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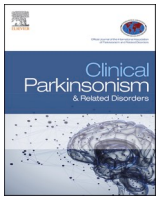

Original Articles

Comparison of clinical measures of motor function with a Holter monitor in Parkinson's disease

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ABSTRACT

Background: Parkinson's disease (PD) is a significant global health challenge, affecting millions worldwide. This sub-study aims to explore the potential of ambulatory monitoring devices in identifying disease severity and progression in patients. As part of the MOMOPA-EC clinical trial, 156 patients with moderate to severe PD underwent 435 assessments using clinical scales and ambulatory monitoring devices (Parkinson's Holter). This sub-study seeks to establish relations between parameters derived from Holter monitors and clinical severity measures to enhance personalized disease management strategies. Methods: In the MOMOPA-EC trial, 435 patient monitoring sessions were conducted, during which patients wore Parkinson's Holter monitors for a week before completing clinical assessments, including the Unified Parkinson's Disease Rating Scale (UPDRS), Parkinson's Disease Questionnaire (PDQ-39), and Freezing of Gait Questionnaire (FoG-Q). Results: The reports obtained during the monitoring of the patients were classified into three groups based on the greater or lesser gait fluidity (according to the measurements from the Parkinson's Holter). All clinical scales were significantly different in each of these groups, indicating that patients with lower stride fluidity had poorer outcomes across

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the different clinical scales. Conclusions: The findings of this study underscore the potential of Parkinson's Holters in providing objective data for personalized disease management in PD patients. Integrating such technologies into routine clinical practice could enhance patient care and treatment strategies by offering clinicians objective insights into both disease progression and therapeutic response.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder characterized by motor symptoms such as tremor, rigidity, and bradykinesia, which significantly impact quality of life. Recent advances in PD research have led to the development of more accurate diagnostic methods and innovative therapeutic approaches [1–3].

The "Monitoring Parkinson's Patients' Mobility for Therapeutic Purposes" (MOMOPA-EC) clinical trial was designed to evaluate the efficacy of clinical control in patients with Parkinson's disease. This sub-study specifically examines the use of Parkinson's Holter monitors within the broader context of the MOMOPA-EC trial, aiming to validate the effectiveness of these devices in providing objective data on motor symptoms and disease progression.

Ambulatory monitoring devices for motor symptoms (Parkinson's Holter monitors) are emerging as pivotal tools that could play a crucial role in future disease management. These devices provide quantitative data on the motor symptoms associated with the disease, offering physicians an objective and detailed view of disease progression and the response to treatment. This not only facilitates a more precise diagnosis but also allows clinicians to personalize therapies and to evaluate their effectiveness over time. Research in this field is growing, with the aim of understanding the relationship between the measurements performed by these devices and other relevant clinical variables for the treatment of Parkinson's patients [4]. Specifically, the device selected for the MOMOPA-EC trial was the Parkinson's Holter STAT-ON [4], capable of continuously detecting motor symptoms such as bradykinesia, dyskinesia, OFF periods, freezing of gait, and gait fluidity in real-life conditions. By capturing these parameters objectively and without supervision, the device offers an ecological and patient-centered perspective on motor status. The authors sought to investigate whether parameters derived from Parkinson's Holter monitors can identify patients who, according to various clinical scales, exhibit a more severe manifestation of the disease or are in a more advanced stage. This investigation was carried out as a sub-study of the MOMOPA-EC clinical trial, where all participants wore a Parkinson's Holter monitor and underwent assessments using different scales under real-world clinical practice conditions.

2. Materials and methods

The MOMOPA-EC clinical trial, from which our sub-study derives, aims to evaluate the effectiveness in reducing OFF time of the Parkinson's Holter compared with standard clinical measures (recorded through a diary of motor fluctuations, which will be completed by all patients)[5]. Our sub-study specifically focuses on analyzing data derived from Parkinson's Holter monitors to explore their potential in providing objective assessments of motor symptoms and disease progression. By examining these specific parameters, we seek to understand how motion sensor data can enhance clinical evaluations compared to traditional methods. By placing a strong emphasis on the role of wearable technology in our sub-study, we aim to demonstrate the added value of Parkinson's Holter monitors in complementing traditional clinical assessments and with the ultimate goal of improving patient management strategies.

