

Gait Parameter Improvement and Influencing Factors in Patients with Parkinson's Disease under a Regional Specialty Alliance Model

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Abstract

Objective: To evaluate the effects of a regional specialist collaborative network management model centered on provincial Parkinson's disease (PD) centers on spatiotemporal gait parameters and medical costs in PD patients, and to explore the assessment value of objective gait indicators and their health economic implications in the chronic disease management of PD.

Methods: A multicenter, prospective cohort study was conducted. A total of 366 PD patients treated at the Second Affiliated Hospital of Nanchang University between January 2022 and January 2024 were enrolled. Patients were assigned to a standardized management group ($n = 192$) or a conventional treatment group ($n = 174$) based on residential coverage within four designated regional specialist alliance units in Jiangxi Province and willingness to undergo regular follow-up. The standardized management group received unified training from the provincial center, remote guidance, and multidisciplinary integrated management, whereas the conventional treatment group received routine outpatient follow-up. In both groups, spatiotemporal gait parameters—including gait speed, stride length, step frequency, double support phase, swing phase, and stride length variability—were collected using an inertial measurement unit system at baseline, month 6, and month 12. Repeated measures analysis of variance was performed to assess intervention effects, and Spearman rank correlation analysis was used to examine the associations between the Unified Parkinson's Disease Rating Scale Part III (UPDRS-III) improvement rate and spatiotemporal gait parameters. PD-related medical costs during 0–6 months and 7–12 months were also collected, encompassing medication costs and non-medication costs (fall-related injuries, rehabilitation, assistive devices, home care, and referrals).

Results: Significant time effects, group effects, and interaction effects were observed for gait speed, stride length, step frequency, double support phase, swing phase, and stride length variability ($p < 0.05$). Notably, for step frequency, while group effects and interaction effects were significant ($p < 0.001$), the time effect did not reach statistical significance ($p = 0.100$). In the standardized management group, step length, gait speed, stride length, and swing phase progressively increased, while double support phase and stride length variability progressively

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decreased; the conventional treatment group exhibited opposite or fluctuating trends. In the standardized management group, the UPDRS-III improvement rate was significantly correlated with stride length variability ($r = -0.738$), gait speed ($r = 0.707$), and stride length ($r = 0.690$). Although similar trends were observed in the conventional treatment group, the correlation coefficients were attenuated, indicating divergent gait-symptom transformation patterns. Total medical costs in the standardized management group increased gradually. Compared with the conventional treatment group, cost increments at month 6 and month 12 were reduced by 23.9% and 34.8%, respectively ($Z = -4.907$, $p < 0.001$; $Z = -8.447$, $p < 0.001$), with particularly pronounced reductions in non-medication costs (fall-related injuries and rehabilitation expenses).

Conclusion: A regional collaborative network management model centered on provincial specialist centers significantly improves gait stability and motor symptoms in PD patients, reduces fall-related medical expenditures through gait optimization, and demonstrates clear health economic advantages.

Keywords: Parkinson's disease; gait analysis; regional specialist alliance; standardized management; medical costs; inertial measurement unit

Introduction

Parkinson's disease (PD) is a common neurodegenerative disorder affecting middle-aged and older adults. Gait impairment, as one of its core motor symptoms, has been identified as a major contributor to disability and falls in patients with advanced disease^[1]. Epidemiological data indicate that approximately 70% of PD patients develop gait abnormalities in the middle to late stages of the disease, which may increase the risk of falls by 3- to 5-fold, with fracture rates reaching 20%–40%^[2,3]. As the disease progresses, the 5-year disability rate may rise above 60%, which could reduce quality of life and add to the socioeconomic burden. With demographic changes, the prevalence of PD has been increasing^[4,5], recent studies suggest that the global burden of PD continues to grow, with the total number of patients in China reaching approximately 5.08 million, associated deaths of 92,000, and disability-adjusted life years of approximately 2.16 million, posing considerable challenges to population health and social resources^[6,7].

Current clinical assessment of PD relies primarily on tools such as the Unified Parkinson's Disease Rating Scale (UPDRS). While these instruments may reflect overall motor function, they have limited sensitivity to subtle gait changes and are susceptible to the influence of examiner experience and the patient's immediate condition. The introduction of inertial measurement unit (IMU) technology offers a useful complement to

these limitations: by recording movement trajectories in real time through sensors, IMU may enable the objective quantification of functional activity levels and gait characteristics^[8,9]. The gait cycle refers to the complete process from the initial contact of one foot to the subsequent contact of the same foot, comprising two phases: stance and swing^[10]. In this study, the Timed Up and Go (TUG) test was used as the gait assessment protocol. This task simulates basic mobility patterns in daily activities and facilitates the acquisition of objective, quantifiable gait parameters for the evaluation of motor function in PD^[11–13].

Nevertheless, the clinical management of gait impairment in PD remains challenging. On the one hand, primary care institutions often lack systematic gait assessment tools and rehabilitation intervention capabilities, and patients frequently do not receive specialist care until severe freezing of gait or recurrent falls have developed, missing the window for early intervention. On the other hand, under traditional management models, gait rehabilitation training for PD patients often lacks standardized protocols and continuous supervision, resulting in low adherence to exercise prescriptions and difficulty maintaining therapeutic effects^[14]. Regional specialty alliances, as an important component of integrated healthcare delivery systems, may address these gaps through the downward transfer of technology from higher-level hospitals, standardized training, and remote guidance, thereby enabling the standardized and continuous management of

gait assessment and intervention. Against this background, the present study established a regional collaborative network centered on a provincial PD specialist center and involving four municipal tertiary hospitals, with the aim of evaluating the effects of a standardized management model on spatiotemporal gait parameters and medical costs in PD patients, and of providing evidence-based support for precise and economical long-term management of the disease.

