted analyses of the PP population.

Table 2
Primary and Secondary Outcomes at Baseline and 3 Months

	SoC		Remote						
	Baseline	3 months	Change from baseline at 3 months	Baseline	3 months	Change from baseline at 3 months	P Value (Endpoint)*	P Value (Change SoC vs REMOTE)**	P Value REMOTE vs SoC (Baseline)***
Primary outcome:									
MDS-UPDRS Part III [#] (PP)	38 (26–52) n = 25	13 (8–20) n = 25	23 (15–34.25) n = 24	30.5 (23.75–41.25) n = 22	10.5 (7.5–17) n = 22	20.5 (10–30) n = 22	0.3592	0.3618	0.1527
MDS-UPDRS Part III [#] (ITT)	38 (26–52) n = 25	13 (7–20) n = 26	23 (15–35) n = 25	30.5 (23–39.5) n = 26	12 (8–19.75) n = 26	19.5 (9.25–26.75) n = 26	0.9529	0.1288	0.0983
Secondary Outcomes:									
Hoehn and Yahr scale	2.5 (2–3) n = 25	2 (1.25–2.75) n = 24	1 (0–1) n = 24	2 (2–2) n = 22	2 (2–2) n = 22	0 (0–1) n = 22	0.7939	0.1579	0.0256
MDS-UPDRS Sum Value	72 (61–91.5) n = 25	33 (24.75–54.75) n = 25	38 (22–50.5) n = 24	62.5 (55–74.25) n = 22	38.5 (26.5–48.25) n = 22	28 (13.75–44.25) n = 22	0.955	0.3270	0.1591
MDS-UPDRS Subscales									
MDS-UPDRS Part I	10 (6–15.5) n = 25	8 (4.5–13.25) n = 26	1.5 (–2.5–4.75) n = 24	10 (5.75–14) n = 22	8 (6.5–15.25) n = 22	1 (–3–4.5) n = 22	0.455	0.657	0.886
MDS-UPDRS Part II	16 (11–22) n = 25	9 (5–15) n = 26	5 (1.25–9) n = 24	16 (9.75–18) n = 22	9.5 (3.75–16.5) n = 22	4 (2–8.5) n = 22	0.9386	0.634	0.549
Primary and secondary clinical outcomes at baseline and at 3-month follow-up. Data are presented as median (interquartile range), unless otherwise indicated. The primary outcome was analyzed in both the per-protocol and intention-to-treat populations; secondary outcomes were analyzed in the per-protocol population.									
[#] MDS-UPDRS Part III scores were assessed in the medication-off condition at baseline and in the medication-on/stimulation-on condition at 3 months.									
*P values in the “Endpoint” column reflect between-group comparisons at 3 months using the Mann–Whitney U test.									
**P values in the “Change SoC vs Remote” column reflect between-group comparisons of change from baseline to 3 months.									
***P values in the “Remote vs SoC (Baseline)” column reflect between-group comparisons at baseline.									
Abbreviations: MDS-UPDRS, Movement Disorder Society–Unified Parkinson’s Disease Rating Scale; PDQ-39, Parkinson’s Disease Questionnaire–39; MoCA, Montreal Cognitive Assessment; LEDD, levodopa equivalent daily dose; BDI-II, Beck Depression Inventory–II; SSEV, Scale for Suicidal Experience and Behavior.									