The primary outcome variable for the main trial is daily OFF time, measured through a diary of motor fluctuations (On/Off). The MOMOPA-EC clinical trial recruited 203 patients diagnosed with moderate to severe Parkinson's disease, each experiencing at least 2 h of daily OFF time. This single-blind trial randomly assigned patients to one of three groups: 1. clinical care with information available from a Parkinson's Holter monitor; 2. clinical care with information available from a diary of motor fluctuations (Hauser's diary); and 3. clinical care without additional information [5].

Although only physicians assigned to the Holter arm had access to the device data for clinical decision-making, all participants, regardless of the allocation group, wore the Parkinson's Holter and completed a Hauser diary for one week. Additionally, all patients completed the PDQ-39 [6] and FoG-Q [7] at home before each medical assessment. The Unified Parkinson's Disease Rating Scale [8] including part II (UPDRS II), III (UPDRS III), and the dyskinesias section of part IV (UPDRS IV), was administered by a physician at each visit.

For this sub-analysis, only valid Holter reports were used ($n = 435$), including 147 from the Holter group, 141 from the Diary group, and 147 from the group without additional information. Holter-derived parameters were analyzed regardless of the allocation group. The trial received approval from the Research Ethics Committee of Hospital de Bellvitge (reference no. AC012/19).

The Unified Parkinson's Disease Rating Scale (UPDRS) is a comprehensive tool for assessing Parkinson's disease severity, segmented into various sections. This study focuses on Part II, which evaluates daily living activities, Part III, which assesses motor function, and Part IV, specifically the section on dyskinesias. The Parkinson's Disease Questionnaire (PDQ-39) measures health-related quality of life, with higher scores indicating lower quality of life. Additionally, the Freezing of Gait Questionnaire (FoG-Q) is used to evaluate the frequency and severity of freezing episodes and their impact on mobility.

The Parkinson's Holter monitor used in the MOMOPA-EC trial was the STAT-ON. This medical device, manufactured by Sense4Care SL (https://www.sense4care.com), is designed to be worn at the waist and monitors motor fluctuations and patient activity on an outpatient basis. This device reports motor fluctuations during activities of daily living as well as episodes of dyskinesia, bradykinesia and freezing of gait. The ability of the STAT-ON to acquire data on these symptoms has been validated in previous studies, demonstrating sensitivities and specificities of approximately 90 % with respect to Hauser's diaries, and correlations of between 0.7 and 0.8 with the Unified Parkinson's Disease Rating Scale (UPDRS III) scores [9–12]. Holter data are stored in its internal memory, allowing users (patients or neurologists) to download it to any mobile phone through an app. The STAT-ON device uses gait analysis to determine motor states. According to the manufacturer's recommendations, STAT-ON should be used for a minimum of 3 days for complete monitoring.

The detection of the motor OFF state by this device is based mainly on stride fluidity, which the Holter monitor reports. Stride fluidity is a continuous variable strongly associated with gait bradykinesia [13–16]. As noted in previous studies, this variable is correlated with the UPDRSIII, in particular Factor I Gait/Posture (Speech, Facial expression, Arising from chair, Posture, Gait, Postural stability, Body bradykinesia) [17].

Information on pharmacological treatment was collected only during the baseline and final study visits. As a result, these data were not available for most of the monitoring sessions included in this sub-analysis. Therefore, neither medication nor comorbidities were included as variables. Since the objective of this sub-study was to compare Holter-derived gait fluidity with clinical severity scales, these factors were not considered essential for the analysis.

For the purposes of this sub-analysis, we focused exclusively on gait

fluidity. This parameter was selected because it is a continuous measure, strongly correlated with bradykinesia, and suitable for patient stratification. It has also been shown to correlate with overall clinical severity. Other parameters captured by the STAT-ON, such as dyskinesia or OFF time, were not considered in this analysis.