Methods

Study design and participants

This was a multicenter, prospective cohort study conducted at the Second Affiliated Hospital of Nanchang University and four regional collaborative units (Yichun People's Hospital, Fuzhou People's Hospital, Jingdezhen First Hospital, and Yingtan People's Hospital) in Jiangxi Province. This study was approved by the Ethics Committee of the Second Affiliated Hospital of Nanchang University (Approval No. 2021-YI-YAN-LUN-SHEN-69). This work was conducted as part of the intramural clinical research project of the Second Affiliated Hospital of Nanchang University (Project No. 2021efyC03).

Between January 2022 and January 2024, consecutive patients with a clinical diagnosis of PD who attended the outpatient clinic or were admitted to the Department of Neurology were enrolled. The inclusion criteria were as follows: (1) fulfillment of the 2015 clinical diagnostic criteria for PD issued by the International Parkinson and Movement Disorder Society (MDS); (2) age between 40 and 90 years; (3) Hoehn-Yahr (H-Y) stage 1–3; (4) initiation of pharmacological treatment with long-term adherence; (5) fixed place of residence and willingness to cooperate with follow-up; (6) voluntary participation with signed informed consent. The exclusion criteria were as follows: (1) secondary parkinsonism or Parkinson-plus syndromes; (2) cognitive impairment or psychiatric disorders preventing effective communication; (3) significant impairment of cardiac, hepatic, or renal function; (4) poor compliance precluding completion of the study protocol.

All participants underwent detailed medical history collection and neurological physical examination. Scale assessments were performed independently by two senior neurologists, and data were verified by a third physician. Based on whether the patient's place of residence was within the coverage area of the four regional specialty alliance units and their willingness to undergo regular follow-up, two cohorts were formed naturally: a standardized management group and a routine care group. Both groups were observed for 12 months, with follow-up data collected at baseline, month 6, and month 12.

Management strategies

The standardized management group received care delivered through the regional specialty collaborative network, with the provincial center providing standardized training, remote guidance, and quality control to collaborative units to achieve homogenization of diagnosis and treatment protocols. The intervention comprised the following components: (1) establishment of a dedicated PD team, with standardized training and quality control in MDS-UPDRS administration, regular remote consultations, and grassroots outreach lectures; (2) development of an online physician-patient communication platform, concurrent with systematic health education and offline mutual support activities; (3) simplification of medication regimens, with remote guidance on dose titration and reminders for scheduled follow-up visits; (4) implementation of a low-protein antioxidant diet, structured exercise, sunlight exposure, psychological support, and rehabilitation interventions; (5) standardized care training for family members and primary caregivers; (6) establishment of a two-way referral green channel: patients were referred to the provincial center for treatment adjustment when UPDRS-III score changes reached or exceeded 5 points, and returned to collaborative units for continued management after stabilization.

Patients in the routine care group attended municipal tertiary hospitals with neurology departments in the province at their own discretion, in accordance with the Chinese Guidelines for the Treatment of Parkinson's Disease (Fourth Edition), and received routine outpatient follow-up without a unified intervention protocol.

Data collection

At baseline, month 6, and month 12, all participants underwent gait parameter acquisition and medical cost assessment.

Gait parameters. Gait data were collected using an inertial measurement unit system (Jeno Science, Shenzhen, China) at a sampling rate of 100 Hz. Ten IMU sensors were placed on the lower back (L5), sternum, bilateral wrists, bilateral thighs, bilateral ankles, and bilateral feet. Participants completed the TUG test, and the following parameters were recorded simultaneously: mean step length of left and right feet (cm), gait speed (m/s), mean stride length of left and right feet (cm), mean cadence of left and right feet (steps/min), double support phase (%), swing phase (%), and stride length variability (%).

Medical costs. PD-related direct medical costs were collected for the 0–6 month and 7–12 month periods, including pharmaceutical, fall-related injury, rehabilitation, assistive device, home nursing care, and referral costs.

Statistical analysis

Statistical analyses were performed using SPSS 26.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed continuous variables were expressed as mean (standard deviation), and between-group comparisons were performed using independent samples *t*-tests; non-normally distributed continuous variables were expressed as median (interquartile range), and between-group comparisons were performed using Mann-Whitney *U* tests. Categorical variables were expressed as frequency (percentage), and between-group comparisons were performed using chi-square tests or Fisher's exact tests. For repeated measures data, two-way repeated measures ANOVA was used; when Mauchly's test of sphericity was violated, the Greenhouse-Geisser correction was applied. If a significant interaction effect between time and treatment was observed, simple effects analysis was performed with Bonferroni correction for multiple comparisons.

The percentage change in UPDRS-III scores from

baseline to month 12 was calculated as an indicator of motor symptom improvement (independent variable), using the following formula:

$$\text{UPDRS-III improvement rate (\%)} = -[(\text{UPDRS-III score at month 12} - \text{UPDRS-III score at baseline}) / \text{UPDRS-III score at baseline}] \times 100\%$$

Positive values indicated alleviation of motor symptoms, whereas negative values indicated deterioration. Changes in gait parameters (dependent variables) were calculated as the difference between month 12 and baseline values (Δ). Given that the distributions of Δ UPDRS-III improvement rate and gait parameter changes deviated from normality (Shapiro-Wilk test, $p < 0.05$), Spearman rank correlation analysis was used to assess the monotonic association between these variables, with Spearman's correlation coefficient (r_s) indicating the strength and direction of the association. Analyses were first conducted in the overall cohort, and subsequently stratified by group (standardized management group vs. routine care group). The significance level was set at $\alpha = 0.05$ (two-tailed), with $p < 0.05$ considered statistically significant. Graphs were generated using GraphPad Prism 10.1.

Results

A total of 366 patients completed the 12-month study protocol, comprising 192 in the standardized management group and 174 in the routine care group. In the standardized management group, 8 patients dropped out: 4 were lost to follow-up, 2 relocated, and 2 withdrew to undergo deep brain stimulation surgery. In the routine care group, 26 patients dropped out: 14 were lost to follow-up, 6 were referred to hospitals outside the province, and 6 voluntarily withdrew from the study (Figure 1).

Baseline characteristics

Baseline data, including age, sex, body mass index (BMI), disease duration, H-Y stage in the on state, and levodopa equivalent daily dose (LEDD), were collected for between-group comparisons. No statistically significant differences were found in any baseline characteristics (all $p > 0.05$), indicating that the two groups had comparable baseline profiles (Table 1).

