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RESEARCH

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Is physical therapy recommended for people with parkinson's disease treated with subthalamic deep brain stimulation? a delphi consensus study

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Abstract

Background Although deep brain stimulation of the subthalamic nucleus (STN-DBS) induces motor benefits in people with Parkinson's disease (PwPD), its effect on motor axial symptoms (e.g., postural instability, trunk posture alterations) and gait impairments (e.g., freezing of gait) is still ambiguous. Physical therapy (PT) effectively complements pharmacological treatment to improve postural stability, gait performance, and other dopamine-resistant symptoms (e.g. freezing of gait) in the general population with PD. Despite the positive potential of combined PT and STN-DBS surgery, scientific results are still lacking. We therefore involved worldwide leading experts on DBS and motor rehabilitation in PwPD in a consensus Delphi panel to define the current level of PT recommendation following STN-DBS surgery.

Methods After summarizing the few available findings through a systematic scoping review, we identified clinically and academically experienced DBS clinicians (n = 21) to discuss the challenges related to PT following STN-DBS. A 5-point Likert scale questionnaire was used and based on the results of the systematic review, thirty-nine questions were designed and submitted to the panel–half related to general considerations on PT following STN-DBS, and half related to PT treatments.

Results Despite the low-to-moderate quality of data, the few available rehabilitation studies suggested that PT could improve dynamic and static balance, gait performance and posture in the population with PD receiving STN-DBS. Similarly, the panellists strongly agreed that PT might help improve motor symptoms and quality of life, and it may be prescribed to maximize the effects of stimulation. The experts agreed that physical therapists could be part of the multidisciplinary team taking care of the patients. Also, they agreed that conventional PT, but not massage or manual therapy, should be prescribed because of the specificity of STN-DBS implantation.

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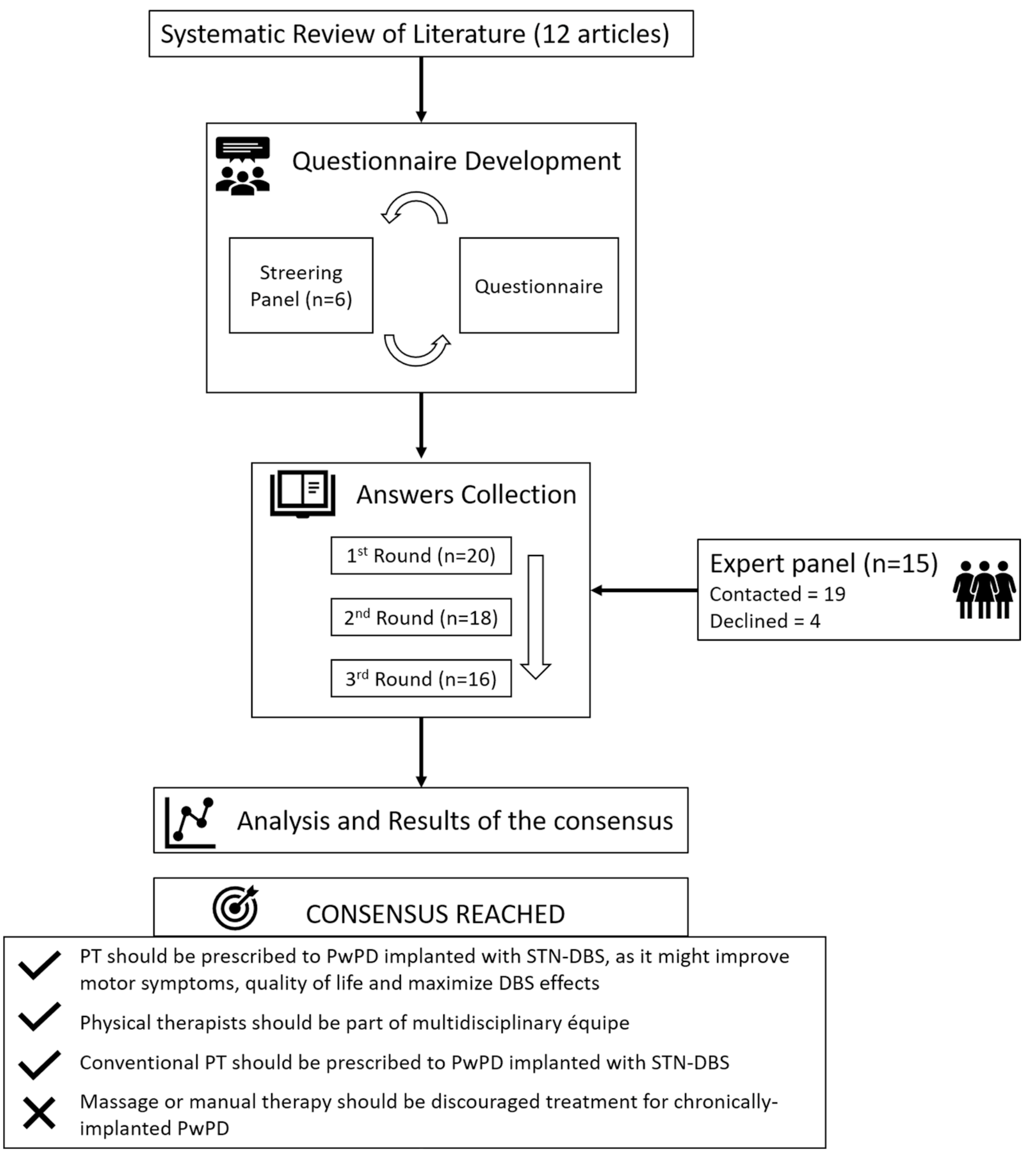
Conclusions Although RCT evidence is lacking, upon Delphi panel, PT for PwPD receiving STN-DBS can be potentially useful to maximize clinical improvement. However, more research is needed, with RCTs and well-designed studies. The rehabilitation and DBS community should expand this area of research to create guidelines for PT following STN-DBS.

Keywords Deep brain stimulation, DBS, Physiotherapy, Motor rehabilitation, Physical therapy, Delphi consensus, Parkinson's disease, Movement disorders, Neuromodulation

Graphical abstract



Introduction

Deep brain stimulation (DBS) is an established treatment for Parkinson's disease (PD) [1], with subthalamic nucleus (STN) being the most common surgical target [2]. Although a number of clinical studies suggests long-term improvement in symptoms such as tremor, rigidity, and akinesia [1], the effect of stimulation on motor axial (e.g., postural instability, trunk posture alterations) and gait impairments (e.g., freezing of gait–FOG) is still unclear [3, 4]. Patients might experience no improvement over time [3, 4], even when stimulation parameters are optimized for appendicular symptoms [1, 3].

Physical therapy (PT) is currently included in the multidisciplinary treatment of PD, but not specifically for patients treated with DBS [5, 6]. PT aims to optimize independence, safety, well-being, and ultimately quality of life, with systematic reviews and meta-analyses confirming PT-induced improvement in motor and non-motor PD impairments [7–9]. In particular, PT effectively complements pharmacological treatment to improve postural stability [7, 10], gait [11, 12], and those symptoms resistant to dopaminergic replacement (e.g. axial motor dysfunctions, FOG) [13, 14] in people with PD (PwPD). Additionally, rehabilitative motor training stimulates a number of neuroplasticity-related events in PwPD [15], including neuronal growth, synaptogenesis, neurotrophic factor expression, and neurogenesis [16–18]. Therefore, PT has the potential to be an effective adjuvant treatment to optimize motor outcomes after deep brain stimulation of the subthalamic nucleus (STN-DBS) surgery. However, this additive effect has not yet been systematically assessed-instead, DBS patients are frequently excluded from exercise trials [19, 20]. Although the current recommendations allow the return to exercise within weeks following surgery, there is no explicit indication for PT [21] and rehabilitative care in clinical settings is led by the personal expertise of physical therapists. Only some insights of safety and effectiveness are currently available, but the studies are characterized by poor methodological rigor and great variability. Therefore, no solid scientific knowledge (e.g., guidelines) is currently available.