2.1. Participants

In the MoMoPa-EC study, patients were recruited from November 2019 to March 2022 from 40 hospitals and health centers that specialized in the treatment of PD distributed throughout Spain.

The protocol required participating neurologists to offer the device to patients who could benefit from ambulatory monitoring of their motor symptoms to better control such symptoms. All recruited patients had to meet the following inclusion criteria: (1) idiopathic PD according to the clinical criteria of the Brain Bank of the United Kingdom[18], (2) Hoehn & Yahr $\geq$ 2 in the OFF state [19], and (3) more than 2 h/day in the OFF state (Hauser diary [20]). Only those patients who, having been clearly informed about the objectives and possible consequences of the study, voluntarily agreed to sign the informed consent form were included. All patients with a Hoehn & Yahr stage equal to 5, who were participating in another clinical trial, or who presented acute intercurrent diseases or a Mini-Mental State Examination score less than 24 were excluded [21]. In addition, all patients with difficulty understanding the study procedures were excluded.

Of the 203 patients screened, 47 did not meet the eligibility criteria. During the trial, 624 monitoring reports were obtained from the 156 recruited patients. Of these, 189 reports had to be excluded from this sub-analysis due to insufficient data in the Holter. The high number of data losses was because the primary aim of the trial did not include Holter data collection, and the protocol did not foresee control mechanisms and repetition in cases of sensor misuse or technical problems in the groups using the diary of motor fluctuations and those without additional information for the neurologist evaluation. As a result, the final analysis included 435 valid reports (Fig. 1).

2.2. Data analysis

In this sub-study, we evaluated the severity of Parkinson's disease using traditional clinical scales within groups of patients with different degrees of stride fluidity (according to the stride fluidity measures from the Parkinson's Holter). For this purpose, all the reports collected with the Holter in the study were grouped as follows: Group 1, reports showing the highest stride fluidity according to the Holter (first quintile); Group 3, reports showing the poorest stride fluidity according to the Holter (fifth quintile); Group 2: the remaining reports, with intermediate fluidity. Subsequently, the average value of each of the clinical scales (UPDRS-II, UPDRS-III, FOG-Q and PDQ-39) was compared within each of these groups.

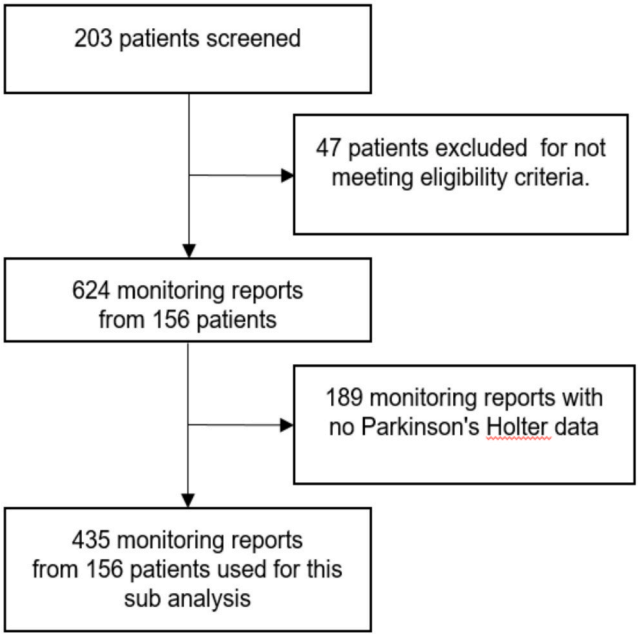

Fig. 1. Diagram of the patient selection process for the subanalysis.

