

Article

Analysis for disease stages of gait in patients with Parkinson's Disease

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Abstract: Understanding the motor patterns underlying the movement of people with Parkinson's disease (PD) is fundamental to the effective targeting of non-pharmacological therapies. This study aims to analyze the gait pattern in relation to the evolutionary stage between I-II and III-IV according to the Hoehn and Yahr scale (H&Y) in people affected by PD. The study was conducted with the participation of 37 PD patients, with a mean age of 70.09 ± 9.53 years, and of whom 48.64% were women. The inclusion criteria were: 1. To be diagnosed with PD; 2. To be in an evolutionary stage of the disease of between I and IV and; 3. To be able to walk independently and without any assistance. Kinematic and spatial-temporal parameters of the gait were analyzed. The results show differences in speed of movement, cadence, stride length, support duration, swing duration, step width, walking cycle duration and double support time between the stages analyzed. These results confirm the differences in PD gait pattern between stages I-II and III-IV. Different behaviors of the same variable were recorded depending on whether the right or left sides were affected by PD.

Keywords: locomotion disorder; cadence; gait oscillation; speed of movement; neurodegenerative disease.

1. Introduction

Parkinson's disease (PD) is one of the most common age-related neurodegenerative diseases [1]. Progressive gait dysfunction is one of the primary motor symptoms in PD [2]. It is usually expressed with a reduction in step length and walking speed, and an increase in step time and cadence [3]. Disturbances in gait and posture are often resistant to drug treatment, deteriorate as the disease progresses, increase the likelihood of falls and result in higher rates of hospitalization and mortality, thus having a negative impact on the patients' quality of life [4]. The difficulty of walking within normal parameters is undoubtedly one of the greatest challenges faced by PD patients.

The H&Y scale is the most widely used instrument for establishing the degree of PD progression by simple staging [5,6]. It is used as the "gold standard" for checking other scales. According to the application of the H&Y scale, the most advanced stages of the disease lead to the worst quality of walking movements in PD sufferers, but limited information is available regarding the evolution of spatial-temporal and kinematic parameters, and the degree to which they contribute to this deterioration of the walking pattern. Therefore, further studies are needed in order to discover what can be done to improve both the extent and quality of PD sufferers' motor skills.

The analysis of walking patterns in healthy people has made it possible to obtain values that are used as references for each variable (speed, cadence, stride length, etc.), which help to diagnose possible alterations in walking when they are analysed [7]. Movement disorders are differentially present throughout the development of various pathologies and may well reflect the underlying pattern of neurodegeneration [1,4]. It would be desirable to have the same values for pathologies which present characteristic patterns of walking, such as Parkinson's disease (stiff gait), because these

help in the early identification of pathologies which generate alterations in gait pattern and cycle, if they have not already been diagnosed.

It is very important to establish which tools will help in the early identification of the different motor changes that occur during the evolution of the disease. From this point of view, it is necessary to make a detailed motor examination in order to determine as precisely as possible where and when it would be most advisable to intervene (from a motor point of view) throughout the course of the disease. Software designed for studying the biomechanics of walking is increasingly modern, specific, easy to use and reliable in providing the information or results that are desired in these studies. Two of the instruments currently used to analyse gait are the well-known inertial sensors [8,9] and dynamometric or force platforms [10], which facilitate the analysis of normal and pathological gaits in different populations.

Studies investigating gait pattern alterations in PD by stage are rare. Therefore, there is a need to identify changes in the pattern of walking as a function of the stage of the disease, by assessing kinematic and spatial-temporal parameters. This will enable health and fitness professionals or physiotherapists to design and implement customised exercise programmes based on the specific needs of PD patients. Early identification is a key factor in establishing effective therapy and reducing costs in health and social care. For this reason, this study aims to analyze the walking pattern (kinetic and spatial-temporal parameters) according to the evolutionary stage (I-II vs III-IV) as specified by the Hoehn and Yahr scale (H&Y) in patients diagnosed with PD.