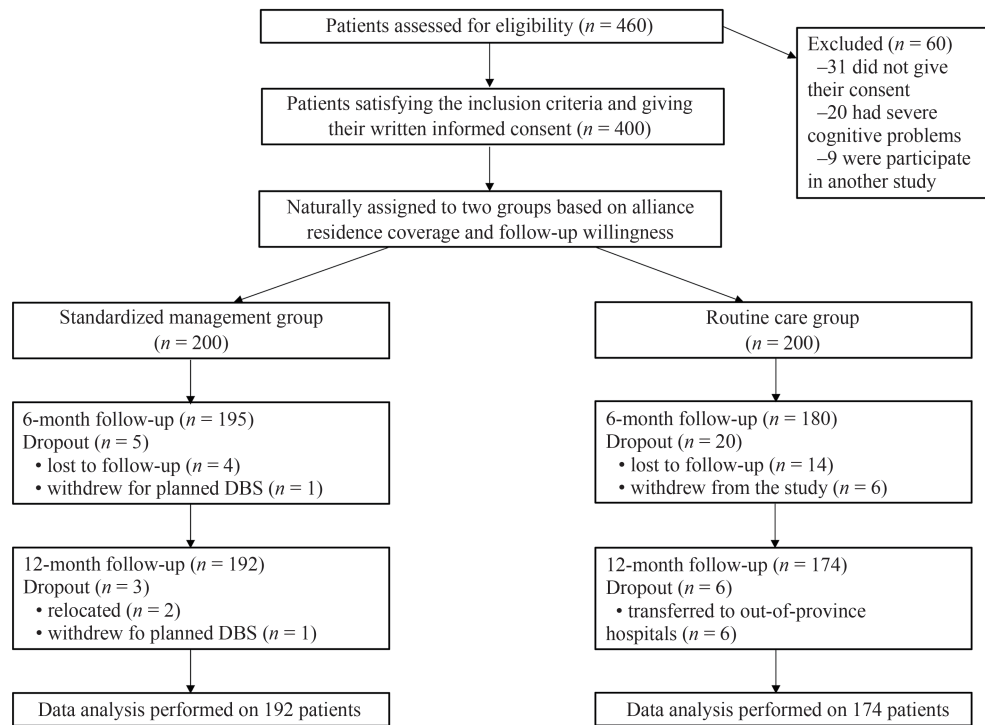


Figure 1: Study flow chart.

Table 1: Comparison of baseline characteristics between the standardized management group and the routine care group

Variables	Standardized management group (n = 192)	Routine care group (n = 174)	Statistical value (Z/t/ χ^2)	p value
Age (year)	63.42 $\pm$ 9.48	65.07 $\pm$ 9.42	-1.675 ^a	0.095
Male, n (%)	103 (53.6%)	90 (51.7%)	0.135 ^b	0.713
Female, n (%)	89 (46.4%)	84 (48.3%)		
BMI (kg/m ²)	23.28 $\pm$ 1.36	23.38 $\pm$ 0.80	-0.846 ^a	0.398
Disease duration (year)	5.5 (4.5, 7.0)	5.5 (4.5,6.5)	-1.905 ^c	0.067
H-Y stage (ON state)	2.5 (2.0, 2.5)	2.5 (2.0,2.5)	-0.725 ^c	0.469
Total LEDD total (mg)	283.29 $\pm$ 79.81	272.53 $\pm$ 71.32	1.355 ^a	0.176
UPDRS-III	31.06 $\pm$ 5.77	30.44 $\pm$ 6.26	-0.865 ^c	0.387
Walk speed (m/s)	0.93 $\pm$ 0.18	0.90 $\pm$ 0.17	-1.183 ^c	0.237
Mean stride length (cm)	91.94 $\pm$ 11.02	92.95 $\pm$ 11.38	1.090 ^c	0.276
Mean cadence (steps/min)	108.63 $\pm$ 10.80	109.29 $\pm$ 11.00	-0.576 ^a	0.565
Double support (%)	21.33 $\pm$ 4.06	21.37 $\pm$ 4.57	-0.121 ^c	0.904
Swing (%)	39.92 $\pm$ 2.10	39.92 $\pm$ 2.32	0.220 ^c	0.826
Mean stride variability (%)	15.80 $\pm$ 2.91	16.49 $\pm$ 3.57	1.557 ^c	0.119

Note: BMI: body mass index; LEDD: levodopa equivalent daily dose; UPDRS-III: Part III of the Unified Parkinson's Disease Rating Scale; Data are expressed as mean $\pm$ standard deviation (SD), frequency (percentage), or median (interquartile range) as appropriate; ^a: independent samples *t*-test (*t* value); ^b: Chi-square test (χ^2 value); ^c: non-parametric Mann-Whitney *U*-test (*Z* value).

Comparison of spatiotemporal gait parameters between the two groups

Repeated measures analysis of variance was performed on spatiotemporal gait parameters at month 6 and month 12 during the treatment period. The results were as follows.

(1) Time effect: except for mean cadence ($F = 2.072$, $p = 0.127$), significant time effects were observed for all remaining parameters. Specifically, mean stride variability ($F = 3.324$, $p = 0.037$), swing ($F = 13.605$, $p < 0.001$), mean stride length ($F = 13.859$, $p < 0.001$), Double Support ($F = 16.408$, $p < 0.001$), and walk speed ($F = 24.121$, $p < 0.001$) all changed significantly over time. In the standardized management group, walk speed, mean stride length, and swing progressively increased, whereas double support, mean stride variability, and mean cadence progressively decreased. Conversely, the conventional treatment group exhibited opposite or deteriorating trends, with walk speed and mean stride length decreasing, double support, mean stride variability, and mean cadence increasing, and swing remaining relatively stable over time.