The multidimensionality of the scales for different symptoms in Parkinson's disease poses a challenge when analyzing the overall patient condition. To reduce the dimensionality of the different clinical scales used and obtain a single variable that allows the different clinical parameters to be compared jointly, we use Radar graphs [22]. Radar graphs are visual representations that enable the display of multiple variables on a single chart. The main utility of radar charts is to visualize patterns and compare strengths and weaknesses across different categories. These charts are commonly used in performance evaluations, competency analyses, strategic decision-making, and visually effective presentations of comparative data. In this study, Radar graphs were used to compare the clinical outcomes of patients with different levels of stride fluidity. The larger the area enclosed by the Radar plot, the more severe the clinical symptoms, providing an intuitive visual summary of the patients' overall clinical status across multiple dimensions. The Radar plots developed for this work illustrate the differences across the three groups in clinical measures UPDRS II, UPDRS III, PDQ-39, and FoG-Q scores, between patients with high, intermediate, and low stride fluidity. These are presented in Fig. 2.. This approach is also valuable in clinical practice, allowing, for instance, the observation of patients' progression over time.

In a radar graph, the normalization of the variables, the logical meaning of each variable itself and the position of a variable within the graph are extremely important. In addition to their visual utility it is possible to work with the graph area offering a very useful dimensional reduction for understanding and analyzing relationships among variables. In this study, normalization based on maximum and minimum values was used; this method is widely used in data processing and statistical analysis to normalize original values by dividing them by the difference between the maximum and minimum value of the variable.

Regarding the statistical analysis, nonparametric methods were used to verify the statistical relevance between the different groups because the data for the groups did not conform to a normal distribution. Specifically, the Mann–Whitney *U* test was applied to compare the most extreme groups, and the Kruskal–Wallis test was used to evaluate differences among the three groups [23,24]. Statistical and graphical calculations were performed in Python (v3.7.5) using the SciPy (1.7.3), Pandas (1.3.5), numpy (1.18.5), matplotlib (3.3.2), Shapely (1.8. 5) and Plotly (5.11.0) libraries.

3. Results

A baseline description of the 435 monitoring reports included in the study is provided in Table 1. Of the 435 monitoring reports, 258 were for men (59 %), and 177 were for women (41 %).

Table 2 shows the medians and the interquartile ranges for each of the groups for the variables of interest and the statistic and p value of the Kruskal–Wallis test. Table 3 shows the Mann–Whitney *U* test for Groups 1 vs 2, Groups 2 vs 3 and Groups 1 vs 3.

Key measures from the analysis include:

For UPDRS II (Unified Parkinson's Disease Rating Scale part II), the median score for Group 1 (highest stride fluidity) was 8 with an interquartile range (IQR) of 7. For Group 2 (intermediate fluidity), the median was 10 with an IQR of 7.5. For Group 3 (lowest stride fluidity), the median was 17 with an IQR of 8.75. The differences between Group 1 and Group 3 were statistically significant (Mann-Whitney *U* test, $p < 0.01$), indicating that lower stride fluidity is associated with greater

Fig. 2. RADAR for the mean questionnaire values of three groups.

Table 1
Clinical scales and Parkinson's Holter recordings included in the analysis.

	Mean	Std dev	Median	IQR
Age	65.04	9.61	65.0	13.0
Hoehn & Yahr [a]	–-	–-	2.5	1.0
UPDRSII [b]	11.58	6.36	11.0	9.0
UPDRSIII [c]	20.51	11.48	20.0	17.0
UPDRSIV [d]	1.52	1.77	1.0	3.0
PDQ-39 [e]	31.18	16.67	29.87	24.37
FoG-Q [f]	10.88	6.13	11.0	10.0
Fluidity (STAT-ON) [g]	7.94	1.6	7.84	2.42

[a] H&Y: Hoehn & Yahr stage, [b] UPDRS-II: Unified Parkinson's Disease Rating Scale, part II, [c] UPDRS-III: Unified Parkinson's Disease Rating Scale, part III, [d] UPDRS-IV: the sum of the dyskinesia score of the Unified Parkinson's Disease Rating Scale, part IV, [e] Self-administered PDQ-39 Scale, [f] Self-administered FoG-Q Scale, [g] Mean fluidity during monitoring extracted from STAT-ON.

impairment in daily-living activities, as measured by the global UPDRS-II score.