	SoC			Remote					
	Baseline	3 months	Change from baseline at 3 months	Baseline	3 months	Change from baseline at 3 months	P Value (Endpoint)*	P Value (Change SoC vs REMOTE)**	P Value REMOTE vs SoC (Baseline)***
Primary outcome:									
MDS-UPDRS Part IV	9 (5–11) n = 25	2.5 (0–7) n = 26	5 (1–6.75) n = 24	8 (4–11) n = 22	2.5 (0–6) n = 22	4 (0–8.5) n = 22	0.379	0.565	0.961
PDQ-39-SI	22.8 (15.6–35.5) n = 24	12.5 (7.9–24.1) n = 24	7.9 (0–12.8) n = 24	24.6 (17.4–40.1) n = 22	18.33 (9.7–30.7) n = 21	6.3 (1–15.1) n = 21	0.41	0.764	0.735
MoCA	27 (26–28) n = 19	26 (24–27) n = 21	-1 (-2–1) n = 19	27 (25–29) n = 19	28 (26–29.5) n = 21	2 (-1–3) n = 19	0.0218	0.0332	0.7188
LEED	955 (731–1232) n = 26	431 (205–710) n = 26	525 (230–705) n = 26	810 (578–1008) n = 22	525 (287–647) n = 22	244 (61–576) n = 22	0.700	0.015	0.277
BDI	8 (4–10.5) n = 24	5 (2–9.75) n = 26	1 (-3.5–4) n = 22	9 (6–11) n = 22	6 (4–9) n = 22	2 (-1–4) n = 22	0.691	0.318	0.337
SSEV	0 (0–0) n = 25	0 (0–0) n = 26	0 (0–0) n = 25	0 (0–0) n = 22	0 (0–0) n = 22	0 (0–0) n = 22	0.8592	> 0.9999	0.2819
Ardouin Scale	3 (2–6) n = 23	3 (2–5) n = 23	0 (-0.5–2) n = 17	5 (2–6.5) n = 21	3 (1–5.25) n = 22	1 (-1–3) n = 21	0.859	0.719	0.593
VAS-Score (1–10)		7.75 (6.25–8.75) n = 20			8.5 (7.375–9.625) n = 18		0.0989		
No. of Patient-Physician Encounters		3.5 (2–6.5) n = 26			3 (1–6) n = 22		0.4025		

Primary and secondary clinical outcomes at baseline and at 3-month follow-up. Data are presented as median (interquartile range), unless otherwise indicated. The primary outcome was analyzed in both the per-protocol and intention-to-treat populations; secondary outcomes were analyzed in the per-protocol population.

MDS-UPDRS Part III scores were assessed in the medication-off condition at baseline and in the medication-on/stimulation-on condition at 3 months.

*P values in the “Endpoint” column reflect between-group comparisons at 3 months using the Mann–Whitney U test.

**P values in the “Change SoC vs Remote” column reflect between-group comparisons of change from baseline to 3 months.

***P values in the “Remote vs SoC (Baseline)” column reflect between-group comparisons at baseline.

Abbreviations: MDS-UPDRS, Movement Disorder Society–Unified Parkinson’s Disease Rating Scale; PDQ-39, Parkinson’s Disease Questionnaire–39; MoCA, Montreal Cognitive Assessment; LEED, levodopa equivalent daily dose; BDI-II, Beck Depression Inventory–II; SSEV, Scale for Suicidal Experience and Behavior.

Secondary Outcomes Both groups demonstrated improvements across multiple secondary motor and nonmotor outcomes (Fig. 2C–O; Table 2). Total MDS-UPDRS scores decreased by a median of – 38.0 points (IQR, 22.0 to 50.5) in the SoC group and – 28.0 points (IQR, 13.75 to 44.25) in the remote group ($P = .33$). MDS-UPDRS Parts II and IV improved comparably in both groups, while Part I scores remained relatively unchanged (Fig. 2D–F; Table 2). Cognitive performance measured by a MoCa decreased slightly in the SoC group (median change, – 1 [IQR, – 2 to 1]) and improved slightly in the remote group (2 [IQR, – 1 to 3]), resulting in a significant between-group difference in change ($P = .03$; Hodges–Lehmann estimate, 2 pts; rank-biserial $r = 0.39$) (Fig. 2G; Table 2). LEDD decreased in both groups, with a larger reduction in the SoC group (median, – 525 mg [IQR, 230–705]) compared with the remote group (– 244 mg [IQR, 61–576]; $P = .015$) (Fig. 2H; Table 2). Quality of life assessed by the PDQ-39 Summary Index improved numerically in both groups, without a significant between-group difference. Patient-reported treatment satisfaction scores were high and similar between groups (Fig. 2I,K; Table 2). Disease stage measured by the Hoehn and Yahr scale improved modestly in the SoC group but not in the remote group, without a significant between-group difference (Fig. 2L; Table 2). Other clinical measures, including BDI-II, Ardouin Scale, SSEV (Fig. 2M–N; Table 2) and the number of programming sessions (Fig. 2O; Table 2), did not differ significantly between groups.