(2) Group effect: significant between-group differences were found for most parameters, including walk speed ($F = 8.160$, $p = 0.05$), double support ($F = 8.309$, $p = 0.004$), swing ($F = 12.210$, $p < 0.001$), mean cadence ($F = 14.742$, $p < 0.001$), and mean stride variability ($F = 66.461$, $p < 0.001$). However, no significant group effect was observed for mean stride length ($F = 1.584$, $p = 0.209$). Among the significant parameters, mean stride variability and mean cadence demonstrated the most pronounced between-group differences. Overall, the standardized management group exhibited superior gait performance in most parameters compared with the conventional treatment group.

(3) Interaction effect: significant interaction effects were observed for all gait parameters ($p < 0.001$), indicating a synergistic relationship between the management model and time. That is, the magnitude of improvement in gait parameters in the standardized management group was significantly greater than that in the conventional treatment group over time, with particularly favorable time-dependent gains in walk speed and gait stability as reflected by mean stride variability (Table 2 and Figure 2).

Comparison of medical costs between the two groups

Pharmaceutical costs increased more rapidly in the standardized management group, whereas non-pharmaceutical costs decreased markedly. In contrast, non-pharmaceutical costs in the routine care group remained persistently elevated. Comparison of total medical costs revealed significant between-group differences in cost changes at month 6 ($Z = -4.907$, $p < 0.001$) and month 12 ($Z = -8.447$, $p < 0.001$). Total costs in the standardized management group increased gradually, while the routine care group showed a larger increment, suggesting that the standardized management model may be associated with more contained medical expenditures in patients with PD (Tables 3 and 4, Figure 3).

Correlation between UPDRS-III improvement rate and spatiotemporal gait parameters

Spearman rank correlation analysis was used to assess the monotonic association between the Δ UPDRS-III improvement rate and changes in spatiotemporal gait parameters (gait speed, stride length, cadence, double support phase, swing phase, and stride length variability). In the overall cohort, the UPDRS-III improvement rate showed the strongest positive correlation with changes in stride length ($r = 0.891$, $p < 0.001$), followed by gait speed ($r = 0.861$, $p < 0.001$), and a strong negative correlation with stride length variability ($r = -0.760$, $p < 0.001$). A moderate positive correlation was observed for swing phase ($r = 0.564$, $p < 0.001$), while cadence ($r = -0.555$, $p < 0.001$) and double support phase ($r = -0.513$, $p < 0.001$) also showed statistically significant negative correlations.

Stratified analysis revealed that in the standardized management group, the UPDRS-III improvement rate was most closely associated with stride length variability ($r = -0.738$, $p < 0.001$), gait speed ($r = 0.707$, $p < 0.001$), and stride length ($r = 0.690$, $p < 0.001$); a moderate positive correlation was observed for swing phase ($r = 0.430$, $p = 0.012$). The associations with double support phase ($r = -0.396$, $p = 0.190$) and cadence ($r = -0.162$, $p = 0.025$) were comparatively weaker.

Table 2: Comparison of clinical scale assessments between the two groups

Scale	Group	Month 0	Month 6	Month 12	Between-group difference at month 6 (between-group <i>p</i>)	Between-group difference at month 12 (between-group <i>p</i>)	<i>F</i> (<i>p</i>) Time effect	<i>F</i> (<i>p</i>) Group effect	<i>F</i> (<i>p</i>) Interaction effect
Walk speed (m/s)	Standardized management group	0.93 ± 0.18	0.95 ± 0.16	0.97 ± 0.15	0.053 (<i>p</i> = 0.005)	0.079 (<i>p</i> = 0.003)	24.121 (<i>p</i> < 0.001)	8.160 (<i>p</i> = 0.05)	28.072 (<i>p</i> < 0.001)
	Routine care group	0.90 ± 0.17	0.89 ± 0.18	0.88 ± 0.19					
Mean stride length (cm)	Standardized management group	91.94 ± 11.02	93.72 ± 11.56	94.71 ± 11.26	1.924 (<i>p</i> = 0.117)	3.593 (<i>p</i> = 0.003)	13.859 (<i>p</i> < 0.001)	1.584 (<i>p</i> = 0.209)	32.966 (<i>p</i> < 0.001)
	Routine care group	92.95 ± 11.38	91.79 ± 11.84	91.12 ± 11.78					
Mean cadence (steps/min)	Standardized management group	108.63 ± 10.80	106.90 ± 10.64	105.48 ± 10.45	-4.575 (<i>p</i> < 0.001)	-7.465 (<i>p</i> < 0.001)	2.072 (<i>p</i> = 0.127)	14.742 (<i>p</i> < 0.001)	24.437 (<i>p</i> < 0.001)
	Routine care group	109.29 ± 11.00	111.48 ± 10.66	112.94 ± 10.24					
Double support (%)	Standardized management group	21.33 ± 4.06	20.88 ± 4.02	20.47 ± 3.92	-1.375 (<i>p</i> = 0.002)	-2.405 (<i>p</i> < 0.001)	16.408 (<i>p</i> < 0.001)	8.309 (<i>p</i> = 0.004)	19.830 (<i>p</i> < 0.001)
	Routine care group	21.37 ± 4.57	22.26 ± 4.47	22.88 ± 4.57					
Swing(%)	Standardized management group	39.92 ± 2.10	40.72 ± 2.16	41.51 ± 2.21	0.821 (<i>p</i> < 0.001)	1.525 (<i>p</i> < 0.001)	13.605 (<i>p</i> < 0.001)	12.210 (<i>p</i> = 0.001)	18.822 (<i>p</i> < 0.001)
	Routine care group	39.92 ± 2.32	39.90 ± 2.15	39.98 ± 2.26					
Mean stride variability (%)	Standardized management group	15.80 ± 2.91	14.63 ± 3.10	13.62 ± 3.16	-2.866 (<i>p</i> < 0.001)	-5.451 (<i>p</i> < 0.001)	3.324 (<i>p</i> = 0.037)	66.461 (<i>p</i> < 0.001)	121.190 (<i>p</i> < 0.001)
	Routine care group	16.49 ± 3.57	17.50 ± 4.05	19.07 ± 5.47					

Note: Data are expressed as mean ± SD for normally distributed continuous variables; independent samples *t*-test was used for comparisons, with *t* as the test statistic.

