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ORIGINAL ARTICLE

Cost-utility analysis of a coadjutant telemedicine intervention for fall prevention in Parkinson's disease

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Abstract

Background and purpose: Adopting telemedicine (TM) enables improved access to specialized care and reduces barriers. The aim was to assess the cost-utility of a coadjutant multidisciplinary TM programme for fall prevention compared to standard in-office visits for individuals with Parkinson's disease (PD).

Methods: This was an 8-month single-blind randomized controlled trial. TM and control groups received in-office visits and standard management care at baseline, 4 and 8 months. In addition, the TM group received remote multidisciplinary visits for 4 months. Gait, motor and non-motor symptoms, daily living activities, balance and frailty were measured using PD-recommended rating scales and wearable sensors. Clinical characteristics were compared at each visit using baseline scores, gender and age as covariates. The incremental cost-effectiveness ratio (ICER) and quality-adjusted life years (QALYs) were calculated at each visit.

Results: Fifty patients were included: 25 patients in the TM group (48% males, mean age 71.1 ± 9.0 years) and 25 patients in the control group (52% males, mean age 69.2 ± 9.4 years). Compared to controls, in the TM group similar QALYs were found but, in contrast, significant improvements in daily living activities, depression, apathy, freezing of gait, balance, quality of life and frailty (all p values <0.05). The use of coadjutant TM intervention in addition to in-office visits was efficient for depression, apathy, freezing of gait, balance and frailty with ICERs, ranging from 91.55 € for non-motor symptoms to 1677.4 € for frailty.

Conclusions: Telemedicine could be considered an efficient coadjutant intervention for PD, especially for non-motor symptoms, enhancing health outcomes and accessibility.

KEYWORDS
cost-effectiveness analysis, health expenditures, Parkinson's disease, telemedicine

INTRODUCTION

In recent years, Parkinson's disease (PD) has seen a surge in both prevalence and disability rates, making it a prominent contributor to the global burden of disability [1]. Effective management of PD relies on personalized care and treatment adjustments, mainly based on in-office assessments, whilst tracking symptoms at home remains challenging [2–4]. However, the emergence of telemedicine (TM) during the COVID-19 pandemic has revolutionized the management of PD [3].

Telemedicine provides innovative approaches, enabling regular objective evaluation of symptoms and treatment adherence in real-world settings. It also improves access to specialized care across various domains, including telemonitoring, teleconsultation, tele-education and tele-treatment [5]. By overcoming distance barriers, TM improves time constraints, travel barriers (e.g., disability), financial burdens for patients, and patient and physician satisfaction, and enhances patients' health-related quality of life (HR-QoL), comparable to in-office visits [6]. Amongst PD symptomatology, falls are associated with increased injuries and comorbidity, high levels of caregiver stress, social isolation and institutionalization, with a significant impact on patients' HR-QoL and healthcare systems [7]. Whilst a growing body of evidence supports the feasibility and effectiveness of TM for PD care, evaluating its cost-utility is crucial for sustainable healthcare delivery. To address the limitations in the existing literature [1,5,8–16] the aim was to assess the cost-utility of a coadjutant multidisciplinary TM programme for fall prevention compared to standard in-office visits for individuals with PD.

MATERIALS AND METHODS

Study design and participants

This was an 8-month, single-blind, randomized, case–control study registered on clinicalTrials.gov (identifier NCT04694443). The trial protocol has been previously published [17]. Reporting followed the Consolidated Standards of Reporting Trials (CONSORT) and Consolidated Health Economic Evaluation Reporting Standards (CHEERS) [18,19].

The multidisciplinary team was composed of two movement disorder neurologists, two movement disorder nurses, one occupational therapist, one physical therapist, one psychologist and four computer engineers (all affiliated with the University of Burgos, Spain). Patients were recruited from the Movement Disorder Unit at Hospital Universitario Burgos from June 2020 to June 2022. We included non-demented, ambulatory patients aged ≥18 years old, diagnosed with idiopathic PD based on the Movement Disorder Society (MDS) criteria [20,21], with a medium-to-high risk of falling (with a history of at least one fall over the past 6 months, and a Hoehn and Yahr [22] stage ≤3), a Montreal Cognitive Assessment score ≥18 [23] and with one of two additional criteria, including freezing of gait (FoG) or self-selected gait speed <1.1 m/s [24]. Patients under treatment with physical or occupational therapy were excluded, as well as those with severe psychiatric or cerebrovascular diseases, severe traumatic brain injuries, severe orthopaedic lower limb or spine disorders, peripheral neuropathy, rheumatological disease or other systemic diseases, and sensory deficiencies that, according to the investigator's judgement, would interfere with the study.