Safety Clinically important and serious adverse events occurred at similar frequencies in both groups (Table 3). Serious adverse events were reported in 3 participants (11.5%) in the SoC group and 4 participants (15.3%) in the remote group. There were no deaths. One case of intracerebral hemorrhage or lead-related edema occurred in the remote group and two in the SoC group; one of these patients developed focal epileptic seizures secondary to cortical hemorrhage. Falls were reported in one participant in the SoC group and two in the remote group. Two cases of surgical site infection or impaired wound healing, including at the implantable pulse generator site, occurred in the remote group. Other adverse events included gait disturbance (2 in each group), speech or voice impairment (1 in SoC), electrode misplacement (1 in remote), postoperative delirium (1 in SoC), and one suicide attempt (SoC). No clear safety signal favoring either strategy was observed.

Table 3
Adverse Events and Serious Adverse Events

Clinically important adverse events	SoC (n = 26)	Remote (n = 26)
Intracerebral hemorrhage	1 (3.8)	0
Lead edema	1 (3.8)	1 (3.8)
Falls	1 (3.8)	2 (7.6)
Surgical site infection or impaired wound healing	0	2 (7.6)
Gait disturbance	2 (7.6)	2 (7.6)
Speech or voice impairment	1 (3.8)	0
Electrode misplacement	0	1 (3.8)
Postoperative delirium	1 (3.8)	0
Suicide attempt	1 (3.8)	0
Death	0	0
Any serious adverse event	3 (11.5)	4 (15.3)
Adverse events and serious adverse events among all randomized participants included in the intention-to-treat population (n = 52). Data are presented as number (percentage). Serious adverse events were defined as events that were life-threatening, required hospitalization or surgical intervention, or resulted in persistent disability. Two serious adverse events in the remote programming group were considered related to the study intervention. No deaths occurred during the study period. Adverse events were assessed and adjudicated by local site investigators.		

Subgroup and Imaging Analyses Post hoc subgroup analyses evaluating age, baseline cognitive performance, motor severity, and dopaminergic medication dose showed no consistent evidence of effect modification (**Supp.** Figure 1). Among participants younger than 60 years, remote programming was associated with a numerically greater improvement in motor symptoms compared with SoC (median change – 10.0 [95% CI – 17.0 to – 5.0]; $P = .12$). In contrast, among those aged 60 years or older, the treatment effect favored SoC, though the difference was small and non-significant (median difference + 2.5 [– 4.0 to 10.0]; $P = .63$). Patients with MoCA scores lower than 25 showed no significant group difference (median difference + 6.0 [– 7.0 to 12.0]; $P = .27$), whereas those with preserved cognition (MoCA $\geq$

25) derived significantly greater benefit from remote programming (median difference – 4.5 [–14.5 to – 1.5]; $P = .042$). Baseline motor severity (MDS-UPDRS III < 35 vs ≥ 35) and LEDD (< 1000 mg vs ≥ 1000 mg) did not modify treatment effects (all $P > .05$). Electrode localization and volumes of tissue activated (VTAs) were comparable between groups across hemispheres and time points. Multivariate analyses revealed no significant differences in stimulation location between groups (all $P > .37$), with no systematic spatial deviation observed (**Supp. Figure 2; Supp. Table 1**). Importantly, comparisons between the early postoperative programming session (day 1–7) and the 90-day assessment demonstrated changes in individual and mean VTAs in both groups, reflecting iterative adjustments of stimulation parameters during the study period.

Discussion

In this multicenter randomized trial, remote programming of STN-DBS was noninferior to SoC programming for improving motor symptoms in patients with PD at 3 months after surgery. The prespecified noninferiority margin was met, and improvements in motor, nonmotor, and patient-reported outcomes were broadly comparable between groups. These findings provide randomized evidence that remote DBS programming is feasible and can achieve clinical outcomes comparable to conventional in-person care during the early postoperative phase. By evaluating remote follow-up programming after standardized inpatient DBS initiation, this study addresses an important evidence gap. Prior studies have largely examined remote programming as an adjunct to in-person visits, limiting conclusions about its independent efficacy.¹⁶ In contrast, our design allows a direct comparison of two postoperative care models and challenges the assumption that in-person neurological examination is always required for effective DBS titration when appropriate technical infrastructure and clinical oversight are available.