Given the potential added value of PT to STN-DBS treatment and the current lack of knowledge, the integration of clinical findings and the experience of leading experts might serve to boost the opening of this field of clinical research and to shape lines of research in it. With these aims, we first performed a systematic scoping review of the articles assessing PT programs in PwPD treated with DBS to summarize the current findings. Then, we asked internationally recognized clinical and academic DBS experts to comment on them and other aspects in a Delphi method-based study [22].

Methods

In this work, we first performed a systematic scoping review to gather the current knowledge on PT protocols in PwPD with DBS. On the basis of the collected results and on the European Physiotherapy Guideline for Parkinson's Disease [23], we created a 5-point Likert scale questionnaire regarding the role of PT and PT interventions in PwPD with DBS to be answered by clinically and academically experienced DBS clinicians.

Systematic scoping review

A systematic scoping review of clinical research articles was performed according to previous studies, since this type of review allows for a broad overview of topics [24–26]. The literature search was conducted in PubMed/MEDLINE, with the following search keywords: ("deep brain stimulation" OR "DBS") AND ("physiotherapy" OR "physical therapy" OR "motor rehabilitation" OR "rehabilitation" OR "training" OR "exercise") AND ("Parkinson's disease" OR "PD"). We considered only clinical studies on PwPD with DBS written in English and published from January 1st, 1994, to June 30th, 2024. Reviews, protocols, simulation studies, conference abstracts or editorials were excluded. Given the paucity of studies on this topic, we decided not to restrict the inclusion criteria further, e.g., considering PwPD who underwent DBS surgery regardless the surgical target (e.g., STN or GPi). After removing duplicates, two independent reviewers (MG and NVM) screened the results of the search based on the titles and abstracts, and then evaluated the full texts of the selected articles. Conflicts were resolved by consensus, if necessary.

The following data were extracted from the selected studies: author, year of publication, study design, characteristics of the subjects, DBS protocol and duration, PT protocol, outcomes and main results. Although the need for quality assessment of selected studies in scoping reviews has been questioned [25], some authors suggest that it improves clarity [27]. Therefore, we performed a quality assessment of the selected studies through the modified version of the Downs and Black checklist [28] (see Table 1 in the Supplementary Materials), which assigns each article a score and evaluation (total score: 11–13, excellent; total score: 9–10, good; total score: 7–8, fair; total score: ≤ 6, poor).

Questionnaire development

As previously proposed [29], the questionnaire was based upon an extensive review of the literature and the European Physiotherapy Guideline for Parkinson's Disease [23]. From the systematic scoping review, we defined a taxonomy of the outcome measures, and related each of them to an improvement area, and a taxonomy of the PT proposed in published studies. Given the frequency of anatomical targets (STN and GPi) for DBS surgery and treatment in the studies considered in the systematic scoping review (88% STN-DBS, 0.7% GPi-DBS; 11.3% undefined), we decided to refer only to STN-DBS for the creation of the questionnaire for the Delphi panel. Then, a Steering Committee (SC) of experts (n = 6) selected within the collaborative network of the leading authors discussed the topics and created a structured questionnaire using a 5-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree) [22]. To do so, the concepts identified in the two taxonomies were translated into two sections of the questionnaire: one is more general and focuses on the opportunity and potential benefits of PT for PwPD receiving STN-DBS; the other, which focuses on the different PT treatments (see Table 2 in Supplementary Materials).

Delphi methodology

The Delphi technique is a multiphase procedure that combines personal viewpoints into a general consensus within a group (panel) [30]. A series of structured questionnaires (rounds) are anonymously completed by experts (panelists) and the responses from each questionnaire fed back in summarized form to the participants [31]. This allows the panelists to reassess their initial judgments, considering the positive aspects of interacting groups (e.g., inclusion of different backgrounds) without the negative ones (e.g., influence of dominant members) [32]. For the purpose of our study, a modified Delphi process [29] was created in three rounds as previously recommended [31]. In rounds one, two and three, the SC together with a broader Experts Panel (EP = 15) conducted quantitative assessments to reach a consensus. Electronic questionnaires were utilised in all steps of the process. To prevent confirmation bias, if a statement reached a consensus in either the first or second round, it was not included in the following round; conversely, statements that did not reach a consensus were included in the following round.

The consensus process is mediated by a "facilitator" who was in charge of coordinating the rounds and providing a summary of the responses that should encourage the experts to rethink their scoring. Despite the absence of guidelines, we considered a "consensus reached" when > 80% of the responses fell within the same response label [22]. Since there is no precise standard for defining an "expert" [33], we chose to involve positional leaders in the scientific field (including neurologists, neurosurgeons, physiotherapists) based on the number of peer-reviewed publications [34, 35], as recommended by prior studies [22]. We considered a response rate of > 70% for each round to preserve the rigor of the technique [36]. To highlight the strength of support through each round, we reported the results of each round separately in both textual (median ± IQR) [32] and graphical representations [33]. As a further analysis, we decided to transform the 5-point Likert scale object of the main analysis into a 3-point Likert scale, i.e., to consider the two highest (4 = agree; 5 = strongly agree) and lowest (1 = strongly disagree; 2 = disagree) points as two points (agree and disagree, respectively), while keeping the middle point (undecided). This secondary analysis was performed only for the results of the third round.

Results

Systematic scoping review

Our search yielded 632 articles (Fig. 1 in the Supplementary Materials). Of those, 615 were excluded after reviewing titles and abstracts, while 17 were further assessed as full texts for eligibility. Of these, only 12 met our inclusion criteria [37–48]. The characteristics of the included studies are summarised in Table 1. One was a case series [47], seven were pilot clinical studies [39, 40, 42–46], two were retrospective studies [37, 38], and two were case-controlled studies [41, 48], for a total of 279 patients enrolled. No randomized controlled trials (RCTs) were found. Of these, 245 had STN-DBS (169 bilateral, 76 not specified), 2 had bilateral GPi-DBS, and 32 had DBS with no specified anatomical target. The number of participants per study ranged between 1 [47] and 73 [37], with four studies involving > 20 participants [37, 39, 44, 48]. The mean age of participants ranged from 57.6 [44] to 67.6 [43] years, with a mean baseline disease severity ranging from 19.1 (UPDRS, part III) [41] to 105.5 (MDS-UPDRS, part III) [48] and a mean disease duration ranging from 10.5 [46] to 18.8 [43]. Only five studies reported the characteristics of the stimulation [38, 39, 41, 43, 46], and seven studies did not specify the duration of DBS treatment before PT treatment [37–39, 41, 45–47]. As for quality assessment, two studies [44, 48] were classified as presenting good methodological quality, six [37–39, 41–43] as fair, and four [40, 45–47] as poor, according to the Modified Downs and Black Quality Assessment Checklist (see Table 3 in the Supplementary Materials). In general, the studies met the criteria regarding the reporting section, however, a few studies [39, 40, 45–47] did not report the actual probability values of the results, and none provided estimates of random variability for the main outcomes or reported the characteristics of patients lost to follow-up. Owing to the limited sample size, external validity could not be guaranteed for most of the articles. With respect to internal validity, no one clearly stated the potential use of data dredging.