Ethical considerations

This study was conducted according to the standards for good clinical practice, the fundamental ethical principles established in the Declaration of Helsinki and the Oviedo Convention, and the requirements of Spanish legislation in the research field. This study was approved by the Institutional Review Board (Comité Ético Complejo Universitario Burgos y Soria, certificate number CEIC 2112, 29 October 2019). All patients read and signed the informed consent form before participating.

Randomization

Randomization was performed using a block gender randomization Excel calculator providing an equal number of males and females (1:1) participating in each group: TM group (in-office visits plus coadjutant TM multidisciplinary intervention); control group (in-office visits).

Study procedures and interventions

Our study consisted of two phases. In the first phase (baseline–fourth month), short-term benefits were assessed. All participants were evaluated in the office at baseline (V0) and 4 months (V1). For the TM group, the occupational therapist brought the equipment for videoconferencing to the patient's homes, set up the room for physical therapy, and evaluated the risk associated with performing different exercises based on the patient's capabilities and home environment. In the second phase (fifth–eighth month), long-term benefits were assessed. All patients allocated to the TM group discontinued the TM programme at the end of the fourth month. All patients received standard medical care provided by the movement disorder neurologist and nurse, with a final in-office visit at 8 months (V2).

In-office visits

At baseline, sociodemographic characteristics were collected, such as age, gender, years of education, living status (urban/rural), PD duration, PD treatments and history of falls (number, characteristics and location). Levodopa equivalent daily dose and dopamine agonist equivalent daily dose at each visit were calculated based on the literature [25], clinical rating scales were administered, and comprehensive physical and neurological examinations were performed, including adherence to consensus-based clinical practice recommendations for fall prevention in patients with PD [26]. Each in-office visit lasted approximately 90 min. If needed, fall prevention measures were implemented through pharmacological and non-pharmacological therapy adjustments, education, nutritional interventions and referrals to other physicians.

Virtual visits

The TM programme included tele-rehabilitation, neurologist and nurse telecare. Nurses were responsible for educating patients on health-related topics, such as nutrition, and collecting the information about fall risk factors, and the neurologists were responsible for clinical care management. The virtual visits with the neurologist and the nurse lasted for approximately 45 min. Tele-rehabilitation and occupational therapy included a personalized programme for each patient, lasting 45–60 min, all conducted in real time. During the tele-rehabilitation sessions, the occupational therapist guided the patients through various exercises and provided education on environmental risks, lifestyle modifications and fall prevention strategies. Sessions commenced with a preparatory physical warm-up involving a series of mobility exercises and stretches, followed by exercises designed for improving body posture, mobility, transfers, axial stiffness, freezing, gait disturbances, balance and coordination. These exercises were based on cognitive sensory–motor training (Perfetti method) [27,28] adhered to a repetitive sensory and motor re-learning protocol. Different exercises were accommodated based on individual patient capabilities, including kinaesthetic tasks (ranging from simple to complex movement discrimination) paired with the corresponding cognitive function (recognition of the direction and distance of the movement), coordination tasks and the corresponding executive cognitive function [27,28].

Assessments

Safety

At each virtual or in-office visit, we measured safety, which was defined as a significant, increased number of falls compared to the previous visit or falls-related comorbidities.

In-office assessments

The assessments were performed during the ON state at V0, V1 and V2. Rating scales used in this study and their interpretation have been described previously [17]. The severity of PD motor and non-motor symptoms was assessed using the MDS Unified Parkinson's Disease Rating Scale (MDS-UPDRS), [29] Non-Motor Symptoms Scale (NMSS), [30]Parkinson's Disease Sleep Scale (PDSS) [31], Beck Depression Inventory II (BDI-II) [32] and Lille Apathy Rating Scale (LARS) [33]. HR-QoL was assessed using the European Health Interview Survey Quality of Life eight-item index (EUROHIS-QOL8) [34] (overall QoL, general health, activities of daily living, self-esteem, social relationships, energy, finances and home) and the EuroQol-5D (EQ-5D) questionnaire (mobility, self-care, usual activities, pain or discomfort, and anxiety or depression) [35]. Comorbidities were assessed using the Cumulative Illness Rating Scale for Geriatrics [36]. Gait and postural balance impairments were assessed using the Mini Balance Evaluation Systems Test (Mini-BESTest) [37] and Freezing of Gait Questionnaire (FOGQ) [38]. Frailty was assessed using the Fried Frailty Index (FRIED) [39]. Information about the number of falls over the last month was provided by the patient/caregiver and recorded at each visit.