However, remote programming was not suitable for all participants. Four patients in the remote group experienced protocol-defined intercurrent events, including two who required crossover to in-person care because symptom control could not be adequately achieved through remote-only adjustments. In both cases, patients reported persistent motor symptoms despite repeated remote programming sessions, particularly gait instability and a sense of unsteadiness while walking. Although the treating physician attempted further optimization through remote parameter adjustments, symptom control was deemed insufficient. The physician therefore considered direct clinical examination necessary to better assess gait and postural stability and concluded that further optimization of stimulation parameters was not feasible through video-based assessment alone. This finding highlights that remote care should not be considered universally interchangeable with in-clinic management. Rather, our results support hybrid care models in which remote programming serves as a first-line or maintenance strategy, with in-person evaluation reserved for patients with insufficient symptom control or complex clinical needs. Patient selection, symptom profile, and programming complexity are therefore likely to be key determinants of suitability for remote approaches.

Safety outcomes were comparable between groups. Serious adverse events occurred at similar frequencies and no deaths were observed. This finding is notable because safety outcomes have been inconsistently reported in prior retrospective studies of remote DBS programming.^{9–15} The comparable safety profile observed in this randomized trial supports the short-term safety of remote programming when delivered within established DBS programs.

Patient-reported outcomes, including treatment satisfaction and quality of life, were high and similar in both groups. These findings are consistent with previous work emphasizing the importance of structured patient feedback in DBS optimization and support the integration of patient-reported outcome measures into remote programming protocols.^{19–21}

The reduction in LEDD was numerically greater in the SoC group than in the remote group but should be interpreted in the context of the modest sample size and pragmatic design. Because the primary endpoint was assessed in the medication-on and stimulation-on state, differences in dopaminergic medication could have influenced motor outcomes. However, the primary endpoint was deliberately assessed under these conditions because the objective of the study was to compare programming strategies in routine clinical care. This pragmatic real-world design reflects everyday DBS management, in which stimulation adjustments and medication changes are typically managed together, although it limits the ability to isolate the independent contribution of stimulation. Several factors may explain the observed difference in medication reduction, including baseline characteristics such as a higher prevalence of tremor in the SoC group and a potentially more conservative approach to medication reduction during early remote follow-up after surgery.

The SoC group demonstrated a small but statistically significant greater decline in cognitive performance relative to the remote group. However, differences observed in secondary outcomes, including cognition, should be interpreted cautiously. The greater LEDD reduction in the SoC group may have contributed to modest between-group differences in cognitive scores, although the study was not powered for cognitive endpoints. On the other hand, cognitive effects following STN-DBS are typically subtle and heterogeneous, and reductions in

dopaminergic medication do not reliably predict cognitive change.^{22–25} Because alternate test forms were not used, practice effects cannot be excluded.

Exploratory subgroup analyses suggested that age and baseline cognitive status may modify treatment response, with younger patients and those with preserved cognition deriving greater benefit from remote programming. These analyses were post hoc, were not adjusted for multiple comparisons, and were limited by the modest sample size. These findings therefore require confirmation in larger studies.

Limitations

This study has several strengths, including its randomized multicenter design, the use of validated clinical and patient-reported outcome measures, and comparable treatment intensity between groups. Limitations include the modest sample size, a slight imbalance in baseline age, limited power for subgroup analyses, and the relatively short follow-up duration, which precludes assessment of longer-term DBS management, rare adverse events, and health-economic outcomes. The 3-month follow-up period was deliberately chosen to capture the early postoperative phase of DBS management rather than the period of fully stabilized long-term stimulation. The initial postoperative programming, including the monopolar review, was intentionally performed in person, as DBS programming in many German centers is routinely initiated shortly after surgery while patients are still hospitalized. In many DBS centers in Germany, device programming is initiated shortly after implantation, during the period in which the microlesion effect subsides and dopaminergic medication is being adjusted. This phase is therefore characterized by frequent reassessment and the need for repeated programming decisions.^{26,27} In our study, patients underwent up to 6.5 programming sessions within the first 3 months (Table 1), indicating that this period represents a clinically relevant window of intensive follow-up in which remote care can be meaningfully compared with SoC management.