PT outcomes and areas of assessment

The effect of PT interventions was evaluated through various outcomes across the studies, which assessed both motor/functional, biomechanical (e.g., gait analyses) and neurophysiological (e.g., EEG) changes (Table 1). The

Table 1 Studies investigating physical therapy programs in patients with Parkinson's disease and deep brain stimulation

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Cohen et al. [37]	Retrospective study	73 patients (23 F; age, mean [range]: 60.6 [43–80] yo; disease duration mean [range]: 13.6 [3–27] yy; UPDRS—Part III: N.	Bilateral STN (n = 71) and GPi-DBS (n = 2) N.R. duration N.R. parameters	Multi-disciplinary personalized rehabilitation treatment (physical, occupational, and speech therapy + nutritional and psychological support)	UPDRS; FIM Assessments pre- and post- hospitalisation	Significant improvements in motor performances and disability
Nampiaparampil et al. [47]	Case series	Case 1: Male patient (age: 70 yo; disease duration: 7 yy; FIM: 39) Case 2: Male patient with previous pallidotomy (age: 65 yo; disease duration: 15 yy; FIM: 25)	Case 1: bilateral DBS Case 2: bilateral STN-DBS N.R. duration N.R. parameters	Case 1: physical, occupational and speech therapy (once a day, for 6 weeks) Case 2: physical, occupational, and speech therapy (once a day, for 4 weeks)	FIM Assessments pre- and post- hospitalization	Case 1: recovery of walking function with walker, and independency in ADL with assistance Case 2: gait, tremor, and dyskinesia improved
Tassorelli et al. [44]	Pilot, pre-post, clinical study	34 patients (15 F; age, mean ± SD: 57.6 ± 9.4 yo; disease duration, mean ± SD: 11.3 ± 4.4 yy; UPDRS—Part III, mean ± SD: 26.8 ± 12.8)	bilateral STN-DBS n = 13: < 1 month after surgery; n = 8: 1–12 months after surgery; n = 13, > 12 months after surgery N.R. parameters	Personalized protocol: • Cardiovascular warm-up (5–10 min); • Stretching—trunk and limbs (15 min); • Strengthening muscles in a functional context—active-assisted or active isometric and isotonic exercises for trunk and limbs (10–15 min); • Relaxing muscles—especially for the flexor muscles (10 min); • Motor skills, coordination, and dual task performance (10 min); • Balance (10 min); • Gait training—with sensory cues (30 min) Once a day, 5 days a week for 4-to-8 consecutive weeks	UPDRS—Part III; FIM; mBI; MGHFAC; standing balance index Assessments pre- and post-rehabilitative intervention	Significant improvement of motor performance, functional independence, standing balance and independent walking ability

Table 1 (continued)

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Nardo et al. [40]	Pilot, pre-post, clinical study	9 patients (2 F; age, mean ± SD: 66.44 ± 5.7 yo; disease duration, mean ± SD: 12.2 ± 6 yy; UPDRS—Part III, mean ± SD: 36.7 ± 6.4)	DBS (months after surgery, mean ± SD: 3.11 ± 1.19) N.R. parameters	Protocol comprising: • Body weight supported and robotic-assisted treadmill training: speed at 1.5 km/h, increased up to 3 km/h as tolerated (45 min) Once a day, for 5 weeks	UPDRS—Part III; Gait kinematics, kinetic, and spatiotemporal parameters Assessments pre- and post-rehabilitative intervention	Significant improvements in gait performance, in all the spatiotemporal gait parameters, and in maximal ankle plantar flexion angle in the toe-off phase
Luna et al. [42]	Cross-over clinical trial	12 patients (5 F; age, mean ± SD: 61.5 ± 10.4 yo; disease duration, mean ± SD: 18.6 ± 5.2 yy; mH&Y, mean ± SD: 2.3 ± 0.3)	bilateral STN-DBS (months after surgery, mean ± SD: 1.7 ± 0.6) N.R. parameters	EG: treadmill training with body weight support (30 min) + physical therapy (60 min) CG: treadmill training without body weight support (30 min) + physical therapy (60 min) • Treadmill training: speed at 0.5 km/h, increased by increments of 0.5 km/h as tolerated • Physical therapy: stretching exercise for trunk, upper and lower limbs muscles (2 min); strengthening exercises for upper, lower limbs, trunk, and scapular muscles (for each, 3 sets of 15 repetitions); exercise for balance (bipodal, tandem and unipodal stance—2 sets of each) twice a week for 8 weeks	Gait kinematics, spatiotemporal and angular parameters Assessments pre- and post-rehabilitative intervention	Significant improvements in pelvis' range of motion; hip's range of amplitude; knee flexion on swing phase; and foot progression range of motion (EG group)

Table 1 (continued)

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Bestaven et al. [43]	Pilot, pre-post, clinical study	10 patients (3 F; age, mean ± SD: 67.6 ± 6.3 yo; disease duration, mean ± SD: 18.8 ± 4 yy; UPDRS—Part III: N.R.)	bilateral STN-DBS (months after surgery, mean ± SD: 94.8 ± 37.2, 60–175 Hz; 60–90 µs; 2.1–4.6 V)	Protocol comprising: • Stretching exercise for trunk muscles (75 min); • Strengthening exercises for trunk muscles, in extension, flexion and rotation (75 min); • Cardiovascular training (30 min) twice a day, 5 days a week for 4 weeks	UPDRS—Part III; UPDRS—Part III axial score (items 18, 19, 20, 22, 27–30); UPDRS—Part III gait score (item 30); UPDRS—Part III postural instability score (item 29); ABD; BBS; 3D kinematic gait analyses Assessments pre- and post-rehabilitative intervention	Significant improvements in gait performances and posture; significant decrease in daily number of falls
Sato et al. [38]	Retrospective study	16 patients (5 F; age, median ± IQR: 61.5 ± 9.5 yo; disease duration, median ± IQR: 13 ± 8 yy; UPDRS—Part III, median ± IQR: 17.5 ± 7.75)	STN-DBS (median: 130 Hz; 60 µs; 1.68 V) N.R. duration	Protocol aiming to improve muscle strength, flexibility, balance, and gait • Flexibility: active assistive range of motion exercise for ankle, hip, and trunk joints • Strength and balance: dynamic balance exercise in the quadrupedal (cat and dog, diagonal balancing exercise) and standing positions (toe-heel weight bearing, one-leg standing, step position) • Gait: active assistive gait training 40 min a day, for 14 days	Mini-BESTest; TUG; UPDRS-III; BI Assessments before, three days after and 2 weeks after surgery	Significant improvements in balance and gait ability

Table 1 (continued)

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Naro et al. [41]	Case-controlled pilot study	EG: 10 patients with STN-DBS (4 F; age, mean ± SD: 62 ± 5 yo; disease duration, mean ± SD: 15 ± 2 yy; UPDRS—Part III, mean ± SD: 19.1 ± 9.03) CG: 10 patients without DBS (5 F; age, mean ± SD: 62 ± 4 yo; disease duration, mean ± SD: 14 ± 2 yy; UPDRS—Part III, mean ± SD: 27.54 ± 1.12)	bilateral STN-DBS (months after surgery: > 12; 130–240 Hz; 60–120 µs; 2.2–3.6 V)	EG, CG: RAS-assisted treadmill training (30 min) + physical therapy (60 min) • RAS-assisted treadmill training: bpm at 85 ± 5 (0.43 m/s), increased by 5 bpm every 3 min up to 120 bpm (0.61 m/s) • Physical therapy: exercises to improve flexibility, balance, gait, and muscular tone and resistance once a day, 6 days a week, for 4 weeks	UPDRS—part III; TUG; 10MWT; BBS; FES; ACE-R; EEG Assessments pre- and post-rehabilitative intervention	EG: Significant improvements in motor performance (self-confidence in balance, sit-to-stand, velocity), walking (velocity), and remodulation of gait cycle–related beta oscillations Both groups: significant improvements in dynamic and static balance, cognitive performance, and the fear of falling
Li et al. [45]	Pilot, clinical study	16 patients (8 F; age, mean ± SD: 60.25 ± 5.6 yo; disease duration, mean ± SD: 10.38 ± 4.33 yy; MDS-UPDRS—Part III, mean ± SD: 59.38 ± 17.07)	bilateral STN-DBS N.R. duration N.R. parameters	Multi-disciplinary treatment (DBS, rehabilitation, medication, psychotherapy), comprising: • Core strength training; • Postural stability training; • Training of sensory function	PDQ-39; MDS-UPDRS—Part III; MDS-UPDRS 3.12; BBS; LoS Assessments pre- and post-surgery, 6 months post-surgery, 12 months post-surgery	Significant improvements in QoL, motor and balance performance at 6 and 12 months
Liang et al. [46]	Pilot, clinical study	15 patients (8 F; age, mean ± SD: 62.5 ± 8 yo; disease duration, mean ± SD: 10.5 ± 4.47 yy; MDS-UPDRS—Part III, mean ± SD: 55.06 ± 16.77)	bilateral STN-DBS (130–170 Hz; 60–90 µs; 1.5–3.5 V) N.R. duration	Protocol comprising: • Stretching exercises for neck, shoulders, chest, and waist muscles (10 min); • Strengthening of back, posterior shoulder, gluteal muscles (at least 1 set of 10 to 15 repetitions for each); • Back extension and bridge exercise (5 s each); • Education to the patient once per day for 8 weeks	PDQ-39, MDS-UPDRS III, degree of camptocormia Assessments pre-, at 1 month and 6 months after surgery	Significant improvements in camptocormia