For UPDRS III (Unified Parkinson's Disease Rating Scale part III), the median score for Group 1 was 12 with an IQR of 12.75. For Group 2, the median was 20 with an IQR of 14. For Group 3, the median was 27 with an IQR of 16.5. The differences between Group 1 and Group 3 were statistically significant (Mann-Whitney *U* test, $p < 0.01$), demonstrating that PD patients with a worse motor state measured by the total UPDRS-III score had worse gait fluidity measured by the Parkinson's Holter.

For PDQ-39 (Parkinson's Disease Questionnaire-39), the median score for Group 1 was 23.28 with an IQR of 19.92. For Group 2, the median was 29.74 with an IQR of 26.35. For Group 3, the median was 36.12 with an IQR of 14.77. The differences between Group 1 and Group 3 were statistically significant (Mann-Whitney *U* test, $p < 0.01$). Therefore, PD patients with a poorer quality of life measured by the global score in the PDQ-39 are also prone to have lower Parkinson's Holter –based stride fluidity.

For FoG-Q (Freezing of Gait Questionnaire), the median score for

Table 2
Results by stride fluidity group (Parkinson's Holter measurement).

	Group 1			Group 2			Group 3			Kruskal–Wallis	
	N[h]	Median	IQR [g]	N[h]	Median	IQR [g]	N[h]	Median	IQR [g]	statistic	p value
Age	87	54	11	261	65	10	87	75	8	169.54	<0.01
Hoehn & Yahr	87	2	0.5	261	2.5	1.0	87	3.0	0.5	31.38	<0.01
Fluidity (STAT-ON)	87	10.15	1.1	261	7.84	1.3	87	5.88	0.77	333.31	<0.01
UPDRSII [a]	87	8	7	261	10	7.5	87	17	8.75	71.61	<0.01
UPDRSIII [b]	86	12	12.75	258	20	14	86	27	16.5	52.89	<0.01
UPDRSIV [c]	87	1	3	261	1	3	87	0	2	9.87	<0.01
PDQ-39 [d]	83	23.28	19.92	257	29.74	26.35	86	36.12	14.77	18.21	<0.01
FoG-Q [e]	84	8.5	11.25	255	10	9	87	14	7	30.73	<0.01
Radar Area [f]	80	28.24	39.09	248	32.25	39.69	85	56.65	47.23	40.69	<0.01

Table 3
Mann–Whitney *U* test results by stride fluidity group.

	Mann-Whitney U					
	Group 1 vs Group 2		Group 2 vs Group 3		Group1 vs Group 3	
	statistic	p value	statistic	p value	statistic	p value
Age	4977.5	<0.01	3389.5	<0.01	215.5	<0.01
Hoehn & Yahr	8818.5	<0.01	8407.5	<0.01	2170.5	<0.01
Fluidity (STAT-ON)	22707.0	<0.01	22707.0	<0.01	7569.0	<0.01
UPDRSII [a]	8133.5	<0.01	5581.0	<0.01	1215.5	<0.01
UPDRSIII [b]	7446.0	<0.01	7289.5	<0.01	1579.0	<0.01
UPDRSIV [c]	12090.0	0.35	13444.0	<0.01	4714.5	<0.01
PDQ-39 [d]	9575.5	0.16	8409.5	<0.01	2155.5	<0.01
FoG-Q [e]	10611.0	0.9	6799.0	<0.01	2276.0	<0.01
Radar Area [f]	8680.0	0.09	6259.0	<0.01	1637.0	<0.01

Group I corresponds to quantile 80, Group 3 corresponds to quantile 20, and Group 2 corresponds to quantile 20 to quantile 80. [a] UPDRS-II: Unified Parkinson's Disease Rating Scale, part II, [b] UPDRS-III: Unified Parkinson's Disease Rating Scale, part III, [c] UPDRS-IV: the sum of the dyskinesia score of the Unified Parkinson's Disease Rating Scale, part IV, [d] Self-administered PDQ-39 Scale, [e] Self-administered FoG-Q Scale, [f] Plot area of Radar Graph.