In the routine care group, the UPDRS-III improvement rate showed the strongest positive correlation with stride length ($r = 0.636$, $p < 0.001$), a strong negative correlation with stride length variability ($r = -0.587$, $p < 0.001$), and a moderate positive correlation with gait speed ($r = 0.541$, $p < 0.001$). Of note, cadence showed a moderate negative correlation with the UPDRS-III improvement rate in this group ($r = -0.496$, $p = 0.037$), with an absolute value larger than that observed in the standardized management group ($r = -0.162$). Swing

phase also showed a moderate positive correlation ($r = 0.429$, $p = 0.013$), whereas the association with double support phase did not reach statistical significance ($r = -0.290$, $p = 0.101$) (Table 5 and Figure 4).

Discussion

PD is the second most common neurodegenerative disorder worldwide, characterized by the interplay between motor dysfunction and non-motor symptoms. As the

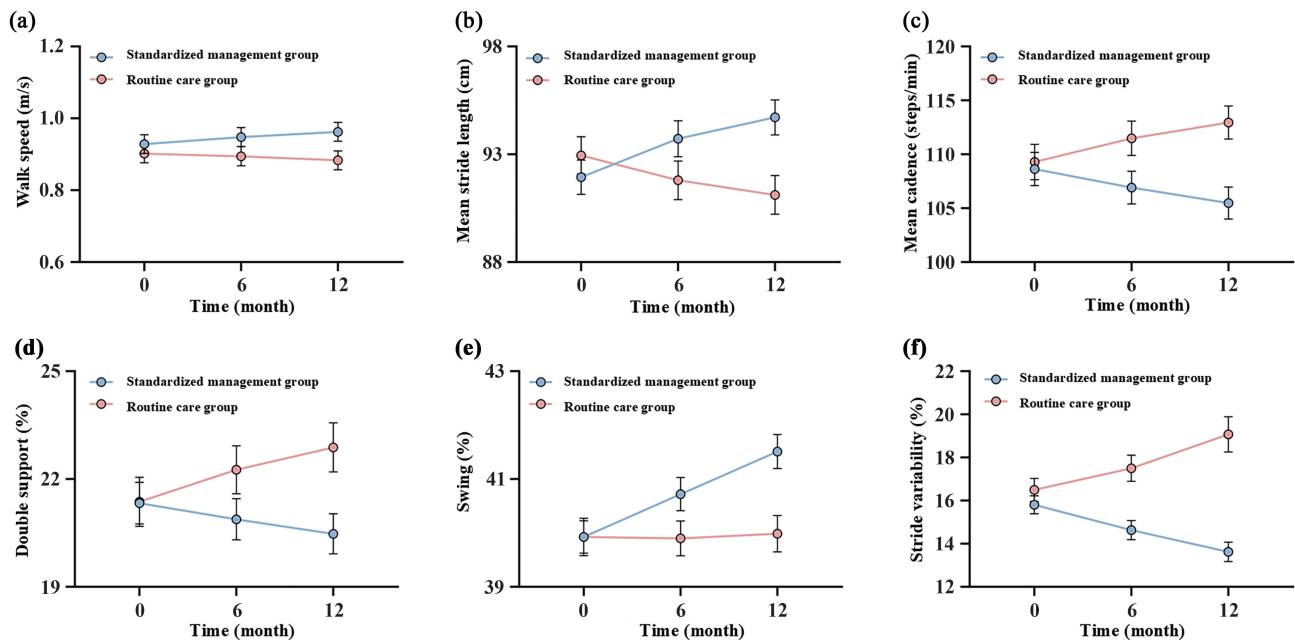


Figure 2: Comparison of temporal trends in spatiotemporal gait parameters between the two groups.

(a) Gait speed; (b) Mean stride length; (c) Cadence; (d) Double support phase; (e) Swing phase; (f) Stride length variability. Blue circles represent the standardized management group; red circles represent the routine care group. Error bars represent mean $\pm$ SD.

Table 3: Comparison of medical costs between the two groups

Cost category	Standardized management group			Routine care group		
	Month 0	Month 6	Month 12	Month 0	Month 6	Month 12
Medication costs (CNY)	72.00 (48.00, 88.00)	162.00 (132.00, 482.50)	291.00 (162.00, 762.00)	57.00 (48.00, 72.00)	132.85 (132.00, 263.00)	263.00 (162.00, 762.00)
Non-medication costs (CNY)	321.50 (232.70, 494.75)	241.00 (164.00, 352.25)	199.50 (128.25, 303.25)	287.00 (244.00, 342.25)	275.50 (234.00, 331.00)	282.00 (237.00, 334.75)
Total medical costs (CNY)	396.50 (300.15, 596.00)	485.15 (310.25, 852.00)	532.50 (321.00, 958.27)	344.50 (301.00, 408.75)	461.00 (388.25, 514.50)	553.00 (473.00, 1017.75)

Note: Data are expressed as median (interquartile range).

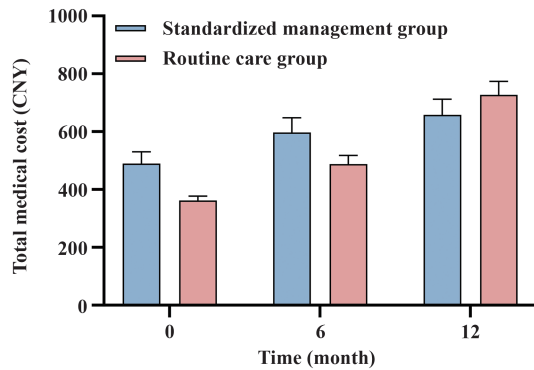
disease progresses, motor symptoms exhibit marked fluctuations, with the incidence of wearing-off phenomena, on-off phenomena, and dyskinesia gradually increasing, leading to progressive impairment of activities of daily living and significant decline in quality of life. Disease progression involves multiple systems, substantially increasing the treatment costs of dopaminergic medications while intensifying the economic burden of rehabilitation interventions and long-term family care, thereby creating a dual challenge for healthcare resource consumption and social support systems^[15–19].