Table 1 (continued)

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Sato et al. [39]	Pre-post, clinical study	60 patients (28 F; age, mean ± SD: 60.7 ± 8.9 yo; disease duration, mean ± SD: 12.2 ± 4.6 yy; MDS-UPDRS—Part III, mean ± SD: 18.1 ± 8.6)	STN-DBS (131.2 ± 6.5 Hz; 58.8 ± 4.9 µs; 1.8 ± 0.5 mA) N.R. duration	General program combining muscle-strengthening exercises, stretching, and balance exercises 40–60 min a day, for 14 days	Mini-BESTest; TUG; TIS; Lower Extremity Extension Torque; 10 Toe-Tapping Seconds; Postural Sway Test Assessments before and three days after after surgery, and just before discharge)	Significant improvements in physical function, balance, and gait ability

Table 1 (continued)

Authors, year	Study design	Patients	DBS protocol and duration	PT protocol	Outcomes	Main results
Canesi et al. [48]	Case-controlled pilot study	EG: 22 patients with DBS (9 F; age, median ± IQR: 63.5 ± 13.5 yo; disease duration, median ± IQR: 17 ± 9 yy; MDS-UPDRS, median ± IQR: 105.5 ± 45.55) CG: 25 patients without DBS (9 F; age, median ± IQR: 69 ± 11 yo; disease duration, median ± IQR: 15 ± 6 yy; MDS-UPDRS, median ± IQR: 86 ± 30)	DBS (months after surgery, median ± IQR: 72 ± 69.6) N.R. parameters	Multi-disciplinary treatment (occupational therapy, speech therapy), comprising physical therapy: • Morning session: warming-up (passive and active mobilization exercises for both upper and lower limbs—10 min), aerobic exercises (walking and cycling, with intensity between 50 and 80% of the maximal heart rate—15 min), active mobilization exercises and strengthening exercises (60–75% of the estimated 1RM—15 min), postural/proprioceptive exercises (10 min), and cooling down (passive and active mobilization exercises—10 min) • Afternoon session: warming-up (10 min), treadmill (15 min), aerobic exercise (intensity between 50 and 80% of the maximal heart rate—15 min), proprioceptive exercises (15 min) and cooling down (passive and active mobilization exercises—10 min) 60 min, twice a day, 5 days a week for 4 consecutive weeks	MDS-UPDRS; BBS; SPDDS; TUG; 6MWT; MoCA Assessments pre- and 24 h after rehabilitative intervention	EG and CG improved physical functioning and performance, balance function and independence in ADL, but without difference between groups

F = females; yo = years old; yy = years; UPDRS = Unified Parkinson's Disease Rating Scale; STN-DBS = subthalamic nucleus deep brain stimulation; GPi-DBS = globus pallidus internus deep brain stimulation; DBS = deep brain stimulation; N.R. = not reported; FIM = Functional Independence Measure; BI = modified Barthel Index; MGHFAC = Massachusetts General Hospital Functional Ambulation Classification; EG = experimental group; CG = control group; ABD = Activities-specific Balance; BBS = berg balance scale; Mini-BESTest = Mini-Balance Evaluation Systems Test; TUG = Timed Up and Go; BI = Barthel Index; RAS = rhythmic auditory stimulation; 10MWT = 10 m walking test; FES = falls efficacy scale; ACE-R = Addenbrooke's Cognitive Examination–Revised; PDQ-39 = Parkinson's Disease Questionnaire; MDS-UPDRS = Movement Disorder Society-Unified Parkinson's Disease Rating Scale; LoS = Limits of Stability; TIS = Trunk Impairment Scale; SPDDS = Self-Assessment Parkinson Disease Scale; 6MWT = 6 Min Walk Test; MoCA = Montreal Cognitive Assessment selected studies examined the role of the PT in PwPD undergoing DBS in 5 main areas of assessment: (I) Motor symptoms and motor decline, as assessed mainly through the UPDRS—part III, including its different scores (e.g., axial score and gait score), or the MDS-UPDRS; (II) Gait performance, as assessed mainly though TUG and gait analyses; (III) Balance and postural instability, as assessed mainly though the BBS and the Mini-BESTest; (IV) Quality of life or activities of daily living, as assessed mainly though the FIM and PDQ-39; and (V) Timing of PT treatment, in terms of the number of months after neurosurgery. Although half of the selected studies did not report the time between surgery and rehabilitation [37–39, 45–47], three considered patients with chronic stimulation (e.g., several years) [41, 43, 48], whereas two patients had only a few months of DBS (< 1 year) [40, 42]. One study [44] enrolled patients with different timings [44]. As shown in Table 2 in the Supplementary Materials, these areas of assessment were used to build the questionnaire for the Delphi panel.

PT treatments

PT treatments and protocols varied considerably across the selected studies (Table 1). Most of them studied the effect of aerobic training with mobility, stretching, strengthening, balance and gait exercises or a combination thereof [38, 39, 43, 44, 46], whereas four [37, 45, 47, 48] considered a multidisciplinary approach. Among them, only one study [48] reported a clear description of the characteristics of the interventions. Three studies assessed the use of treadmill training: one [40] associated with body weight and robotic support, one [42] with body weight support and physical therapy (stretching, strengthening and balance exercises), and one [41] with rhythmic auditory stimulation. Similarly, PT protocols markedly differed in terms of intensity, frequency, and duration. Only three studies reported the intensity (i.e., session length) of the treatment [38, 39, 48], which ranged from 40 to 60 min. The frequency ranged from twice weekly for 8 weeks [42] to twice a day weekly for 4 weeks [43, 48], for a total duration ranging from 2 [38, 39] to 8 [42, 44, 46] weeks.

Delphi panel results

For the SC, 7 authors were invited but only 6 agreed to participate (response rate: 85.7%). For the EP, of the 20 authors identified, 2 declined to participate and 3 did not reply (response rate: 75%). Therefore, the overall number of the panellists was 21 (overall response rate: 77.7%-see Table 4 in the Supplementary Materials), which is within the recommended range [32]. Demographic characteristics of the panellists are displayed in Table 5 in the Supplementary Materials. Briefly, most of them were male (81%), between 50 and 59 years old (47.6%) and highly experienced (95.2% and 85.7% with > 10 years of experience in neurostimulation field and DBS clinical trials, respectively).

For the 11 general considerations on PT (Table 2), the first round led to no consensus for any of the statements (Fig. 2 in the Supplementary Materials); in the second round, the consensus was reached in three statements (Fig. 1); and finally, in the third round, the consensus was reached in four additional statements (Fig. 2). In the second round, the panellists strongly agreed that PT might help improve motor symptoms (Statement 1) and quality of life (Statement 4) of PwPD undergoing STN-DBS, recommending physical therapists to be part of the multidisciplinary équipe taking care of the patients (Statement 11) (for all, 89% strongly agreed, median ± IQR: 5 ± 0). After the third round, the panellists strongly agreed on the need to prescribe PT to PwPD implanted with STN-DBS as soon as the clinical conditions are stable (Statement 8–94% strongly agreed, median ± IQR: 5 ± 0) and to chronically-implanted patients (Statement 9–88% strongly agreed, median ± IQR: 5 ± 0), because it might help maximize the effects of stimulation (Statement 5–88% strongly agreed, median ± IQR: 5 ± 0). Finally, they suggested that PT be prescribed in treatment guidelines as complementary treatment for PwPD treated with STN-DBS (Statement 10–88% strongly agreed, median ± IQR: 5 ± 0).

The secondary analysis performed on the third round of answers revealed an agreement on three further statements (Fig. 3 in the Supplementary Materials). Specifically, the experts agreed that PT treatments suggested in the literature for postural instability (Statement 2–94% agreed) and gait disability (Statement 3–88% agreed) for PwPD could also be useful for PwPD under STN-DBS treatment; similarly, they agreed that PT could alleviate the burden of caregivers taking care of these patients (Statement 7–88% agreed).