Remote assessments

STAT-ON™ [40,41], a wearable, single, validated sensor located at the waist, was used to monitor PD ON and OFF states, bradykinesia index (based on the fluidity of movement), dyskinesia, FoG and gait parameters (speed of stride, cadence, time walking, step length, number of steps) in all patients, for 1 week a month throughout the study (8 months). This information was used for PD management and blind assessments in both groups.

Cost-utility data

Healthcare expenditures were assessed using questionnaires on direct medical and non-medical costs. Costs were calculated by multiplying the amount of each resource used by its unit cost in euros (€). Medical costs were collected from patient medical records and external medical services information provided by patient/caregiver reports, which included costs for medical visits, hospitalization, and the products and services used for prevention, diagnosis or treatment. Total medical costs were calculated by multiplying the number of medical and paramedical visits, emergency room visits, admissions, durations and diagnostic procedures performed over 4 months by their respective unit costs. These unit costs were obtained from the Diagnosis-Related Groups Classification System for healthcare costs, approved by the Spanish Ministry of Health and the finance department of the Hospital Universitario Burgos (Spain) [42]. Pharmacological costs, including antiparkinsonian and other treatments, were estimated by multiplying the daily medication cost by 120 days [43]. Non-medical costs included travelling to medical centres, social services, paid caregivers, accommodation adaptations and special equipment, based on patient/caregiver reports. These costs were calculated by multiplying the number of events/procedures over 4 months by their respective unit costs. Paid caregiver costs were calculated by multiplying the weekly hours of home help by the hourly rate over 4 months. The cost of STAT-ON™

for 8 months per patient for both groups, the additional costs for videoconferencing, which included physiotherapy and occupational therapy, and neurologist and nurse visits for the TM group were included. Sensors and videoconferencing equipment costs were allocated to V0. Total costs were calculated as the median (interquartile range) of the sum of direct medical and non-medical costs over 1 year.

During in-office visits, patients completed the EQ-5D questionnaire. Quality-adjusted life years (QALYs) were calculated based on the EQ-5D measures established for the Spanish population, where zero indicates death and 1 indicates perfect health. QALY is the standard measure for valuing health outcomes, with one QALY defined as the addition of 1 year of healthy life expectancy. We used the incremental cost-effectiveness ratio (ICER) for cost-utility analyses, which indicates the cost per unit of effectiveness when one therapeutic option is chosen instead of another. ICERs were calculated based on the gained QALYs and the improvement in each clinical rating scale from the TM intervention and the comparator (control group) at V1 and V2 (for more detailed information, see Appendix S1).

$$\text{ICER} = \frac{\text{median total costs }[\text{TM}](\text{Dif 4m} - \text{baseline}) - \text{median total costs }[\text{control group}](\text{Dif 4m} - \text{baseline})}{\text{median score rating scale }[\text{TM}](\text{Dif 4m} - \text{baseline}) - \text{median score rating scale }[\text{control group}](\text{Dif 4m} - \text{baseline})}$$

where Dif 4m is the difference at the 4-month visit. The same formula was applied at the 8-month visit.

Outcome measures

Primary outcome measures for the cost-utility analysis were QALY ICERs, the ICERs for each corresponding clinical rating scale, and the comparison of direct and non-direct costs between the TM and control groups at V1. Secondary outcome measures were the comparison of clinical rating scores and QALYs between the TM and control groups at V1 and V2.

Sample size and statistical analyses

The sample size was estimated using the Epidat® 4.1 statistical software at 25 patients per group, with an 80% power (5% probability of type 1 error) to detect a reduction in the incidence of falls (25%–60% in the intervention group, and 2% in the control group) and a 9% dropout rate, with a confidence level of 95%.

The normality of the variables was evaluated using the Kolmogorov–Smirnov test. Descriptive analyses of participant characteristics are presented as frequencies (percentages) and mean/median values, along with corresponding standard deviation or interquartile range. Differences between groups were assessed using the independent *t* test for normally distributed variables and the Mann–Whitney *U* test for non-normally distributed variables. Categorical variables were analysed using the chi-squared test or Fisher's exact test. Group comparisons at V0 were performed using Bonferroni corrections for multiple comparisons. To compare the differences between groups at V1 and V2, non-parametric analysis of covariance tests were used, including age, gender and baseline rating scores as covariates. Statistical analyses were performed using the SPSS V.29.0 (IBM SPSS Statistics for Windows, Armonk, NY, USA) software, with the significance level set at 0.05.