Clinical assessment of PD has long relied on subjective tools such as the UPDRS, which, although capable of reflecting overall motor function, lacks sensitivity to subtle gait changes and is susceptible to interference from examiner experience and the patient's immediate condition^[20]. Studies have demonstrated that real-world digital mobility outcome measures (including gait speed, cadence, and activity intensity) exhibit higher validity than traditional UPDRS-based assessments, better reflecting patients' actual mobility capacity and disease progression^[21,22]. In recent years, gait analysis

Table 4: Comparison of total medical costs between the two groups

Group	Total medical costs (CNY)	
	Change from baseline at month 6	Change from baseline at month 12
Standardized management group	26.50 (-10.75, 166.00)	52.80 (12.37, 348.15)
Routine care group	54.00 (39.75, 194.00)	236.50 (100.50, 644.00)
Z value	-4.907	-8.447
p value	< 0.001	< 0.001

Note: Data are expressed as median (interquartile range). Between-group comparisons were performed using the Mann-Whitney *U* test.

**Figure 3:** Bar chart comparing total medical costs between the two groups.

technology based on IMUs has not only enabled objective quantification of functional activity levels but also holds unique clinical value due to its alignment with daily mobility capabilities^[23–27].

In this study, IMU sensors were applied synchronously during the standardized TUG test, with assessments conducted during the medication “ON” state, during which patients’ motor function most closely approximates their real-world post-medication performance. At the full-cohort level, the UPDRS-III improvement rate showed strong positive correlations with stride length ($r = 0.891$) and gait speed ($r = 0.861$), and a negative correlation with stride length variability ($r = -0.760$). The bradykinesia and freezing of gait resulting from dopaminergic neurodegeneration manifest core features including shortened stride length, decreased gait speed, and irregular gait rhythm, all of which can be concurrently

Table 5: Spearman rank correlation analysis between the improvement rate of UPDRS-III scores and changes in gait parameters

Gait parameter	Overall ($n = 366$)	Standardized management group ($n = 192$)	Routine care group ($n = 174$)
Walk speed (m/s)	$r = 0.861$ ($p < 0.001$)	$r = 0.707$ ($p < 0.001$)	$r = 0.541$ ($p < 0.001$)
Stride length (cm)	$r = 0.891$ ($p < 0.001$)	$r = 0.690$ ($p < 0.001$)	$r = 0.636$ ($p < 0.001$)
Cadence (steps/min)	$r = -0.555$ ($p < 0.001$)	$r = -0.162$ ($p = 0.025$)	$r = -0.496$ ($p = 0.037$)
Double support (%)	$r = -0.513$ ($p < 0.001$)	$r = -0.396$ ($p = 0.190$)	$r = -0.290$ ($p = 0.101$)
Swing (%)	$r = 0.564$ ($p < 0.001$)	$r = 0.430$ ($p = 0.012$)	$r = 0.429$ ($p = 0.013$)
Stride variability (%)	$r = -0.760$ ($p < 0.001$)	$r = -0.738$ ($p < 0.001$)	$r = -0.587$ ($p < 0.001$)

Note: Data in the table are presented as correlation coefficients (r) with corresponding p values in parentheses. Spearman rank correlation analysis was performed. The improvement rate of UPDRS-III scores (%) was calculated as $-(\text{score at month 12} - \text{baseline score}) / \text{baseline score} \times 100\%$ and served as the independent variable. Changes in gait parameters were calculated as (value at month 12 – baseline value) and served as the dependent variables.

ameliorated by effective therapeutic interventions. However, stratified analysis revealed significant differences in the strength of associations between the two groups. In the standardized management group, the absolute values of correlation coefficients for gait speed, stride length, and stride length variability were significantly higher than those in the conventional treatment group, suggesting that under this model, the alleviation of motor symptoms was concurrently translated into improvements in gait quality and stability. This benefit arises from the synergistic effects of multidisciplinary intervention: unified training from the provincial center ensures standardized implementation of task-oriented exercise prescriptions, remote medication titration reduces the interference of wearing-off fluctuations on gait rhythm, and continuous rehabilitation supervision promotes functional neuroplasticity. In contrast, the moderate negative correlation between cadence and UPDRS-III improvement rate in the conventional treatment group may reflect a festination-like compensatory pattern, wherein patients are compelled to increase cadence to maintain mobility when stride length cannot be effectively increased. Notably, cadence measurements in