For the 28 statements on PT treatments (Table 2), no consensus was reached after the first and second rounds (Fig. 4, 5 in the Supplementary Materials). After the third round, consensus was reached in three statements (Fig. 3). Indeed, the panellists agreed on the prescription of conventional PT (i.e., physiotherapist-supervised active exercise interventions targeting gait, balance, transfers or physical capacity, or a combination thereof) as soon as the clinical conditions of the implanted patients are stable (Statement 12–81% strongly agreed, median ± IQR: 5 ± 0) and in chronically-implanted patients (Statement 13–81% strongly agreed, median ± IQR: 5 ± 0). Additionally, massage or manual therapy was discouraged as treatment for chronically

Table 2 Five-point Likert questionnaire with the results (median ± IQR) for each round

Statement*	1st round (n = 20; RR = 95%)	2nd round (n = 18; RR = 86%)	3rd round (n = 16; RR = 76%)
Physical Therapy in PwPD implanted with STN-DBS			
S1. Physical therapy might help improving motor symptoms of PD in PwPD implanted with STN-DBS	5 ± 1	5 ± 0–C.R	–
S2. Physical therapy treatments suggested in literature for postural instability in not-implanted PwPD might help improving postural instability also in PwPD implanted with STN-DBS	4 ± 0.5	4 ± 0	4 ± 0
S3. Physical therapy treatments suggested in literature for gait disability in not-implanted PwPD might help improving postural instability also in PwPD implanted with STN-DBS	4 ± 1	4 ± 0	4 ± 0
S4. Physical therapy might help improving quality of life of PwPD implanted with STN-DBS	5 ± 1	5 ± 0–C.R	–
S5. Physical therapy might help maximizing effects of stimulation in PwPD implanted with STN-DBS	4 ± 1	5 ± 0.75	5 ± 0–C.R
S6. Physical therapy might help slowing pathological motor decline of PwPD implanted with STN-DBS	4 ± 1.25	4 ± 1.75	4 ± 0.5
S7. Physical therapy might help alleviating caregiver burden of PwPD implanted with STN-DBS	4 ± 1	4 ± 0	4 ± 0
S8. Physical therapy should be prescribed to PwPD implanted with STN-DBS as soon as the clinical conditions are stable	5 ± 2	5 ± 0.75	5 ± 0–C.R
S9. Physical therapy should be prescribed for chronically implanted PwPD with STN-DBS	4 ± 1.25	5 ± 1	5 ± 0–C.R
S10. Physical therapy should be prescribed in treatment guidelines as complementary treatment for PwPD implanted with STN-DBS	5 ± 1.25	5 ± 0	5 ± 0–C.R
S11. Physical therapist should be part of the multidisciplinary équipe taking care of PwPD implanted with STN-DBS	5 ± 0.25	5 ± 0–C.R	–
Physical Therapy Treatment in PwPD implanted with STN-DBS			
S12. Conventional physiotherapy (i.e., physiotherapist-supervised active exercise interventions targeting gait, balance, transfers or physical capacity, or a combination thereof) should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 2	5 ± 1	5 ± 0–C.R
S13. Conventional physiotherapy (i.e., physiotherapist-supervised active exercise interventions targeting gait, balance, transfers or physical capacity, or a combination thereof) should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4 ± 1	5 ± 0.75	5 ± 0–C.R
S14. Treadmill training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 2	4 ± 1.75	4 ± 1
S15. Treadmill training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4 ± 1.25	3.5 ± 1	3.5 ± 1
S16. Massage or Manual Therapy should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3 ± 1.25	2 ± 1	2 ± 0
S17. Massage or Manual Therapy should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3 ± 1	2 ± 1	2 ± 0–C.R
S18. Cueing (visual, auditory) should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 2	4 ± 1	4 ± 1.25
S19. Cueing (visual, auditory) should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4 ± 2	4 ± 1	4 ± 1.25
S20. Dance-based training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3 ± 1.25	3 ± 2	3 ± 1
S21. Dance-based training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3 ± 1	3.5 ± 2	3 ± 0.25
S22. Tai Chi-based training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3 ± 1.25	3 ± 0	3 ± 0
S23. Tai Chi-based training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3 ± 1.25	3 ± 1	3 ± 0
S24. Cognitive movement strategies (e.g., stand up right; bring the weight on the heels; transfer the weight to one leg; step out with the other leg, make a large step, and keep on walking) should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 1	4.5 ± 1	5 ± 1
S25. Cognitive movement strategies (e.g., stand up right; bring the weight on the heels; transfer the weight to one leg; step out with the other leg, make a large step, and keep on walking) should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4 ± 1	4.5 ± 1	4 ± 1

Table 2 (continued)

Statement*	1st round (n = 20; RR = 95%)	2nd round (n = 18; RR = 86%)	3rd round (n = 16; RR = 76%)
S26. Aerobic training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	5 ± 2.25	5 ± 1	5 ± 0.25
S27. Aerobic training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	5 ± 2	5 ± 1	5 ± 0.25
S28. Muscle strengthening should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 2	5 ± 1	5 ± 1
S29. Muscle strengthening should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4.5 ± 2	5 ± 1	5 ± 1
S30. Robot-assisted gait training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	2.5 ± 1	2 ± 0.75	2 ± 1
S31. Robot-assisted gait training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	2.5 ± 1	2 ± 0.75	2 ± 1
S32. Aquatic exercise should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3 ± 2	3 ± 1.75	3 ± 1
S33. Aquatic exercise should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3 ± 2.25	3.5 ± 1.75	3 ± 1
S34. Virtual reality and exergames should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3 ± 1.25	3 ± 0.75	3 ± 0.25
S35. Virtual reality and exergames should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3 ± 2	3 ± 1	3 ± 0
S36. Resistance training should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	3.5 ± 1.5	3.5 ± 1.75	3 ± 1
S37. Resistance training should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	3.5 ± 1.25	4 ± 1.75	3 ± 1
S38. Exercise to improve trunk and limbs flexibility and range of motion should be suggested as PT treatment for PwPD implanted with STN-DBS, as soon as the clinical conditions are stable	4 ± 1.25	4 ± 0.75	4 ± 0
S39. Exercise to improve trunk and limbs flexibility and range of motion should be suggested as PT treatment for PwPD chronically implanted with STN-DBS	4 ± 1.25	5 ± 1	4.5 ± 1

*Delphi Panel members were asked to rate their agreement with the statement (1 = strongly disagree; 2 = disagree; 3 = undecided; 4 = agree; 5 = strongly agree); R.R. = response rate; C.R. = consensus reached; PD = Parkinson's disease; PwPD = people with Parkinson's disease; STN-DBS = subthalamic nucleus deep brain stimulation

implanted patients (Statement 17–81% disagreed, median ± IQR: 2 ± 0).

The secondary analysis performed on the third round of answers revealed an agreement on several other statements (Fig. 6 in the Supplementary Materials). Specifically, the experts agreed that PwPD implanted with STN-DBS, regardless of time, should be prescribed cognitive movement strategies (Statement 24–100% agree; Statement 25–100% agree), aerobic training (Statement 26–94% agree; Statement 27–94% agree), muscle strengthening (Statement 28–81% agree; Statement 29–81% agree), and exercise to improve trunk and limb flexibility and range of motion (Statement 38–88% agree; Statement 39–88% agree). Conversely, the experts did not recommend robot-assisted gait training (Statement 30–81% disagree; Statement 31–94% disagree) and massage or manual therapy as soon as the clinical conditions are stable (Statement 16–81% disagree).

Discussion

To answer the question of the use of PT in PwPD receiving STN-DBS, in this study, after summarizing the current scientific knowledge, we asked the opinion of clinical and academic DBS experts applying a Delphi methodology. The 21 experts agreed that PT might maximize the effects of stimulation, improving both motor symptoms and quality of life. PT should be prescribed in treatment guidelines in the form of conventional physiotherapy (i.e., physiotherapist-supervised active exercise interventions targeting gait, balance, transfers or physical capacity, or a combination thereof), and physical therapists should be part of the multidisciplinary équipe taking care of PwPD implanted with STN-DBS. However, massage or manual therapy should not be suggested.