2. Materials and Methods

This is a primary study of a descriptive type (cross-sectional), in which a health-related population problem was analyzed; the study group comprising PD patients at different evolutionary stages of the disease. Thirty-seven PD patients aged between 49 and 87 years, with a mean age of 70.06 ± 9.53 years, participated in the study, of whom 18 were women. The inclusion criteria were being diagnosed with PD, the evolutionary stage of the disease being between I and IV according to the H&Y scale (a higher score indicates more severe impairment and disability), and being able to walk independently and without any assistance.

2.1. Subjects

The participants of the study were selected through a research proposal addressed to the Parkinson's Association of the province of xx, specifically in the towns of xx and xx, by means of a collaborative framework agreement established between the association and the University of xx for research purposes. Participants volunteered to participate in the study, and those who met the inclusion criteria outlined above were selected. All participants were informed of the objective of the study and signed the informed consent form. The study was submitted to the ethics committee of the Regional Ministry of Health, being assigned the code: CEIC: 2017/343, prior to the start of the research. All the procedures were undertaken in accordance with the ethical standards of the Helsinki Declaration of 1975, as revised in 2008, and Good Clinical Practice [11].

2.2. Instruments

Anthropometric measurements. The height (cm) and weight (kg) of the participants were recorded with the subjects barefoot and wearing light clothing. The subjects' body mass index (BMI) was calculated using the formula: weight/height^2 (kg/m^2). The measuring devices used were a Tanita TBF300 scale with an accuracy of 0.1 kg and a Handac stadiometer with an accuracy of 1.0 mm. The anthropometric measurements were taken following the ISAK (International Working Group of Kinanthropometry) protocols [12].

Dynamometric corridor. The subjects' gait was evaluated by means of the pressure platforms E.P.S.-R1 of the LORAN-Engineering Company (Italy) [10]. This corridor is composed of three platforms with 2304 sensors on an active surface of 2400cm², with a thickness of 7 mm, which facilitates the dynamic bipodal analysis of the patients. The kinetic variables evaluated by the dynamometric platforms in the gait corridor were as follows: Average foot-support area (cm²), maximum foot pressure (Kpa) and average foot pressure (Kpa).

Inertial Sensor. The inertial system used for the study of walking was Wiva® Science [8]: an inertial sensor with the dimensions 40x45x20mm and a weight of 35gr. The Wiva® sensor includes an accelerometer, a magnetometer, and a gyroscope, which allows information to be recorded on the angular velocities reached, by inertial detection devices placed on the L4-L5 spinal segment. In addition, Wiva® collects data on the total time required to complete the task. All this information is sent via Bluetooth to a computer where it is stored on the Biomech Study 2011 v.1 software.1. The spatio-temporal parameters evaluated using Wiva® Science were as follows: speed of movement (m/s), cadence (steps/min), stride length (m), stride length/height (m), step width (m), gait cycle time (s), time spent on double supports (s), average single support time (s), support time (% walking cycle), swing time (% gait cycle), right and left foot half angle (°), right and left leg acceleration gradient, right and left leg deceleration gradient and step roll symmetry.

2.3. Procedure

Personal data was collected from each patient individually before the test was performed. Data collection was always carried out in the morning, 1.5 hours after receiving medication, confirming that the patient was in an "ON" state. The data was recorded on two days a week (Tuesday and Thursday), and in two different locations, where the association has administrative and therapeutic offices.

For the collection of the walk analysis data, each subject was anonymously registered on the Biomech software, along with the following data: patient code, date of birth, gender, weight (kg), height (cm), shoe size and anthropometric measurements of the upper and lower limbs.

The dynamometric corridor was made up of three platforms located on the floor and connected to each other by means of assembly elements that allowed them to be joined sequentially. These platforms were connected via a USB cable to the power supply and a laptop, which saved the data from the step-by-step analysis onto the Biomech program. Preparatory to the test: the patients were requested to walk repeatedly on the platforms. Their walking gait was performed in the usual way, with a normal stride speed so as not to alter their gait pattern, while the repetitions and practice familiarised the patients with the texture and surface of the platforms. Procedure: For the analysis of the gait in the dynamometric corridor, the patients had to: 1. Stand at a distance of 1.5 m from the platform, and; 2. Undertake the following verbal instructions: "Walk at a normal speed until the mark located 1.5 m from the end of the corridor is reached." The patients performed three runs along the corridor and the most stable steps were selected.