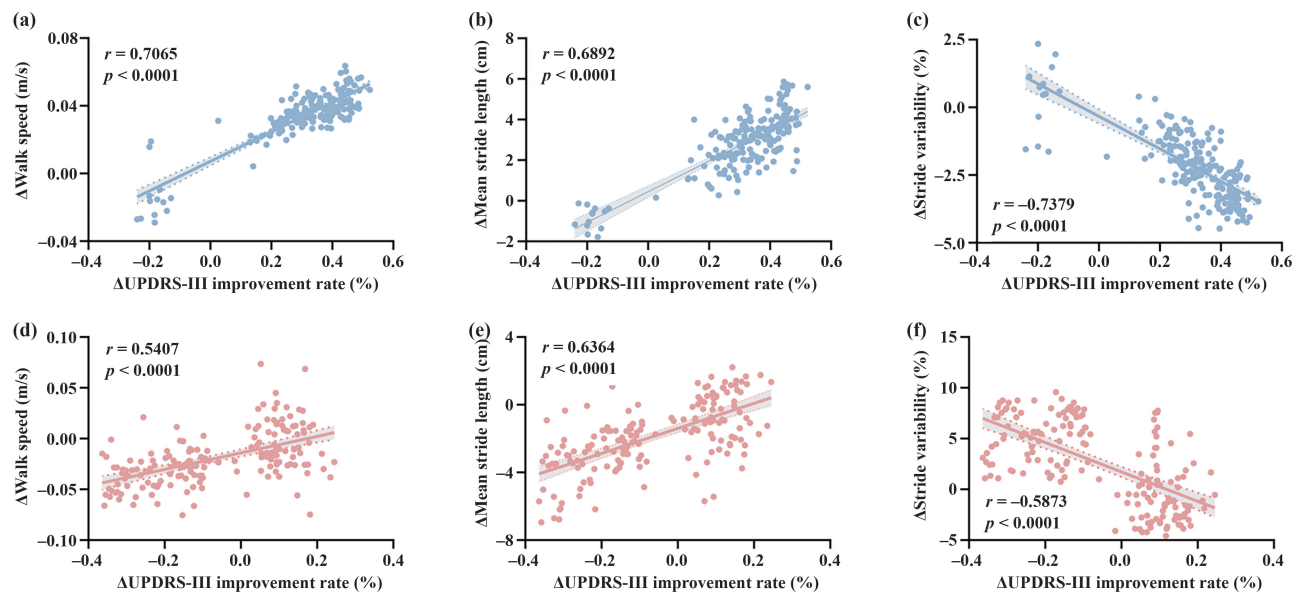


Figure 4: Scatter plots illustrating the relationship between the improvement rate of UPDRS-III scores and changes in gait parameters in the two groups.

Panels (a)–(c) represent the standardized management group; panels (d)–(f) represent the routine care group. The x-axis represents the improvement rate of UPDRS-III scores (%). The y-axis represents changes in gait speed (m/s) in panels (a) and (d), stride length (cm) in panels (b) and (e), and stride length variability (%) in panels (c) and (f), respectively. Blue scatter points indicate the standardized management group, and red scatter points indicate the routine care group. Solid lines represent linear fitted trend lines, and shaded gray areas represent the 95% confidence intervals. Spearman rank correlation analysis was applied.

clinical settings may be confounded by the structured nature of the testing environment. Previous studies have indicated significant differences in the modifiability of gait speed between clinical and free-living environments in PD patients^[28]. The flat, quiet, and obstacle-free hospital testing conditions reduce the demand for cadence modulation. Although the TUG test in this study simulated basic daily mobility, it could not fully replicate the complexity of real-world environments, resulting in insufficient manifestation of compensatory cadence changes.

The multidisciplinary integrated management model in this study shares core elements with the European inpatient PD multimodal comprehensive therapy (PD-MCT) approach. Single-center studies have confirmed that inpatient multidisciplinary care significantly improves IMU gait parameters, overall motor function, and quality of life in PD patients, with good concordance between objective indicators and subjective scale improvements^[29,30]. Ziegler et al.^[31] further demonstrated that the beneficial effects of inpatient PD-MCT on activities of daily living can persist for up to 3 months post-

discharge, contingent upon patients' sustained adherence to training protocols. However, existing inpatient rehabilitation studies are generally limited by small sample sizes, short follow-up periods, and lack of cost data. The regional specialist alliance model in this study is based on outpatient and remote management, substantially lowering implementation barriers while maintaining intervention intensity, thereby providing a scalable alternative for chronic PD management in resource-limited settings.

From a health economic perspective, the standardized management group exhibited a 34.8% reduction in the increment of total medical costs compared with the conventional treatment group, a difference primarily driven by decreased non-medication costs (fall-related injuries, rehabilitation, and referral expenses). Enhanced gait stability represents the key mechanism underlying cost containment. In this study, the reduction in double support phase and stride length variability in the standardized management group directly reflected improved gait stability, thereby reducing fall events and associated medical expenditures.

Limitations

First, IMU gait data were collected under standardized TUG conditions, which, while ensuring comparability, may not fully capture patients' gait adaptability in real-world complex environments. Future studies should incorporate wearable devices for long-term monitoring in free-living conditions to bridge the gap between "clinical performance" and "real-world capability". Second, cadence measurements in clinical settings may be confounded by the structured characteristics of the environment, and its predictive value in real-world settings warrants further validation. Third, the 12-month follow-up period represents a moderate duration; the long-term evolution of gait parameters and cost trajectories require further observation.

Conclusion

In summary, the standardized PD management model based on a regional specialist alliance significantly improved gait stability and motor efficiency during the medication "ON" state through the integration of objective IMU gait monitoring and multidisciplinary structured intervention. The strong associations between gait speed, stride length, and stride length variability with the UPDRS-III improvement rate validate the sensitivity of these parameters as therapeutic efficacy indicators. Meanwhile, the differential cadence association patterns between the two groups reveal the regulatory role of management models in the efficiency of "symptom-to-function" translation. Grounded in outpatient and remote management, this model achieves cost optimization while maintaining clinical efficacy, offering a practical reference for the precision and sustainability of chronic PD management.

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Authors' contributions

Yajing Cui conceived the study, collected and analyzed the data, and drafted the manuscript. Lin Chen provided resources and supervised the work. Jiahao Zhao collected the data and performed the statistical analysis.

Wei Huang conceived the study, provided resources, and supervised the work. All authors reviewed, edited, and approved the final version of the manuscript and agree to its publication.

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Ethics approval and consent to participate

The research protocol was prospectively reviewed and granted approval by the Research Ethics Committee of the Second Affiliated Hospital of Nanchang University. (Approval No. 2021-YI-YAN-LUN-SHEN-69) All participants provided written informed consent prior to enrollment. Separate written authorization was additionally obtained from individuals for the publication of any potentially identifiable images or data included in this article.

Disclosure of artificial intelligence (AI) use

The authors used Gemini and DeepL as language-editing tools to improve grammar, clarity, and readability. The AI tools were not used for data analysis, data generation, image processing, or scientific content creation. All outputs were carefully reviewed and verified by the authors, who take full responsibility for the final content.

Competing interest

The authors declare no conflicts of interests.

Consent for publication

All the authors consent to the publication of identifiable details, which can include data within the text to be published by *Translational Neurology and Neurosurgery*.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author (Wei Huang, E-mail: 13677080198@163.com) upon reasonable request.