PT or no PT?

Considering the caveats and methodological limitations found in the systematic scoping review, it might be only

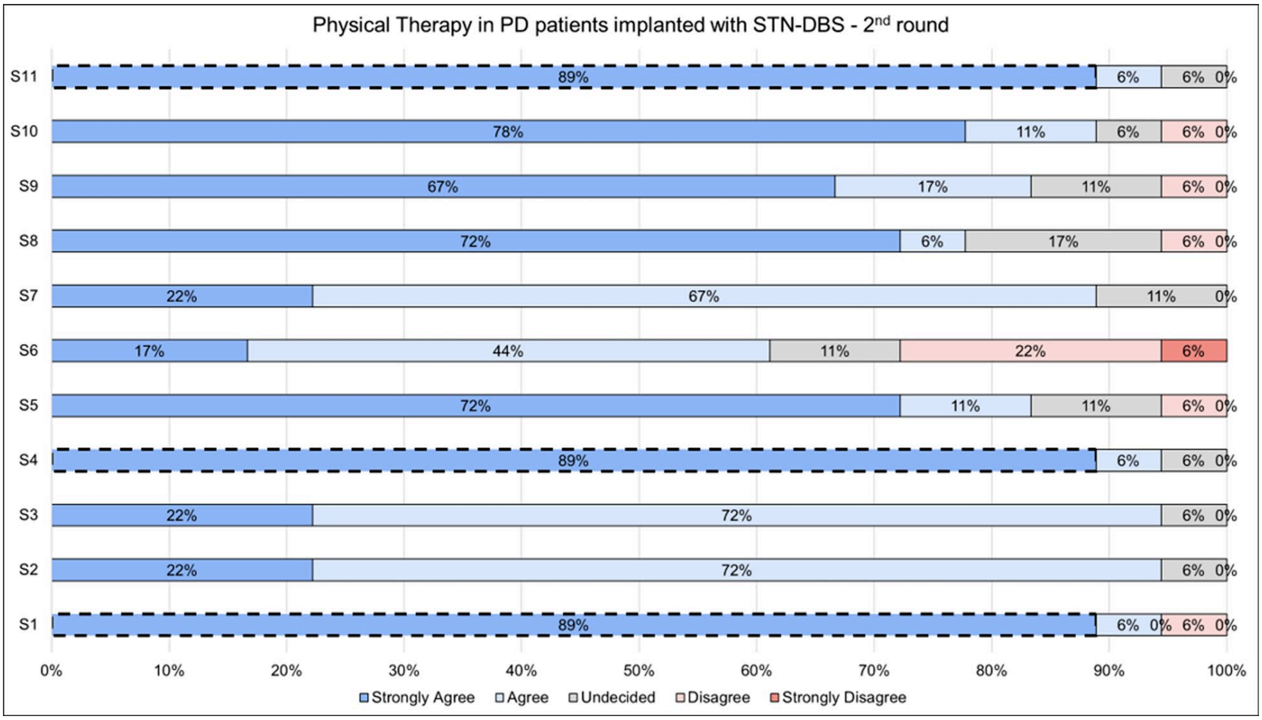


Fig. 1 Percentage of agreement for the 11 general considerations on physical therapy after subthalamic nucleus deep brain stimulation in patients with Parkinson's disease (Statement 1–11) among the Delphi Panel members, as result of the second round. Statement 1, Statement 4 and Statement 11 reached a consensus, i.e., 89% of the responses fell within the response label "strongly agree". PD = Parkinson's disease; STN-DBS = subthalamic nucleus deep brain stimulation; S = statement

qualitatively argued that PT for PwPD treated with STN-DBS could improve dynamic and static balance [38, 39, 41, 44, 45, 48], gait performance [38–44] and posture [43], ultimately leading to a significant decrease in the daily number of falls [43] and the fear of falling [41], with an increase in motor performance [37, 39, 41, 44, 45, 48], functional independence [37, 44, 48], and quality of life [45]. Therefore, our expert consensus is highly important for establishing whether PT should be potentially beneficial for PwPD treated with STN-DBS. The experts agreed that PT might improve motor symptoms and quality of life, maximizing the effects of electrical stimulation. Additionally, in our secondary analysis, the experts considered that PT could be helpful for caregivers, and that PT treatments already suggested for postural instability and gait disability in PwPD could also be effective for PwPD receiving STN-DBS, in line with the limited number of clinical studies [38–44, 46, 48].

Although STN-DBS has been demonstrated to be highly effective at controlling motor symptoms in PwPD [49], some clinical issues remain open. After initial improvement following STN-DBS [50, 51], postural instability [52] and gait disturbances [53, 54] have been reported to worsen over time [55]. Some findings even suggest no significant improvement in trunk rigidity [56]. Although it is not clear whether this deterioration might be due to PD progression rather than DBS treatment, taken together, this worsening might determine physical inactivity, increase in falls [57], and secondary complications [58] after STN-DBS surgery. On the other hand, solid scientific knowledge confirms that PT maximizes independence, well-being, and quality of life [59, 60], in addition to improving motor (such as postural instability [7, 10], gait impairments such as festination, FOG [13, 14]) and non-motor (e.g., depression, apathy, and fatigue [8, 9]) PD symptoms. It is reasonable to hypothesize that this evidence in the general PD population would also apply to PwPD implanted with STN-DBS, where exercise and STN-DBS might exert a complimentary, positive effects on PD severity and mobility. This coupled effect has already been shown for exercise and dopaminergic medication on muscle force production, UPDRS III scores, and mobility in PwPD [61]. Finally, both STN-DBS [62] and PT [15] were suggested to stimulate a number of neuroplastic and neuroprotective biochemical events in PwPD. For example, while STN-DBS could preserve nigral dopamine neurons from degeneration [63, 64] and increase the level of neurotrophic factors in the nigrostriatal