Group 1 was 8.5 with an IQR of 11.25. For Group 2, the median was 10 with an IQR of 9. For Group 3, the median was 14 with an IQR of 7. The differences between Group 1 and Group 3 were statistically significant (Mann-Whitney *U* test, $p < 0.01$). As expected, PD patients with lower stride fluidity measured by the Parkinson's Holter (Group 3) had worse global score on the FoG-Q.

These measures clearly demonstrate that patients with higher stride fluidity tend to have better clinical outcomes across all evaluation scales.

4. Discussion

In the present study we demonstrate that the Parkinson's Holter STAT-ON has sensitivity to detect motor PD severity. Patients with reduced stride fluidity display poorer outcomes in all analyzed clinical scales, making this parameter useful for identifying individuals with a more severe manifestation of the disease. This relationship was confirmed through Radar graph area, which is a compound variable that results from a process of reducing the dimensionality of the different questionnaires. From a clinical point of view, our results are consistent because PD patients with poorer motor state (UPDRS-III) and worse daily-living activities performance (UPDRS-II) exhibit worse stride fluidity measured by the sensor. Besides, a greater severity of motor symptoms [25] is a risk factor for developing FoG among other well-known risk factors such as a worse cognitive status. In line with this, patients with worse FoG-Q score and worse quality of life (PDQ-39 score) present lower fluidity scores.. However, in the present study we have not included cognitive rating scales to address specifically the correlation between cognition severity and Parkinson's Holter STAT-ON gait parameters.

As far as we know, there are no other studies on motor symptom monitoring systems for Parkinson's that have utilized multiple clinical scales, assessing various aspects of the disease, and that have been conducted under the actual conditions of routine clinical practice, without any control over the use of sensors by the researchers. In other studies using sensors with other body locations, moderate to strong correlations with sensor-based measurements and clinical scales have been found. Hence, the KinetiGraph wrist-device (PKG; Global Kinetics Corporation) has been compared with the results of the UPDRS III scale in experiments conducted in a controlled environment, demonstrating a moderate correlation (R of 0.64) [26]. Kinesia (Great Lakes Neuro-Technologies), another device for monitoring motor symptoms of Parkinson's disease placed in wrist/ankle, has shown good correlation with the UPDRS III scale, also in a laboratory setting [27]. These studies have thus been limited to comparisons with standard instruments for measuring motor symptoms but no other aspects of the disease. In a recent study [28] using a lower back accelerometer a moderately correlation with the MDS-UPDRS (part II-r = 0.60 and parts I and III-r = 0.50) was found. In this study, the authors also find that digital mobility sensor measures are more sensitive to change over time than each part of the clinical rating scale. Although in this study the MDS-UPDRS-III scale is used for clinical evaluation, they also demonstrate that a greater number of sensor-based measures reflecting gait quality are more associated with MDS-UPDRS-II more than part III, reflecting that part II of the scale evaluates difficulties in daily-living activities (dressing or transfers) and part III is mainly focused on tremor or rigidity. Nevertheless, in line with our results, these results reflect the importance of having PD specific sensor-based measurements to predict PD severity to therefore implement the correct treatment interventions.

In previous studies conducted with the same device (STAT-ON), very good consistency has been reported between different monitoring and analysis tools for the motor aspects of the disease; for example, in [9,13], sensitivities and specificities were reported to be approximately 90 % with respect to Hauser's diaries or correlations of between 0.7 and 0.8 with the UPDRS III. These studies were also conducted in controlled environments where patients received specific education and training and extensive follow-up by researchers. This environment is completely different from that in this study, which was conducted in real clinical practice conditions, without researchers overseeing the patients' use of the sensor. Patients used it autonomously and without supervision at home after receiving instructions from their doctor. This can lead to a scenario in which there is a significant loss of data during monitoring. In our case, almost 30 % of the monitoring data were lost, due to poor use of the sensor by the user and, at the beginning of the study, due to poor management of the sensors by researchers, which was corrected by modifying the protocol. The loss rate for monitoring was reduced to practically 0 toward the final third of the project when all the technical aspects were refined and the researchers acquired sufficient experience in relaying instructions to the patients. Although the lack of oversight regarding the proper use of the sensor may compromise the correspondence between sensor reports and clinical data, we consider it a significant strength of this study. This study shows a very reliable snapshot of the use of this type of tool in clinical practice, clearly identifying the problems and advantages that professionals may experience using these tools in their day-to-day lives. For this reason, the authors highly value the results presented in this study. The difference between Group 1 (greater stride fluidity) and Group 3 (less stride fluidity) was statistically significant for all the evaluation scales used in the project and for the composite variable that represents the results of all scales. The authors believe that this analytical approach is much more appropriate and makes the use of this type of tool much more intuitive in routine clinical practice.