References

1. Chapuis S, Ouchchane L, Metz O, et al. Impact of the motor complications of Parkinson's disease on the quality of life. *Mov Disord*. 2005;20(2):224-230.
2. Mirelman A, Bonato P, Camicioli R, et al. Gait impairments in Parkinson's disease. *Lancet Neurol*. 2019;18(7):697-708.
3. Russo M, Amboni M, Pisani N, et al. Biomechanics parameters of gait analysis to characterize Parkinson's disease: a scoping review. *Sensors (Basel)*. 2025;25(2):338.
4. Bloem B R, Okun M S, Klein C. Parkinson's disease. *Lancet*. 2021;397(10291):2284-2303.
5. Dorsey E R, Bloem B R. The parkinson pandemic—a call to action. *JAMA Neurol*. 2018;75(1):9.
6. Barone P, Antonini A, Colosimo C, et al. The PRIAMO study: a multicenter assessment of nonmotor symptoms and their impact on quality of life in Parkinson's disease. *Mov Disord*. 2009;24(11):1641-1649.
7. GBD 2016 Parkinson's Disease Collaborators. Global, regional, and national burden of Parkinson's disease, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Neurol*. 2018;17(11):939-953.
8. Monje M H G, Foffani G, Obeso J, et al. New sensor and wearable technologies to aid in the diagnosis and treatment monitoring of Parkinson's disease. *Annu Rev Biomed Eng*. 2019;21(1):111-143.
9. Sica M, Tedesco S, Crowe C, et al. Continuous home monitoring of Parkinson's disease using inertial sensors: A systematic review. *PloS One*. 2021;16(2):e0246528.
10. Di Biase L, Di Santo A, Caminiti M L, et al. Gait analysis in Parkinson's disease: an overview of the most accurate markers for diagnosis and symptoms monitoring. *Sensors*. 2020;20(12):3529.
11. Mirelman A, Bonato P, Camicioli R, et al. Gait impairments in Parkinson's disease. *Lancet Neurol*. 2019;18(7):697-708.
12. Pang T Y, Cheng C T, Feltham F, et al. Feasibility of imu-based wearable sonification: toward personalized, real-time gait monitoring and rehabilitation. *Biosensors*. 2025;15(10):698.
13. Mejia A C, Sapienza S, Paccoud I, et al. Consensus on the clinical utility of digital mobility outcomes for personalized clinical decision support in Parkinson's disease. *Neurol Res Pract*. 2025;7(1):66.
14. Monticone M, Ambrosini E, Laurini A, et al. In-patient multidisciplinary rehabilitation for Parkinson's disease: A randomized controlled trial. *Mov Disord*. 2015;30(8):1050-1058.
15. Tanner C M, Ostrem J L. Parkinson's disease. *N Engl J Med*. 2024;391(5):442-452.
16. Bloem BR, Okun MS, Klein C. Parkinson's disease. *Lancet*. 2021;397(10291):2284-2303.
17. Kurth T, Brinks R. Projecting Parkinson's disease burden. *BMJ*. 2025;388:r350.
18. Alshimemeri S, AlSudais H, Alamri NK, et al. Burden, anxiety, and depression among caregivers of Parkinson's disease patients. *J Parkinsons Dis*. 2024;14(7):1495-1505.
19. Shalash A, Schumacher-Schuh AF, Salama M, et al. Mapping the Parkinson's pandemic: unveiling and addressing the global burden. *J Parkinsons Dis*. 2026:1877718X261459875.
20. Atrsaei A, Corrà MF, Dadashi F, et al. Gait speed in clinical and daily living assessments in Parkinson's disease patients: performance versus capacity. *NPJ Parkinsons Dis*. 2021;7(1):24.
21. Urbanek JK, Roth DL, Karas M, et al. Free-living gait cadence measured by wearable accelerometer: a promising alternative to traditional measures of mobility for assessing fall risk. *J Gerontol A Biol Sci Med Sci*. 2023;78(5):802-810.
22. Kirk C, Packer E, Polhemus A, et al. A systematic review of real-world gait-related digital mobility outcomes in Parkinson's disease. *NPJ Digit Med*. 2025;8(1):585.
23. Salzmann L, Bichsel O, Rohr-Fukuma M, et al. Lower limb motor effects of DBS neurofeedback in Parkinson's disease assessed through IMU-based UPDRS movement quality metrics. *Sci Rep*. 2025;15(1):44579.
24. Michaud M, De l'Escalopier N, Voisard C, et al. Real-world gait study of Parkinson's disease using wearable sensors: a systematic review. *J Neuroeng Rehabil*. 2026;23:251.
25. Maddumage Dona S, Sullivan K, Lehn A, et al. A smart shoe system for gait analysis and remote monitoring in Parkinson's disease-a validation study. *Sensors (Basel)*. 2026;26(14):4446.
26. Xie J, Zhao H, Zhang M, et al. Interpretable features for quantifying motor symptoms of Parkinson's disease with wearable sensors. *Measurement*. 2026;275:121402.
27. Maetzler W, Domingos J, Srulijes K, et al. Quantitative wearable sensors for objective assessment of Parkinson's disease. *Mov Disord*. 2013;28(12):1628-1637.
28. Nishi Y, Fujii S, Ikuno K, et al. Adjustability of gait speed in clinics and free-living environments for people with Parkinson's disease. *J Mov Disord*. 2024;17(4):416-424.
29. Kleinholdermann U, Mügge FCJ, Carapezza T, et al. Multidisciplinary inpatient care for Parkinson's disease: a single-centre cohort study on improvements in gait, overall motor function, and quality of life. *Neurol Res Pract*. 2025;7(1):62.
30. Oppermann J, Tschentscher V, Welzel J, et al. Clinical and device-based predictors of improved experience of activities of daily living after a multidisciplinary inpatient treatment for people with Parkinson's disease: a cohort study. *Ther Adv Neurol Disord*. 2024;17:17562864241277157.
31. Ziegler K, Messner M, Paulig M, et al. Activities of daily living are improved by inpatient multimodal complex treatment for PD-a real-world cohort study. *Mov Disord Clin Pract*. 2023;10(1):42-54.