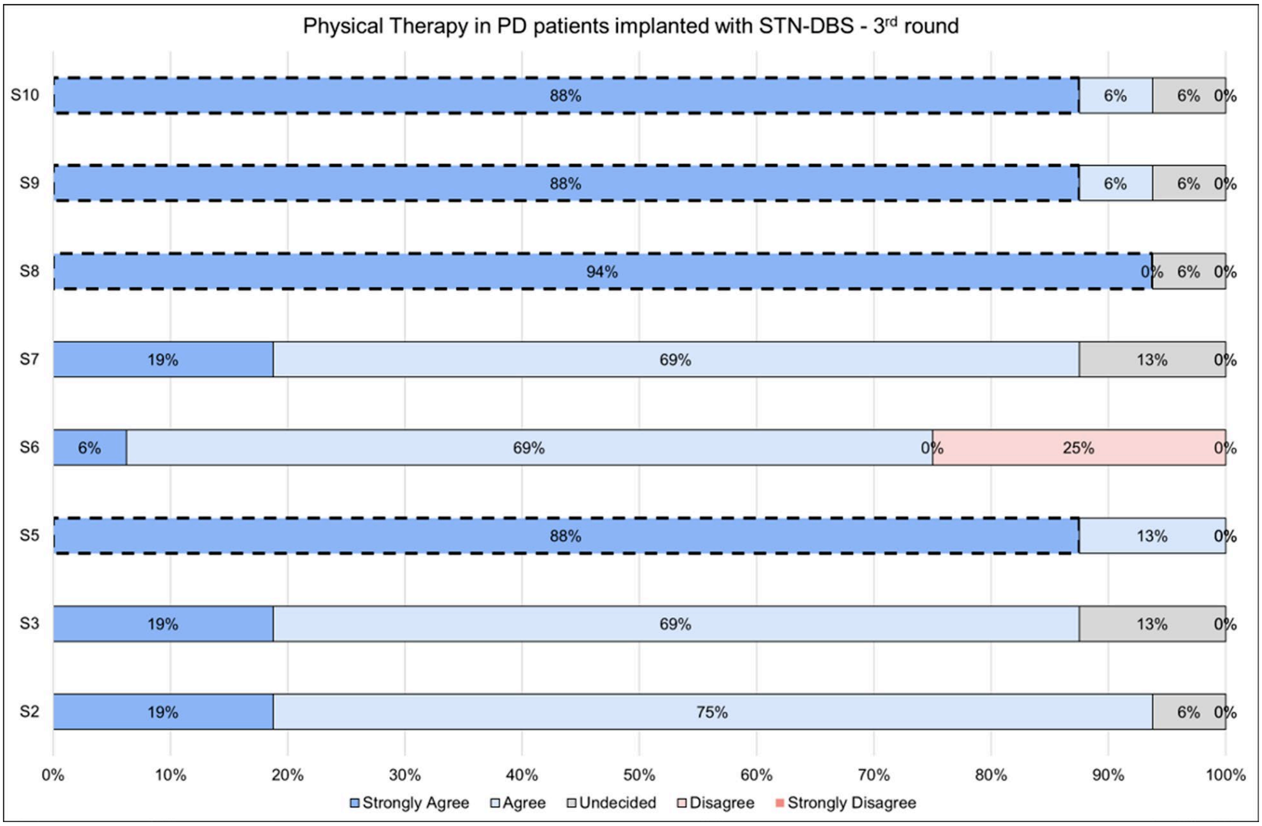


Fig. 2 Percentage of agreement for the 11 general considerations on physical therapy after subthalamic nucleus deep brain stimulation in patients with Parkinson's disease (Statement 1–11) among the Delphi Panel members, as result of the third round. Statement 5, Statement 8, Statement 9 and Statement 10 reached a consensus, i.e., respectively, 88%, 94%, 88% and 88% of the responses fell in the response label "strongly agree". PD = Parkinson's disease; STN-DBS = subthalamic nucleus deep brain stimulation; S = statement

system and primary motor cortex [65], PT and exercise would increase neuronal growth, synaptogenesis, neurotrophic factor expression, and neurogenesis [16–18]. The combination of STN-DBS and PT in PwPD could boost these neurochemical mechanisms and biological pathways, attenuating disease progression and enhancing compensatory neuronal strategies. However, all these assumptions remain speculative, and no data are available—which is likely why experts couldn't reach an agreement on this.

PT prescription

The panel agreed that PT should be prescribed for PwPD implanted with STN-DBS, both in post-acute and chronic phases. Additionally, they suggested that PT should be included in treatment guidelines, and that physical therapists should be involved in the multidisciplinary team in charge of patients. The low-risk nature of PT coupled with the potential benefit for improving motor function and quality of life in PwPD with STN-DBS supports these statements. According to the studies selected in our systematic scoping review, PT in these patients might be well tolerated–although the duration of the rehabilitation period might be an obstacle for completion [40]. Additionally, PT appears to be safe, with several studies reporting no intervention-related adverse effects [41, 42]. For example, Bestaven et al. [43] reported that, despite initial doubts and apprehension, all the enrolled subjects agreed with and completed the PT protocol. Also, current recommendations allow patients to return to exercise within weeks following surgery [66]; therefore, it appears that PT should be considered a nonharmful intervention for PwPD with STN-DBS, even more so because PT is commonly a supervised treatment. Indeed, physical therapists could contribute to the care of patients after implantation surgery (e.g., in the management of complications after surgery [67] or during the adaptation of stimulation parameters [67]) or in the chronic phase (e.g., modifying pathological movement patterns [68] or teaching patients to adapt motor strategies and relevant activities of daily living to the new conditions [68]). In addition to the technical aspects of intervention, PT treatment characteristically requires multiple sessions for quite long periods—a time

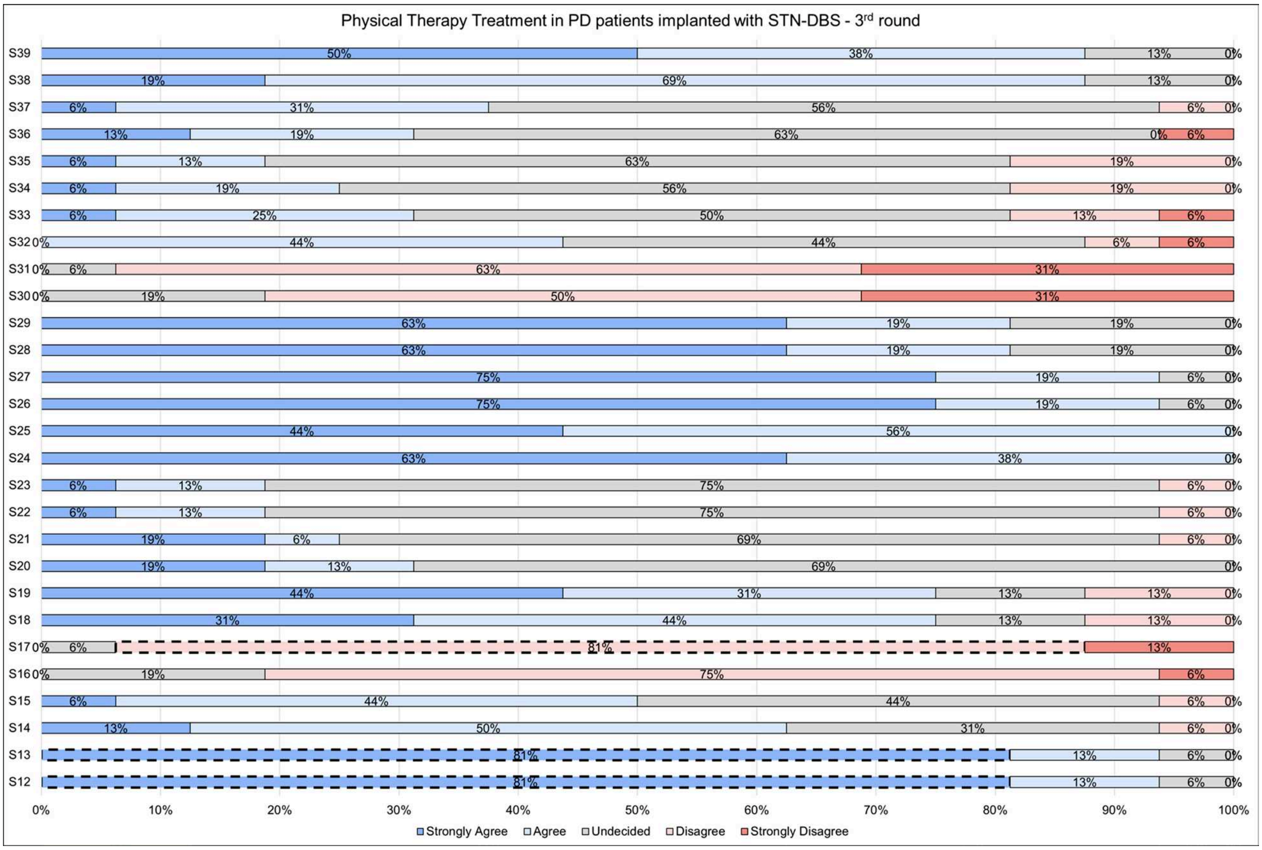


Fig. 3 Percentage of agreement for the 28 statements on physical therapy treatments after subthalamic nucleus deep brain stimulation in patients with Parkinson's disease (Statement 12–39) among the Delphi Panel members, as result of the third round. Statement 12 and Statement 13 reached a consensus, i.e., for both, 81% of the responses fell in the response label "strongly agree". Statement 17 reached a consensus, i.e., 81% of the responses fell in the response label "disagree". PD = Parkinson's disease; STN-DBS = subthalamic nucleus deep brain stimulation; S = statemen

where patient-therapist relationship can be developed for explanations or counselling. This could represent an occasion to increase the cooperation and motivation of patients and caregivers, which is fundamental to achieve a good outcome after DBS [69].

PT protocols

Despite the very limited scientific knowledge found in the systematic scoping review, the panellists agreed that conventional PT should be prescribed to PwPD implanted with STN-DBS, regardless of the time from surgery. Interestingly, when the experts' opinions were reconsidered on a 3-point Likert scale, several PT treatments were also considered effective for PwPD receiving STN-DBS—cognitive movement strategies, aerobic training, muscle strengthening, and exercise to improve trunk and limbs flexibility and range of motion.