In addition, the primary motor outcome was assessed in the medication-on/stimulation-on condition, which does not isolate the specific contribution of DBS independent of dopaminergic therapy. This approach was nevertheless chosen deliberately to reflect real-world postoperative DBS care, in which motor outcomes emerge from the combined and evolving interaction between stimulation adjustments and medication management.

Individual DBS parameter adjustments during programming sessions were not systematically recorded. The objective of the trial, however, was not to analyze specific programming strategies but to compare two models of postoperative DBS care delivery, and physicians were therefore free to adjust stimulation parameters according to routine clinical practice. Programming changes could include modifications of stimulation amplitude, frequency, pulse width, or contact selection. While this pragmatic design reflects real-world DBS management, it does not allow detailed analysis of the specific parameter changes underlying the observed outcomes. Nevertheless, additional imaging analyses (**Supp.** Figure 2) demonstrated changes in the resulting VTAs during the study period, directly reflecting ongoing adjustments of stimulation parameters in both groups. Importantly, VTAs were comparable between groups across hemispheres and time points, indicating that both programming strategies produced similar spatial distributions of stimulation and supporting the comparable clinical outcomes observed.

Conclusion

In conclusion, remote DBS follow-up programming after standardized inpatient initiation was feasible, safe, and noninferior to conventional in-person follow-up care during the first 3 postoperative months. These findings support remote programming as a practical component of hybrid postoperative DBS care pathways, particularly for patients with limited access to specialized centers. Longer-term studies should define durability, cost-effectiveness, and the scenarios in which selective in-person troubleshooting remains necessary.

Abbreviations

ANCOVA — Analysis of covariance.

BDI-II — Beck Depression Inventory–II.

CI — Confidence interval.

COM — Center of mass.

DBS — Deep brain stimulation.

FEM — Finite element method.

H&Y — Hoehn and Yahr scale.

ICH E9(R1) — International Council for Harmonisation guideline on estimands and sensitivity analysis in clinical trials.

IPG — Implantable pulse generator.

ITT — Intention-to-treat.

LEDD — Levodopa equivalent daily dose.

MANOVA — Multivariate analysis of variance.

MDS-UPDRS — Movement Disorder Society–Unified Parkinson’s Disease Rating Scale.

MNI — Montreal Neurological Institute.

MoCA — Montreal Cognitive Assessment.

PD — Parkinson disease.

PDQ-39-SI — Parkinson’s Disease Questionnaire–39 Summary Index.

PP — Per-protocol.

SAE — Serious adverse event.

SoC — Standard of care.

SSEV — Scale for Suicidal Experience and Behavior.

STN — Subthalamic nucleus.

STN-DBS — Subthalamic nucleus deep brain stimulation.

VAS — Visual analog scale.

VTA — Volume of tissue activated.

Declarations

Data availability

Deidentified individual participant data, including the data dictionary, will be made available to qualified researchers upon reasonable request. Data will be made accessible beginning with publication and for a period of five years thereafter. Requests for data access should be directed to PD Dr. Thomas Koeglsperger. Data will be shared after approval of a methodologically sound proposal and the signing of a data access agreement.

Disclosures

T.K. has received speaker fees from Abbott, Medtronic, and AbbVie. T.K. serves as the vice president of the German DBS Society (AG-THS e.V.). M.R. is funded by the Federal Ministry of Research, Technology and Space (ACS_iIMMUNE, 01EO2105), and he received fees from Zambon, Ever Pharma, AbbVie and Bial. C.B. has received a speaker fee from Abbott, has organized information days for patients supported by Abbott, Boston Scientific and Medtronic, and is board member of the German DBS Society (AG-THS e.V.).

Competing interests

The authors declare no competing interests related to this manuscript.

Authors roles

VZ, CB, TMK, MR, JJR, JD, AS, GH & TK made substantial contributions to the conception or design of the work. JS, WZ, and TK interpreted the data and drafted the manuscript. JS, WZ, TK, MS and AC did the statistical analysis and directly accessed and verified the underlying data. UH, EK, and JHM made a substantial contribution to the acquisition or analysis of trial data. All authors had full access to all the data in the study, were involved in revising the manuscript, and had final responsibility for the decision to submit for publication.