RESULTS

Fifty-three patients were screened, and 50 were included in the study (Figure 1), with 25 patients assigned to each group. The TM group consisted of 12 men (48%), with a mean age of 71.1 ± 9.0 years. In this group, three patients were on second-line therapies for advanced PD (12%), one patient was on levodopa gel (4%) and two patients on apomorphine pumps (8%). The control group consisted of 13 men (52%), with a mean age of 69.2 ± 9.4 years. In this group, five patients were on second-line therapies for advanced PD, three on levodopa gel (12%) and two on apomorphine pumps (8%). None of the patients were undergoing treatment with deep brain stimulation. A total of 42 patients (84%) completed the study (Figure 1).

At baseline, the TM and control groups had no significant differences regarding sociodemographics, clinical characteristics, PD severity and travelling distances. However, there was a trend indicating higher participation of patients living in rural areas in the TM group compared to the control group (Table 1).

Clinical outcomes

At V1, the TM group showed significant improvements in MDS-UPDRS II, LARS, BDI-II, FRIED, FOGQ, Mini-BESTest and EUROHIS-QOL scores compared to the control group. Additionally, there was a trend towards improvement in the sensor-based walking time, number of steps per day and bradykinesia index in the TM group. At V2, residual benefits persisted for BDI-II, LARS, PDSS, FRIED, Mini-BESTest and EUROHIS-QOL scores. There were no significant differences in QALYs between the TM and control groups at V1 and V2 (Appendix S1). In terms of safety, no significant events were reported.

Cost-utility outcomes

Total and direct costs were higher in the TM group compared to the control group ($p = 0.02$), due to higher total and direct costs in the

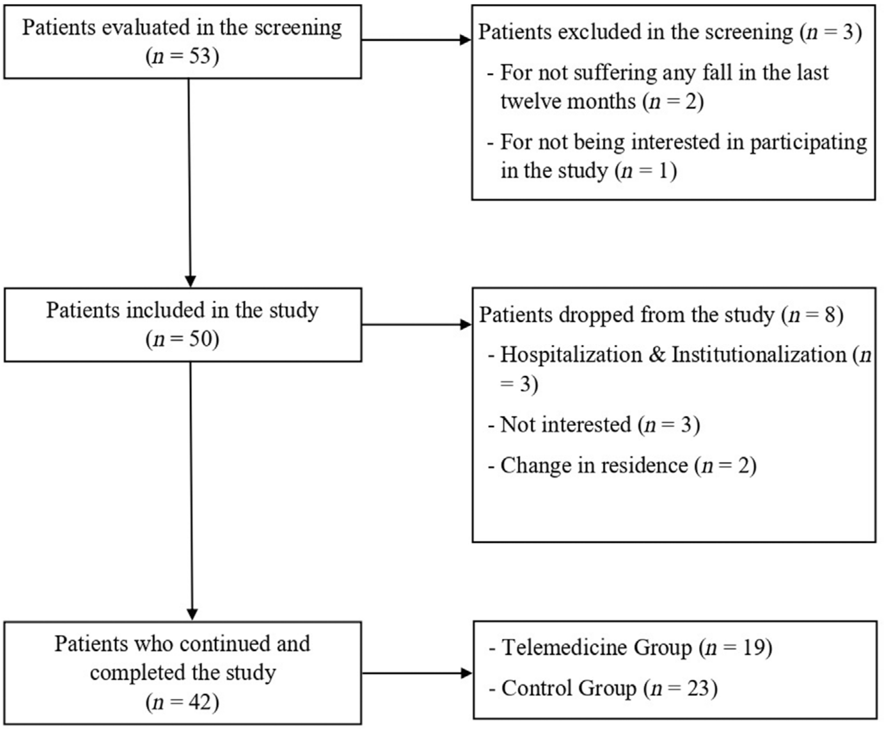

FIGURE 1 Patients' flow of participation.

TM group at V0 (p=0.003, respectively). Detailed information on costs is included in Table 2 and Figure 2. Considering the clinical outcomes where significant differences were observed, TM was efficient for depression, apathy, FoG, balance and frailty interventions, with ICERs ranging from 91.55 € for NMS to 1677.4 € for frailty (Table 3).