The results on conventional PT-like interventions [38, 39, 42–44, 46, 48] as shown by our systematic scoping review, suggest a positive effect on motor and functional PD symptoms. A number of findings suggest similar effects for the general PD population [9], although without superiority over other types of treatment [70]. For example, several studies suggest that multifactorial conventional PT interventions including muscle strengthening, increasing of range of movement, balance training and gait training have positive effects on balance dysfunction and postural instability in PwPD [15, 71]. Additionally, balance training improves self-confidence while performing activities of daily living and reduces the fall rate [21], whereas gait training improves FOG, gait speed and step length, even months after the treatment [11, 14]. PwPD with STN-DBS implants might benefit from the same evidence observed in the general PD population. In addition, robust evidence suggests that other recommended PT treatments reduce PD motor symptom severity and improve motor function in PwPD [72–75]. Recently, various forms of aerobic training (treadmill walking, stationary cycling) have shown to slow motor progression in PwPD who are not yet on dopaminergic medication [76, 77].

On the other hand, the panellists agreed that massage or manual therapy should not be applied in chronically implanted patients, nor should robot-assisted gait training be recommended. While no evidence is currently available in PwPD treated with STN-DBS, a systematic review suggests that the evidence in the general PD population is limited and conflicting in some cases due to methodological concerns [78]. The European Physiotherapy Guideline for Parkinson's disease released a weak recommendation for using massage or manual therapy to reduce pain and muscular spasms, but highlighted the need to always combine it with other types of interventions as no evidence supports their use to improve physical and functional performance [23]. Conversely, the literature reports encouraging results [38, 40–42] of robot-assisted gait training, including in PwPD [79].

Rehabilitative considerations

In PwPD under STN-DBS treatment, motor [80, 81] and functional [82] strategies established in years of disease need to be readapted after the rapid changes induced by the stimulation. This requires the active involvement of the patient in a rehabilitation pathway to optimize the benefits of DBS. For example, pathological movement patterns typical of gait in PD [83] need to be gradually adapted to improve the mobility achieved by STN-DBS [68]. Additionally, since STN-DBS is a symptomatic but not resolutive treatment, PwPD receiving STN-DBS might need PT treatment during their lifetime. It was proposed that general motor rehabilitation principles studied for PwPD, such as personalizing motor strategies and applying motor learning techniques (e.g., repetition, task-specific training) [84], are applicable to those PwPD undergoing DBS [68]. However, some differences from the general PD population critical for PT programs might be considered:

I. *Pre-surgery characteristics of the patients*. PwPD candidates for STN-DBS surgery have a confirmed diagnosis of idiopathic PD, are young (younger than 69 years but may be older) and have no or little cognitive dysfunction [69, 85]. From a pharmacological point of view, these patients strongly respond to dopamine medication and have complications of levodopa therapy (e.g., dyskinesias, on–off fluctuations) [85, 86]. These criteria create a particular subgroup of the PD population, whose characteristics must be considered when planning PT interventions.

II. *Actual clinical characteristics of the patients*. A new, DBS-induced phenotype of PD was proposed, where tremor, rigidity, bradykinesia, on–off fluctuations and dyskinesias are well-controlled, but gait impairments, postural instability and abnormalities are still present [49]. Therefore, these should be the primary targets of PT interventions. In addition, stimulation-induced side effects need to be considered, such as dysphagia [3] and speech disorders (e.g., dysarthria) [87], cognitive (e.g., alteration of verbal fluency) [88, 89], psychological (e.g., impulsivity, depression) [90] and autonomic (e.g., constipation, swallowing) [90, 91] impairments. Besides motor rehabilitation, also other rehabilitative health professions [91] (e.g., speech therapy, occupational therapy, neuropsychology) could be involved and treatment tested.

III. *Presence of hardware*. A systematic review of hardware-related complications of DBS reported that lead migration or dislocation (0–19% of interventions) and fracture or failure of some parts of the DBS system (0–15% of interventions) are among the most common complications after DBS surgery [57, 92]. Therefore, although PT programs appear to be safe, a more intensive research program must consider hardware presence and frailty. In addition, the use of any physical forces (e.g., magnetic fields) that could interfere with DBS components should be avoided.

IV. *Interaction between stimulation and PT*. In light of the opportunities given by advanced DBS technologies [93, 94] such as adaptive DBS [95], it is likely that patients might need specific DBS programming while undergoing PT sessions to increase their performance and optimize benefits. This should be a further research topic to be considered as physiotherapists and DBS experts interact to develop effective and personalized rehabilitation programs.

Limitations

The panel conclusions should not be viewed as a replacement for clinical judgment or original research; rather, our results are relevant mostly in terms of future research directions, which will foster the development of the field of rehabilitation after STN-DBS in PwPD. Indeed, they are based on the collective expertise of a panel of experts who can draw on both their personal experience and scientific knowledge—even more so that our panel was gender- and nation- imbalanced (majority was male, and all experts coming from North America or Europe). Consensus-based results provide only a level 4 evidence being expert opinions [96, 97], which represents the lowest level of evidence [98]. Also, one should consider that our panel was geographically. More discussion and empirical evidence coming from methodologically precise studies (e.g., RCTs) are needed to support the feasibility of our results, especially considering that other common stimulation targets (e.g., the GPi) were not considered in this study.

Conclusion

Despite the limited, low-quality knowledge currently available on the role of PT in PwPD and STN-DBS, the panellists agreed that PT could improve the motor symptoms and quality of life of these patients and should be considered as part of management in the form of conventional PT, as part of the management guidelines. In conclusion, the PT is a safe intervention that can prescribed to PwPD receiving STN-DBS to maximize clinical improvements. Even though providing only level 4 evidence, this Delphi consensus represents a call to both the motor rehabilitation (but also occupational, speech and neuropsychological) and DBS community to start working and interacting to deepen this field of research. Well-designed and well-performed clinical trials (e.g., blinded RCT) could provide high-level evidence for PT, for example verifying whether current guidelines are applicable to this population or whether specific treatments can be of support clinical care, which for years has been relegated to the personal expertise of physical therapists despite the increasing number of PwPD implanted with STN-DBS.

Abbreviations

DBS	Deep brain stimulation
PD	Parkinson's disease
STN	Subthalamic nucleus
STN-DBS	Deep brain stimulation of the subthalamic nucleus
GPi	Globus pallidus internus
GPi-DBS	Deep brain stimulation of globus pallidus internus
FOG	Freezing of gait
PT	Physical therapy
PwPD	People with Parkinson's disease
SC	Steering committee
EP	Experts panel
UPDRS	Unified Parkinson's Disease Rating Scale
MDS-UPDRS	Movement Disorder Society—Unified Parkinson's disease rating scale
TUG	Timed up and go
BBS	Berg balance scale
Mini-BESTest	Mini Balance Evaluation Systems Test
FIM	Functional Independence Measure
PDQ-39	Parkinson's Disease Questionnaire—39

Supplementary Information

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Additional file 1.

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Author contributions

M.G., F.L., M.S., A.P., N.M., and R.D. performed the conceptualization. M.G., S.M., T.B., N.V.M., F.L., M.S., A.P., N.M., R.D., A.S., A.F., A.A.K., A.M.L., C.H., E.M., J.V., J.K.K., K.D.F., L.T., S.O., M.S.O., P.L., V.V.V., and Y.T performed the investigation. M.G. and S.M. drafted and wrote the main manuscript text. M.G., S.M., and N.V.M. performed the experimental data acquisition and statistical analysis. M.G. prepared the result visualization. A.P. and S.M. were responsible for validation, reviewing, and editing the original work. M.G., S.M., T.B., N.V.M., F.L., M.S., A.P., N.M., R.D., A.S., A.F., A.A.K., A.M.L., C.H., E.M., J.V., J.K.K., K.D.F., L.T., S.O., M.S.O., P.L., V.V.V., and Y.T reviewed and edited the original work. All authors read and approved the submitted version of the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

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