Application protocol for the Wiva® Science sensor: The Wiva sensor was fitted to each patient by means of an ergonomic waist band, at the height of the lumbar vertebra 5. Once the Wiva was placed on their waist, the patients were asked to walk in a straight line and to follow any further instructions. The walking gait was to be performed in a normal and natural way. Procedure: For the gait analysis, the patients had to: 1. walk a distance of three meters in a straight line with the Wiva® Science sensor in place; 2. stop and remain immobile for three seconds; 3. turn 360° and stop for another three seconds. The verbal instructions were as follows: "Walk at your normal speed until you reach the mark located 1.5 meters from the end of the corridor", "stop, turn all the way around, and stop again".

In both tests the gait cycle had to be performed in a natural way (with the usual speed and form), barefoot, without help, without load, and over three repetitions to achieve several analyses of the gait, whilst monitoring the support of both the right and the left foot. The patients had to listen carefully to the spoken instructions. Finally, readings were obtained from both feet, providing numerical and graphic data for each phase of the gait cycle to help in the interpretation of the results obtained in the study

2.4. Statistical Analysis

A descriptive analysis was carried out using central tendency measures (mean and standard deviation/standard and percentages) of demographic, kinetic and spatial-temporal variables, both globally and by segmenting the database by gender and stage of Parkinson's disease (H&Y: I-II vs III-IV). The Kolmogorov-Smirnov test ($p>0.05$) was used to prove the normality of the variables under study. The homogeneity of the sample, and the potential differences in variables of gender and stage of Parkinson's disease have been verified through the student test t for independent data. With the aim of analyzing the possible association that the spatial-temporal parameters may have presented, a Pearson correlation analysis was performed to identify, if applicable, the degree of this association. The statistical analyses were carried out using the IBM-SPSS v21 for Windows statistical package. Significance was considered for $p<0.05$.

3. Results

Of the 37 participants in the study, 22 are at H-Y: I-II stage and 15 at H-Y: III-IV stage (Table 1). The youngest group of Parkinson's patients present a higher state.

Table 1. Sociodemographic and clinical characteristics of the participants.

	Total n=37	Hoehn-Yahr I-II (n=22)	Hoehn-Yahr III-IV (n=15)
	Mean±SD	Mean±SD	Mean±SD
Age (years)	70.06±9.53	70.45±10.40	69.67±8.41
Gender, male (%)	50.6%	54.5%	46.7%
Hoehn-Yahr stage	2.49±0.72	1.86±0.31	3.13±0.41

In Table 2, reference is made to the comparative analysis of spatial-temporal and kinetic parameters as a function of the PD stage. This analysis identified the presence of statistically significant differences between the groups, in the main variables analysed.

Table 2. Analysis of gait parameters (spatiotemporal and kinetic) in patients with PD.

	Hoehn-Yahr			
	I - II		III-IV	
	Mean	SD	Mean	SD
Gait speed (m/s)	1.03	0.24	0.83	0.17**
Cadence (steps/min)	84.80	13.77*	95.08	10.55**
Stride length (m)	1.08	0.22	1.02	0.21*
Right step length (m)	0.49	0.21	0.53	0.22*
Left step length (m)	0.59	0.23	0.49	0.20**
Stride length/height (m)	0.65	0.11	0.64	0.13
Step width (m)	0.10	0.02	0.12	0.04**

Stride time (s)	1.24	0.12	1.49	0.20**
Double support time (s)	0.12	0.04	0.22	0.04**
Single support time (s)	0.50	0.08	0.52	0.01
<i>Right step time (s)</i>	0.48	0.08	0.52	0.01
<i>Left step time (s)</i>	0.52	0.09	0.53	0.02
Stance (% gait cycle)	62.62	2.93	72.51	5.52**
Swing duration (% gait cycle)	37.38	4.36	27.49	4.47**
Right foot angulation (°)	9.00	8.58	11.66	10.88**
Left foot angulation (°)	9.60	9.14	9.50	7.89
Acceleration gradient right leg	6.50	2.48	5.31	3.95
Acceleration gradient left leg	7.33	3.59	5.46	1.70
Deceleration gradient right leg	-26.99	18.12	-18.18	12.50**
Deceleration gradient left leg	-18.31	14.14	-16.04	13.54
Swing symmetry in stride	1.00	0.18	1.04	0.26
Foot support surface (cm ²)	122.85	39.46	126.00	24.63
Average foot pressure (Kpa)	147.8	24.72	123.69	47.85
Maximum foot pressure (Kpa)	400.79	73.89	414.89	125.05

Correlation analysis by stage (Table 3), among the kinetic variables, reveals that the greatest number of variables with significant correlations are recorded for stage I-II patients. More specifically, we must indicate that the walking cycle duration variable is the variable which has the highest correlation with the other variables analyzed.