DISCUSSION

This study investigated the clinical benefits and cost-utility of a coadjutant multidisciplinary TM intervention for fall prevention compared with standard in-office PD visits. Overall, TM interventions were efficient for FoG, balance, frailty and NMSS. Moreover, based on the sensor-based measurements, we observed a trend for increased physical activity in the TM group, providing valuable ecological information and lifestyle behaviour modifications. Regarding safety, improvement in gait and physical activity was not associated with increased falls.

Our findings indicate that, whilst the initial investment in TM equipment and the work-up tests led to higher total and direct costs in the TM group at V0, the TM intervention efficiently managed gait and NMSS without significantly impacting costs at V1 and V2.

Cost-utility of health interventions does not mean a reduction of costs after implementing a health intervention, as substantial health improvements often come with increased costs or reducing the time allocated for visits. Of note, in a systematic review in 2022 on the determinants of the cost-effectiveness of TM, the authors revealed that randomized trials with more rigorous economic evaluations have not shown favourable results for TM interventions, indicating that the selection of the control group is particularly challenging [44]. In our study, remote assessments with STAT-ON™ were used, providing, on the one hand, blind information about motor symptoms and physical activity but, on the other hand, useful ecological information, which was used for better PD management in both groups. In consequence, the design of our study is quite challenging because even the control group benefitted from some aspects of TM, resulting in a non 'pure' control group. Supporting our design with the advantages of getting ecological information and the growing use of wearables in clinical practice, the non-use of this additional remote information could be considered disadvantageous for the study and perhaps unethical for the control group.

Interestingly, a trend for increased FoG was observed based on the STAT-ON™ information in the TM group compared to the information provided by the FOGQ. In this regard, there is no compelling explanation, and possibilities include a rater placebo effect for the FOGQ, limited statistical power, or, in contrast, higher sensitivity with STAT-ON™ for freezing episodes due to increased physical activity in the TM group compared to controls.

Regarding HR-QoL, using generic quality-of-life surveys such as the EQ-5D is advantageous because they cover multiple aspects of health and can be used in different diseases. Our study did not observe any significant differences in QALYs between the TM and control groups, in contrast to the information provided by EUROHIS-QOL. To explain this discrepancy, the limited accuracy of QALYs could be considered, including its floor and ceiling effects, and limited ability to detect clinically relevant changes in outcomes [45] or the control group's characteristics in our study.

Consistent with our results, previous studies have suggested that TM interventions may improve PD management [46–49]. However, the existing evidence regarding TM being more or less effective than

TABLE 1 Comparison between telemedicine and control groups at baseline.

	Control group (*n* = 25)	Telemedicine group (*n* = 25)	*p* value
Age	69.2 (9.4)	71.1 (9.0)	0.45
Gender (males, %)	13 (52)	12 (48)	0.50
Education (years)	11.6 (3.9)	9.8 (5.5)	0.18
MoCA	23.6 (4.1)	22.8 (3.5)	0.49
Rural (%)	7 (28)	10 (40)	0.27
Distance to medical centre (km)	66.0 (42.0; 616.0)	78.0 (42.0; 426.0)	0.54
PD duration (years)	10.2 (5.3)	12.9 (5.5)	0.17
Hoehn and Yahr stage	2.0 (2.0; 2.0)	2.0 (2.0; 2.0)	1.00
LEDD	1308.4 (607.9)	1325.6 (599.8)	0.92
BMI	26.1 (2.9)	25.6 (3.3)	0.64
NMSS	73.4 (28.7)	73.0 (31.8)	0.97
LARS	−23.0 (−31.0; −15.0)	−25.0 (−27.5; 19.0)	0.58
BDI-II	13.9 (9.0)	14.1 (8.5)	0.98
PDSS	94.2 (26.3)	102.3 (18.6)	0.48
CIRS-G	5.2 (3.6)	5.0 (2.13)	0.78
Number of falls over the last month	1.0 (0.0; 2.0)	1.0 (0.0; 1.5)	0.14
FOGQ	10.6 (5.3)	12.1 (6.1)	0.38
Mini-BESTest	21.8 (6.0)	17.8 (6.3)	0.02
FRIED	0.50 (0.00; 2.00)	2.00 (0.50; 3.00)	0.05
Non-frail (%)	17 (68.0)	12 (48.0)	0.05
Frail (%)	8 (32.0)	13 (52.0)	0.10
MDS-UPDRS	13.1 (5.4)	13.0 (6.1)	0.76
MDS-UPDRS I	16.5 (6.5)	18.1 (7.0)	0.39
MDS-UPDRS II	40.9 (11.2)	43.2 (11.7)	0.48
MDS-UPDRS III	7.2 (3.7)	7.1 (4.5)	0.94
MDS-UPDRS IV			
STAT-ON™	84.3 (47.9; 140.0)	67.0 (42.55; 101.5)	0.21
Average walking time, min/day	9289.6 (5419.0; 14341.9)	7363.0 (4047.0; 11081.8)	0.20
Number of steps/day	7.9 (7.5; 8.1)	6.7 (6.4; 8.3)	0.50
Bradykinesia index	1.3 (0.4; 6.3)	2.8 (0.9; 8.3)	0.25
Average number of episodes of FoG/day	34.2 (13.8; 42.3)	26.8 (17.7; 33.6)	0.34
Average % on time/day over the last week			
EUROHIS-QOL	3.4 (0.6)	3.3 (0.5)	0.67
QALYs	0.60 (80.51; 0.83)	0.74 (0.51; 0.84)	0.40