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Figures

Figure 1

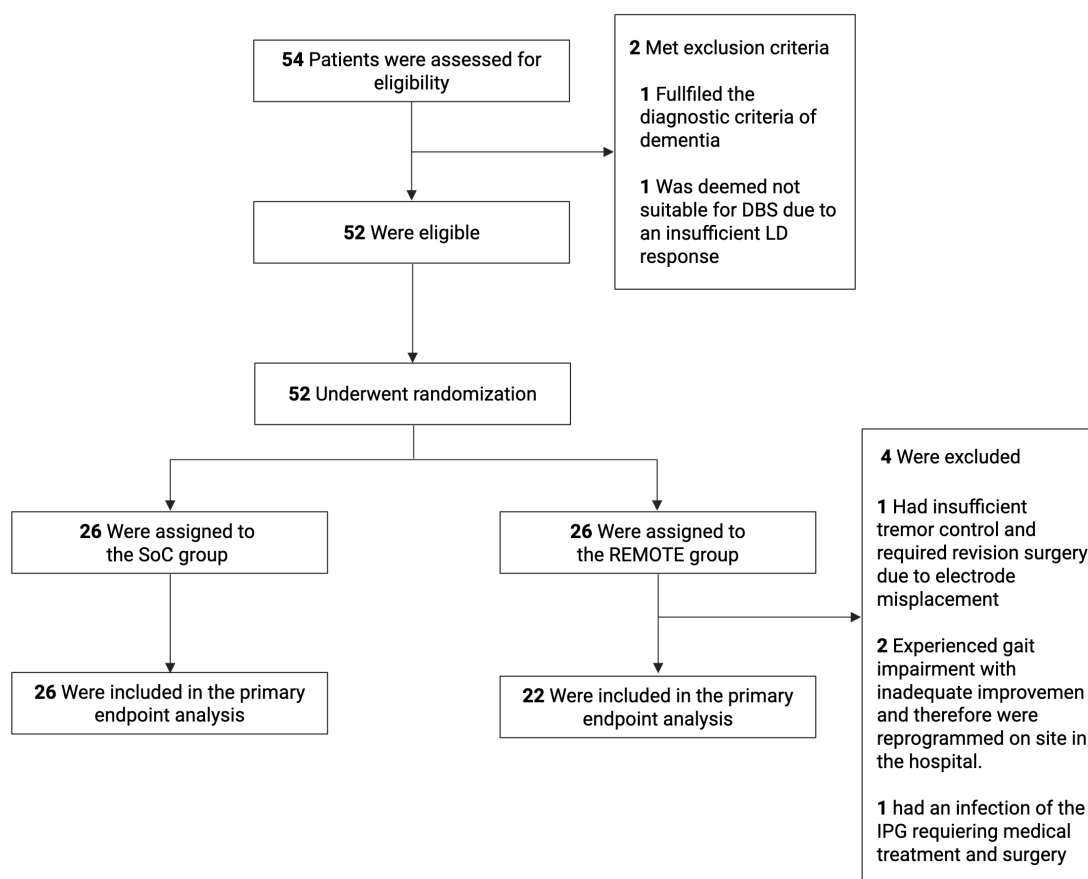


Figure 1

Participant Flow Through the Study CONSORT flow diagram showing participant screening, randomization, allocation to standard-of-care (SoC) or remote DBS programming, follow-up, and inclusion in the per-protocol and intention-to-treat analyses.