Table 3. Correlations between spatiotemporal parameters depending on the stage of the disease.

	Hoehn-Yahr				Hoehn-Yahr			
	I-II				III-IV			
	Gait speed (m/s)	Cadence (steps/min)	Stride length (m)	Step width (m)	Gait speed (m/s)	Cadence (steps/min)	Stride length (m)	Step width (m)
Stride time (s)	r=-0.644 sig=0.012	r=0.420 sig=0.047	r= -0.663 sig=0.021	r= 0.818 sig=0.004	r=-0.331 sig=0.048	r=0.579 sig=0.038	r= -0.438 sig=0.041	r= 0.666 sig=0.043
Double support time (s)	r=-0.471 sig=0.017	r= 0.414 sig=0.049	r=-0.244 sig=0.041	r= 0.611 sig=0.031	r=-0.201 sig=0.056	r= 0.477 sig=0.050	r=-0.388 sig=0.054	r= 0.633 sig=0.049
Swing duration (% gait cycle)	r=0.414 sig=0.044	r=-0.350 sig=0.092	r=-0.601 sig=0.011	r=-0.518 sig=0.040	r=0.701 sig=0.145	r=-0.698 sig=0.144	r=-0.655 sig=0.129	r=-0.596 sig=0.346
Deceleration gradient	r=0.569 sig=0.017	r=-0.470 sig=0.022	r=0.368 sig=0.046	r=0.345 sig=0.045	r=0.243 sig=0.349	r=-0.369 sig=0.222	r=0.545 sig=0.040	r=0.505 sig=0.043

Figure 1. Evolution of gait speed depending on the stage of PD.

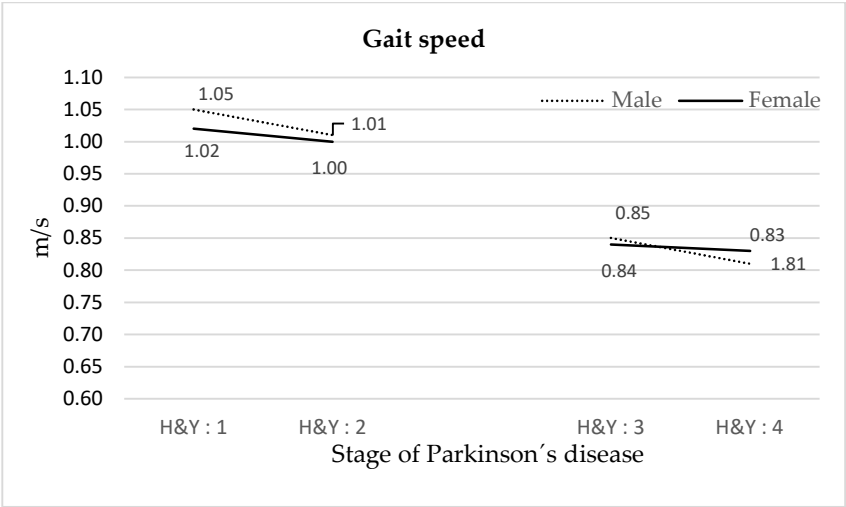
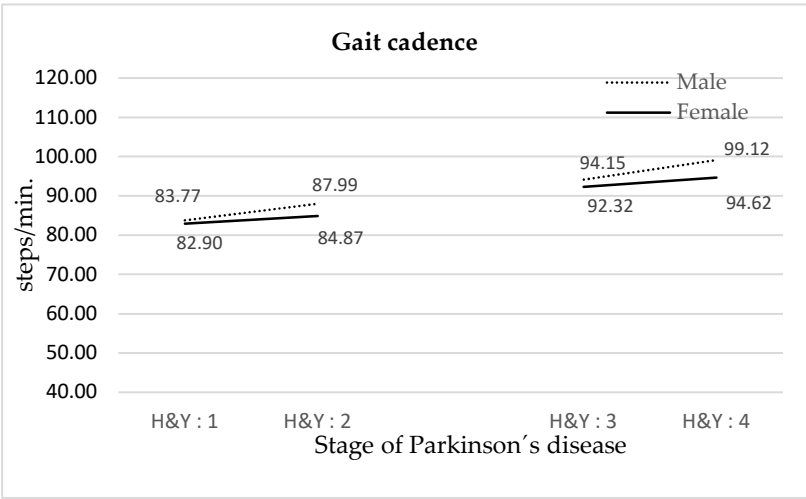