Note: Bonferroni *p* value corrected: <0.001. All variables are expressed in mean (standard deviation), except for distance to medical centre and Hoehn and Yahr stage in median (interquartile range), and gender and rural in percentages. Travel distance indicates the distance from patients' home to the clinical centre.

Abbreviations: BDI-II, Beck Depression Inventory II; BMI, body mass index; CIRS-G, Cumulative Illness Rating Scale for Geriatrics; EUROHIS-QOL8, European Health Interview Survey Quality of Life 8-item index; FoG, freezing of gait; FOGQ, Freezing of Gait Questionnaire; FRIED, Fried Frailty Index; LARS, Lille Apathy Rating Scale; LEDD, levodopa equivalent daily dose; MDS-UPDRS, Movement Disorder Society Unified Parkinson's Disease Rating Scale; Mini-BESTest, Mini Balance Evaluation Systems Test; MoCA, Montreal Cognitive Assessment; NMSS, Non-Motor Symptoms Scale; PD, Parkinson's disease; PDSS, Parkinson's Disease Sleep Scale; QALYs, quality-adjusted life years.

in-office care is limited and inconclusive [50–52]. Many patients may prefer a combination of TM and in-office care [53] as it is feasible, safe, increases empathy and reduces the travel burden [1,54,55]. In this regard, our study further supports the feasibility, societal perspective and safety of this combined approach for patient-centred care interventions, as well as education for lifestyle behaviour modifications. However, it was not possible to evaluate the difference in travel time due to the combined nature of our intervention, nor the out-of-pocket expenses of patients and the employer costs of sick leave from work (absenteeism) and lowered productivity whilst at work (presenteeism), as these data were not collected [56].

In order to extrapolate our results to other healthcare settings, other factors should be taken into account such as the country-specific legislation for TM reimbursement, the density of physicians, the technological infrastructure, including digital literacy, and the gross domestic product devoted to healthcare expenditure [44].

TABLE 2 Comparison of the median total, direct and indirect costs.