In addition to the lack of patient supervision during Holter monitoring, it is noteworthy that patients self-administered the FoG-Q and PDQ-39 scales at home, whereas the UPDRS was administered by a doctor at a subsequent appointment, which in some cases occurred up to two months later.. All of this could have reduced the correspondence between the clinical scales and the sensor reports. On the other side, it is important to highlight that the duration of the recording with the Holter (for a minimum of 4 days and up to 10 days) is also a significant difference from previous studies, where, generally, patients have been monitored for much shorter periods. [9–13,15,26,27,29–31]. Therefore, the realistic measurement conditions of our study render its results non-comparable with those of any previous study.

Gait analysis is a crucial diagnostic and prognostic measure of health and disease [32]. Among all the parameters offered by the sensor, we chose stride fluidity as a marker due to its strong correlation with bradykinesia and its ability to provide continuous, objective data on daily motor fluctuations. This continuous monitoring can capture variations

in motor performance that single UPDRS assessments may miss. This sub-study compares clinical scale levels across groups of patients with varying degrees of fluidity, aiming to determine whether fluidity is a reliable parameter for patient classification. In this context, fluidity is the parameter under investigation, while the clinical scales serve as the gold standard for comparison.

We recognize the limitation of comparing continuous sensor data with clinician-derived UPDRS scores obtained weeks later. The protocol did not include contemporaneous measurements of electronic and UPDRS data due to logistical constraints and the primary focus of the trial being broader than just the Holter data collection. This is precisely why we consider our work a sub-study and acknowledge its limitations. Another limitation is the absence of cognitive assessment. The MoMoPa-EC trial did not include systematic cognitive evaluations, as its focus was on motor clinical monitoring and ambulatory gait analysis. However, it is important to note that patients with significant cognitive impairment (MMSE < 24) were excluded from the trial, limiting the range of cognitive variability within the sample. Although cognitive impairment can influence gait disturbances, we do not believe this compromises the validity of our findings. The aim of this sub-analysis was to compare two instruments for assessing motor severity, rather than to identify predictors of clinical status. Nonetheless, we acknowledge that the absence of cognitive data limits the depth of patient characterization. Including such measures would have provided a more comprehensive understanding of the sample and may be relevant in future research. Despite all these limitations, another observational, open-label study with Parkinson's Holter STAT-ON [33] has shown that the sensor has sensitivity to detect treatment interventions. Future studies will aim to include simultaneous electronic and clinician-derived assessments, as well as cognitive evaluations, to strengthen the validity of the comparisons.

All these technological tools for monitoring the symptoms of PD that are being developed and that can already be found in the market have the potential to transform the management of Parkinson's disease. However, to achieve this change, it is necessary to carry out more studies based on clinical practice and to offer professionals connections between the results of these new tools and routine examination conducted in clinical practice. From the perspective of the authors, this remains one of the main barriers to their widespread clinical implementation. The dependence on subjective reports by patients through the current tools and, therefore, the lack of objective and continuous standard references makes it very difficult to create reliable links between the results generated by the new technological tools and the results generated by classic examinations. We hope that studies such as this will help to overcome this barrier by establishing robust connections between existing tools and emerging monitoring devices, thereby facilitating their practical implementation.

Author Contributions:

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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