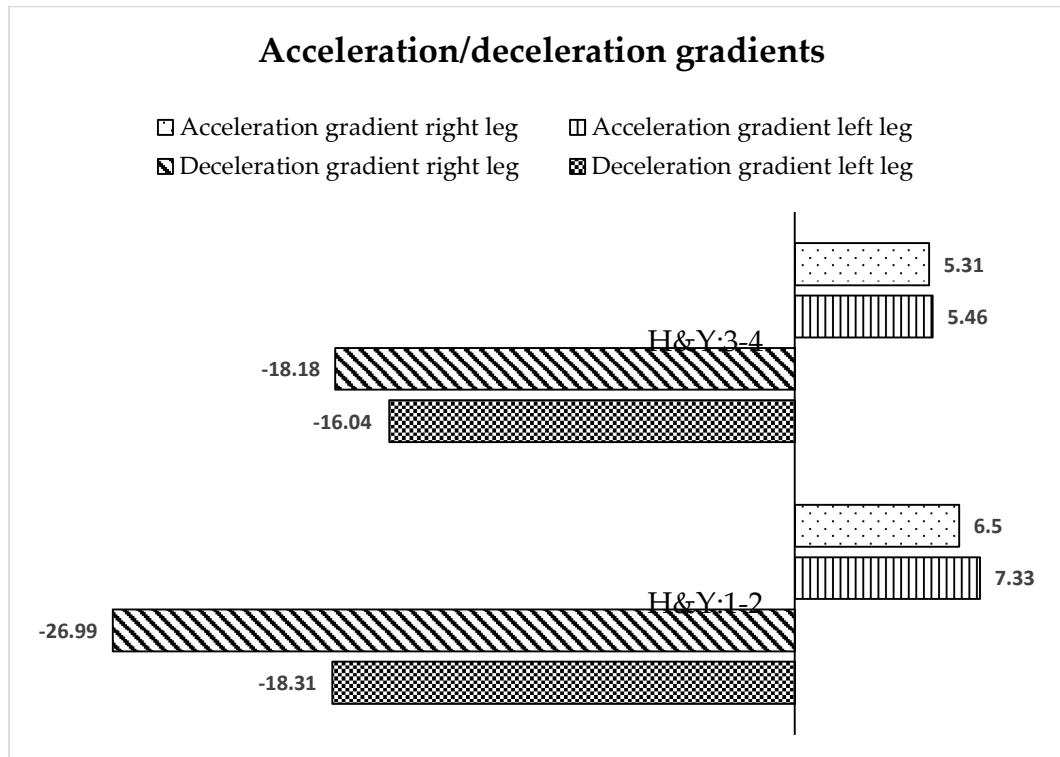
Figure 1 illustrates a decrease in walking speed concurrent with an increase in the stage of PD for both genders. The decrease is less significant in stage III-IV patients, and in women respectively.

Figure 2. Evolution of gait cadence according to the stage of PD.



In Figure 2 the cadence for both genders increases as the PD stage rises. The smallest increase is in women.

Figure 3. Acceleration/deceleration gradients of gait depending on the stage of PD.



The behavior of the acceleration and deceleration gradient of the left leg in both stages is similar, but in the right leg there are significant differences in the deceleration gradient in stages H-Y I-II.