	Baseline			V1 (4 months)			V2 (8 months)		
	Control group	**Telemedicine group**	***p* value**	**Control group**	**Telemedicine group**	***p* value**	**Control group**	**Telemedicine group**	***p* value**
Total costs (€)	2212 (1.773; 4.809)	4737 (4.132; 6.003)	0.003	2080 (1.325; 4.5780)	2627 (1.607; 4.114)	0.34	2.045 (1.068; 4.173)	2.683 (1.919; 4.148)	0.18
Direct costs (€)	2.114 (1.761; 4.739)	4274 (3.464; 5.793)	0.003	1.895 (1.1445; 4.565)	1.808 (1.127; 3.387)	0.99	1.925 (1.015; 4.158)	1.926 (1.428; 2.926)	0.58
Videoconferencing equipment (€)	–	1883 (1.883; 1.883)	<0.0001	*	*	*	*	*	*
sensors (€)	400 (400; 400)	400 (400; 400)	–						
Pharmacological treatment (€)	1.130 (786; 3.311)	938 (642; 1.529)	0.53	1213 (797; 2.32)	1.144 (838; 2.02)	0.75	1.319 (786; 1.856)	978 (798; 2.022)	0.84
Non-pharmacological treatment (€)	0.00 (0.00; 0.00)	0.00 (0.00; 40.00)	0.12	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.32	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.76
Work-up tests (€)	48 (0.00; 124)	208 (0; 423)	0.02	104 (0; 157)	1.144 (838; 2.02)	0.82	104 (0; 229)	104 (0; 249)	0.81
In-office visits (€)	336 (205; 496)	316 (149; 737)	0.80	301 (167; 518)	114 (0; 406)	0.82	290 (202; 358)	384 (202; 739)	0.38
Number of neurologist visits	1 (1.00; 2.00)	1 (1.00; 3.00)	0.54	1 (1; 1)	5 (5;5)	<0.0001	1 (1.00; 1.00)	1 (1.00; 2.00)	0.15
Number of non-neurological visits	3 (2; 4)	3 (1; 7)	0.43	2 (2; 4)	5 (5; 5)	0.54	3 (2; 5)	4 (2; 7)	0.26
Hospital admissions (€)	0 (0; 0)	0 (0 1)	0.12	0 (0; 0)	3 (2; 5)	0.72	0 (0; 0)	0 (9;795)	0.53
Indirect costs (€)	90 (32; 251)	210 (38; 982)	0.14	22 (12; 366)	0 (0; 0)	0.04	15 (11; 114)	164 (28; 977)	0.01
Travel to medical centre (€)	14 (11; 36)	20 (14; 39)	0.06	14 (11; 24)	168 (38; 994)	0.05	14 (11; 41)	28 (13; 70)	0.08
Others (€)	60 (0; 288)	54 (0; 694)	0.99	54 (0.0; 352)	54 (0; 960)	0.80	54 (0.0; 288)	54 (0; 960)	0.50

Note: The time periods used for assessing costs were the 4 months preceding each visit.

*Videoconferencing equipment and sensor costs were attributed to V0 exclusively.

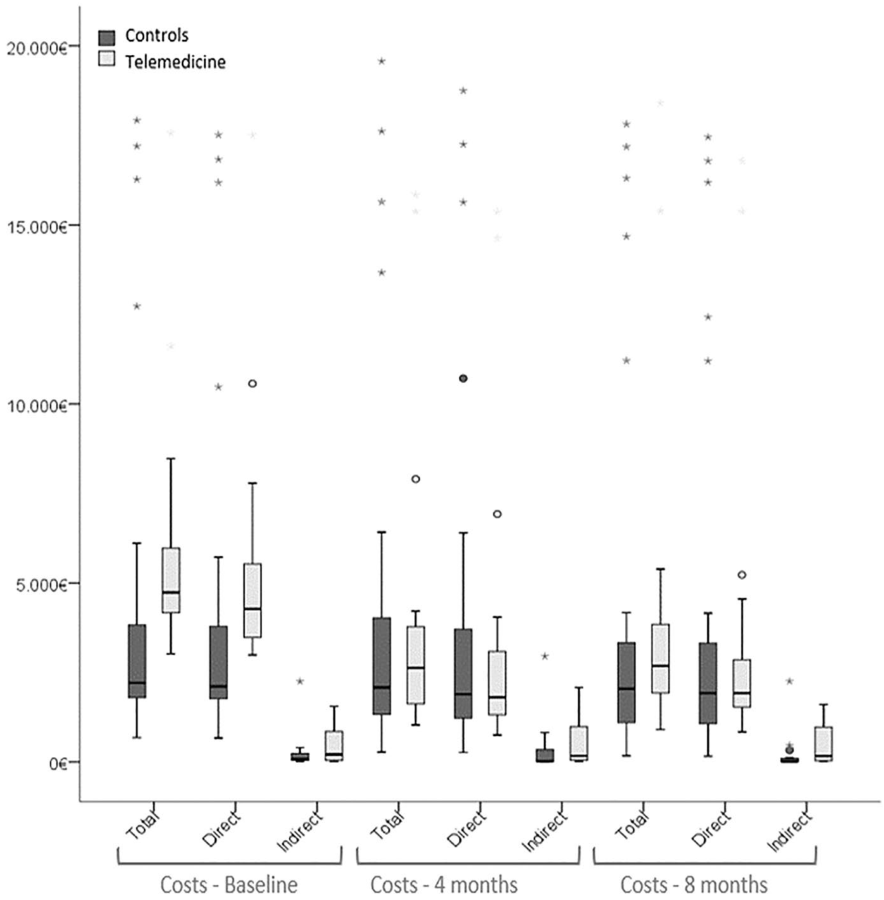

FIGURE 2 This graph represents the total, direct and indirect costs of the telemedicine and control groups.