Figure 2

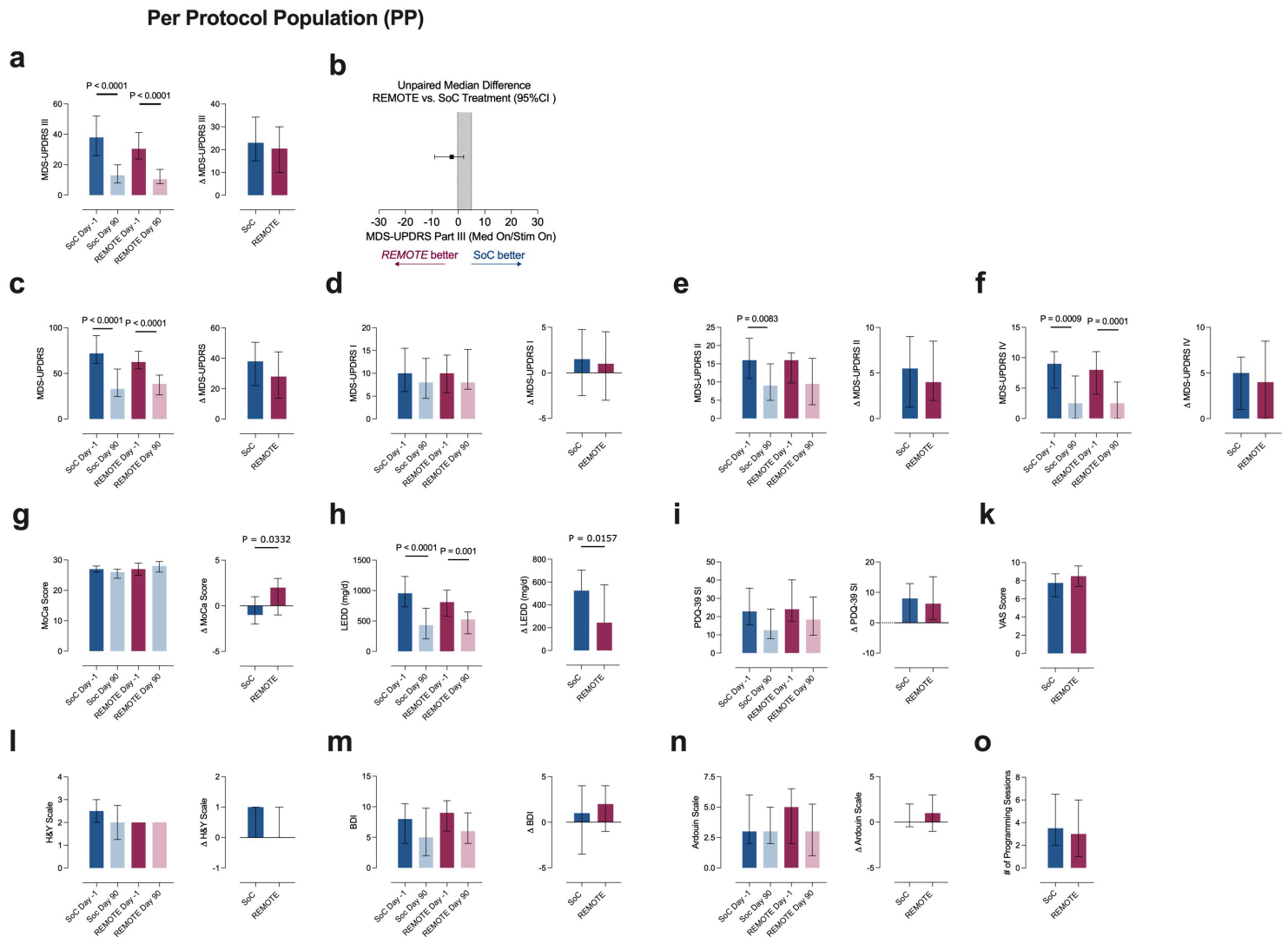


Figure 2

Primary and Secondary Outcomes (A) Movement Disorder Society–Unified Parkinson’s Disease Rating Scale (MDS-UPDRS) Part III scores at baseline and at 3 months for the standard-of-care (SoC) and remote programming groups. **(B)** Forest plot showing the median between-group difference in change in MDS-UPDRS Part III score with 95% confidence intervals (Cis) in the per-protocol population. **(C–O)** Secondary outcomes at baseline and 3 months, including total MDS-UPDRS score **(C)**, MDS-UPDRS Part I **(D)**, Part II **(E)**, and Part IV **(F)**, Montreal Cognitive Assessment (MoCA) **(G)**, levodopa equivalent daily dose (LEDD) (mg/d) **(H)**, Parkinson’s Disease Questionnaire–39 (PDQ 39-SI) Summary Index **(I)**, patient-reported treatment satisfaction on a 0–10 visual analog scale (VAS) **(K)**, Hoehn and Yahr stage **(L)**, Beck Depression Inventory–II **(M)**, Arduin Scale of Behavior in Parkinson Disease **(N)**, and number of DBS programming sessions during the study **(O)**. For each outcome, left panels show within-group changes from baseline to 3 months, and right panels show between-group differences in change. Bars indicate median values with interquartile ranges. Between-group comparisons were performed using the Mann–Whitney U test.

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