4. Discussion

The objective of the study was to analyze how the motor pattern of walking is modified depending on the stage of the PD patient. The findings of this study confirm that in the analysis of the kinetic and spatial-temporal variables considered important in previous studies, there is a worsening as the disease progresses, with significant deterioration in stage III-IV as compared to stage I-II. The technology used in this study allowed a very precise evaluation of gait disorders by stages, and this more detailed information makes it possible to better target the design of motor interventions aimed at slowing down the progression of the disease as it relates to the gait pattern.

As the disease progresses, changes in gait are accentuated between both groups, manifesting themselves through a decrease in the speed of movement. This behavior is maintained for each stage and gender, but there is a quantitative leap between stages II and III. Cadence increases as the stage increases, suggesting that an attempt is made to compensate for the loss of speed [13]. Speed and cadence behavior are consistent with other studies [14–16]. Other variables that influence gait pattern are an increase in the gait cycle duration, time and duration of double support, duration of swing, and step width. These variables reinforce the observation that walking speed decreases as the PD stage increases, and may be related to problems of dynamic balance [17,18]. The behavior of the variables above does not coincide with the study by Schlachetzki et al. [19], as far as Stage I and III PD are compared.

Stride length behavior is worthy of separate treatment, as it generally decreases as PD progresses, coinciding with the results of Schlachetzki et al. [19]. In a more detailed analysis, an observation of right-stride length shows opposite behaviour to that of left-stride length. The length of the right foot stride in stage I-II is less than in stage III-IV. But the decrease in left leg stride length

from stage I and II to stage III and IV indicates further deterioration. If the variables of a lateral analysis of PD sufferers are observed, significant differences are also observed in the mean angulation of the right foot and the deceleration gradient of the right leg, these being significant differences which are not recorded in the left leg. We do not have an explanation for these results, which makes it necessary to analyze in greater depth the stride length variable. Some authors mention the asymmetry of motor dysfunctions in PD, with symptoms being more visible on the more affected side and deteriorating with the progression of the disease [20]. Others indicate that gait asymmetry is a relatively late change in gait dynamics [2]. The current study appears to be in line with Grajic et al. [21], stating that in early PD patients, gait parameters are asymmetric.

Focusing on the step width correlation analysis, significant correlations were demonstrated (with an "r" higher than 0.6) between the duration of the walking cycle and time spent on double support in stages I-II and III-IV. The rest of the variables do not present this behaviour. Stage I-II patients present a greater number of relationships between variables, suggesting a more stable gait pattern. Siragy and Nantel [17] state that each spatial parameter reflects a different aspect of motor control which contributes to a stable gait. Our study identified a large number of gait pattern variables that differ between stages I-II and III-IV in PD, which seems to indicate the need for different interventions depending on the stage of the patient, and even differing interventions for each leg.

This study has a number of limitations which follow below. First, the sample was selected for suitability, and the size of the sample was small, which made it impossible for the study to be conducted from stage to stage, as stages I-II and III-IV had to be grouped together. Secondly, the evaluation tools have not previously been used by many researchers, which makes discussion of the data more difficult. It is recommended that future research work is undertaken with a larger sample size, and that the gait is analyzed at each stage of PD according to the Hoehn & Yahr classification reference system. It is also suggested that the Parkinsonian gait study is undertaken without the effect of medication (stage Off), since our study was conducted while participants were following their usual medication cycles and the effects of medication on gait cycle should be considered for analysis. Finally, the extent of the patients' laterality and the areas which are affected should be incorporated into the analysis for deeper study.

To sum up, this study has enabled us to provide additional information on the specific gait disturbances associated with each stage of PD, which is useful since a detailed gait analysis is key for understanding their complex pathophysiology in the disorder. Our results may also contribute to the development of a more objective evaluation of motor rehabilitation programs, the effectiveness of which will be demonstrated in the treatment of neurodegenerative disorders such as PD.

5. Conclusions

Of the kinetic and spatial-temporal variables which are considered important in the literature, this analysis revealed a significant deterioration linked to the progression of PD through its four stages. The most significant deterioration occurred in stages III-IV as compared to stages I-II.

Regardless of the patients' gender, in this study, between stages II and III a decrease in the speed of movement and an increase in the gait cadence was noted.

Asymmetry in the spatial-temporal parameters of gait was recorded in the early stages of PD.

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