TABLE 3 ICERs for telemedicine implementation: costs (€) per unit of the rating scale.

Rating scale	4 month visit	8 month visit
BDI-II	454.50	568.13
LARS	454.50	454.50
FOGQ	1136.26	1136.26
Mini-BESTest	−568.13	−454.50
FRIED	1677.40	1546.71
PDSS	−495.19	−230.39
NMSS	91.55	129.21
MDS-UPDRS II	535.42	1252.73
EUROHIS-QOL	−588.28	−909.94

Note: The incremental cost-effectiveness ratios (ICERs) were calculated for the rating scales where significant clinical differences were observed.

Abbreviations: BDI-II, Beck Depression Inventory II; EUROHIS-QOL8, European Health Interview Survey Quality of Life 8-item index; FOGQ, Freezing of Gait Questionnaire; FRIED, Fried Frailty Index; LARS, Lille Apathy Rating Scale; MDS-UPDRS II, Movement Disorder Society Unified Parkinson's Disease Rating Scale, activities of daily living; Mini-BESTest, Mini Balance Evaluation Systems Test; NMSS, Non-Motor Symptoms Scale; PDSS, Parkinson's Disease Sleep Scale.

In this regard, the threshold to pay more money for health gains varies. Whilst there is a general consensus for QALYs in Western countries ranging from England and Wales £20,000–30,000 per QALY to $50,000 per QALY in the United States [57], established limits of ICERs for motor and especially NMSS in PD are lacking. For Spain, considering the Spanish gross domestic product devoted for healthcare expenditure was US$29.675 in 2021 [58], the estimated ICERs for gait and NMSS improvement obtained in our study could be considered within appropriate limits in PD [45,59,60]. Of note, our study's ICERs attributed to NMSS were remarkably low, indicating that TM could be considered an efficient tool to improve NMSS in PD.

Several limitations should be considered when interpreting our results. The single-blind design of the study and reliance on self-reported measures, especially for NMSS during the COVID-19 pandemic, which was associated with isolation, could introduce bias. Additionally, the relatively short duration of the intervention, the reduced number of falls in both groups and the small sample size might not have captured the long-term cost-effectiveness and sustainability of the intervention. Likewise, different exposure times (number of neurologist and nurse visits) were different in the TM and control groups due to the design of our study as a 'coadjutant intervention', which probably impacted the study results. Cost-utility findings may vary depending on country-specific health settings and priorities, limiting the generalizability of our results. Future studies should focus on identifying the specific components of TM that contribute most to cost-utility analyses, which could help refine and optimize TM programmes for PD management.

In conclusion, TM is a potentially efficient approach for improving NMS and some gait features in patients with PD. However, the higher initial costs associated with TM interventions compared to in-office care highlight the need for further research to explore long-term sustainability. Future actions include the optimization of TM interventions focusing on larger sample sizes and extended follow-up periods.

AUTHOR CONTRIBUTIONS

Esther Cubo: Conceptualization (lead); writing—original draft (lead); formal analysis (lead); writing—review and editing (equal). Mohammad Rohani: Writing—review and editing (equal). Negin Eissazade: Writing—review and editing (equal). Álvaro Garcia-Bustillo: Conceptualization (supporting); writing—original draft (supporting); writing—review and editing (equal). José Miguel Ramírez-Sanz: Methodology (lead); writing—review and editing (equal). José Luis Garrido-Labrador: Methodology (lead); writing—review and editing (equal). Alicia Olivares-Gil: Methodology (lead); writing—review and editing (equal). Florita Valiñas-Sieiro Rn: Methodology (lead); writing—review and editing (equal). Marta Allende-Río Rn: Methodology (lead); writing—review and editing (equal). Josefa Gonzalez-Santos: Methodology (lead); writing—review and editing (equal). Jerónimo Javier Gonzalez-Bernal: Methodology (lead); writing—review and editing (equal). Sara Calvo-Simal: formal analysis (supporting); writing—review and editing (equal). José Trejo: Methodology (lead); writing—review and editing (equal). José Francisco Diez-Pastor: Methodology (lead); writing—review and editing (equal). David García-García: Methodology (lead); writing—review and editing (equal). Álvar Arnaiz-González: Methodology (lead); writing—review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The abstract information is available: https://explore.openaire.eu/search/dataset?pid=10.5281%2Fzenodo.10418460.

DATA SOURCE CODE

All the source codes for the tele-rehabilitation system are publicly available on Github: https://github.com/admirable-ubu/FIS-FBIS/.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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