

# A posturographic procedure assessing balance disorders in Parkinson's disease: a systematic review

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**Abstract:** Postural instability is common in Parkinson's disease (PD), often contributing to falls, injuries, and reduced mobility. In the clinical setting, balance disorder is commonly diagnosed using clinical tests and balance scales, but it is suggested that the most sensitive measurement is the force platform. The aim of this systematic review was to summarize the methods and various posturographic procedures used to assess the body balance and gait in PD. A systematic review was conducted of papers published from 2000 to 2017. Databases searched were PubMed and EBSCO. Studies must have involved patients with PD, used force platform or motion analysis system as a measurement tool, and described posturographic procedure. The Physiotherapy Evidence Database (PEDro) scale was used to assess the methodological quality of the included studies. A total of 32 studies met the inclusion criteria. The PEDro scores ranged from 5 to 7 points. The analysis of the objective methods assessing balance disorders revealed a large discrepancy in the duration and procedures of measurements. The number of repetitions of each trial fluctuated between 1 and 8, and the duration of a single trial ranged from 10 to 60 seconds. Overall, there are many scales and tests used to assess the balance disorders and disabilities of people with PD. Although in many included studies the authors have used posturography as a method to evaluate the postural instability of PD patients, the results are contradictory. To solve this issue, it is indicated to establish a "gold standard" of procedures of measures of balance.

**Keywords:** Parkinson's disease, posturography, balance disorders, postural instability

## Introduction

Maintenance of body balance is important for daily life. Balance is the ability of the human body to maintain the position of its center of gravity (COG) within the area of its base of support (BOS), and balance requires a continuous feedback system that processes visual, vestibular, and somatosensory inputs and executes neuromuscular actions.<sup>1,2</sup> However, Hof<sup>3</sup> introduced the concept of the "extrapolated center of mass" XcoM, and the authors proposed the new definition of human balance: the XcoM must remain within the boundaries of the BOS.

Parkinson's disease (PD) is a chronic and progressive degenerative disorder of the central nervous system, which is characterized by resting tremor, rigidity, bradykinesia, and postural instability. PD affects all age groups, but it is most commonly found in the elderly population.<sup>4</sup>

Postural instability is a common clinical problem in PD which often contributes to falls, injuries, and reduced mobility. Postural instability is due to a dysfunction of postural reflexes and is generally a manifestation of the late stages of the disease.<sup>5</sup>

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A number of clinical tests and balance scales have been used to assess the postural stability, the risk of falling, and motor symptoms in PD.<sup>6</sup> Despite widely used clinical tests, research suggests that some of the tests are not able to identify differences in postural instability and mobility between people with PD and age-matched healthy adults.<sup>7-9</sup> Moreover, postural instability is diagnosed in stage 3 in Hoehn and Yahr (H&Y) scale,<sup>10</sup> but there are some evidences that the postural sway can be abnormal in the early stage of PD before the onset of clinical symptoms.<sup>11</sup> This fact is extremely important, when one use existing methods to identify and quantify the balance disorders in PD patients who do not complain about problems with their postural instability. Nardone and Schieppati<sup>12</sup> suggested posturography to be a useful technique of an early recognition and evaluation of balance dysfunction in PD. This is crucial in clinical practice. Also, with the use of posturography, one may gain a better understanding of the pathophysiological mechanisms of balance disorders in PD.<sup>13,14</sup> Therefore, force plate posturography is a major tool to recognize the balance dysfunction in PD, and it can provide a more objective and sensitive measure of postural instability. This notion is confirmed by the extensive literature on its use in PD.<sup>15-17</sup> In addition, according to the Evidence-Based Medicine policy, the most valuable and reliable scientific evidence is based on an objective assessment,<sup>18</sup> and the posturography is the one of the such methods.

The main purpose of this study was to conduct a systematic review of the published literature on the different methods used to assess balance and gait in individuals with PD.

In addition, this systematic review summarized various posturographic procedures and standard measures of postural sway variability used in studies on balance disorders in PD.

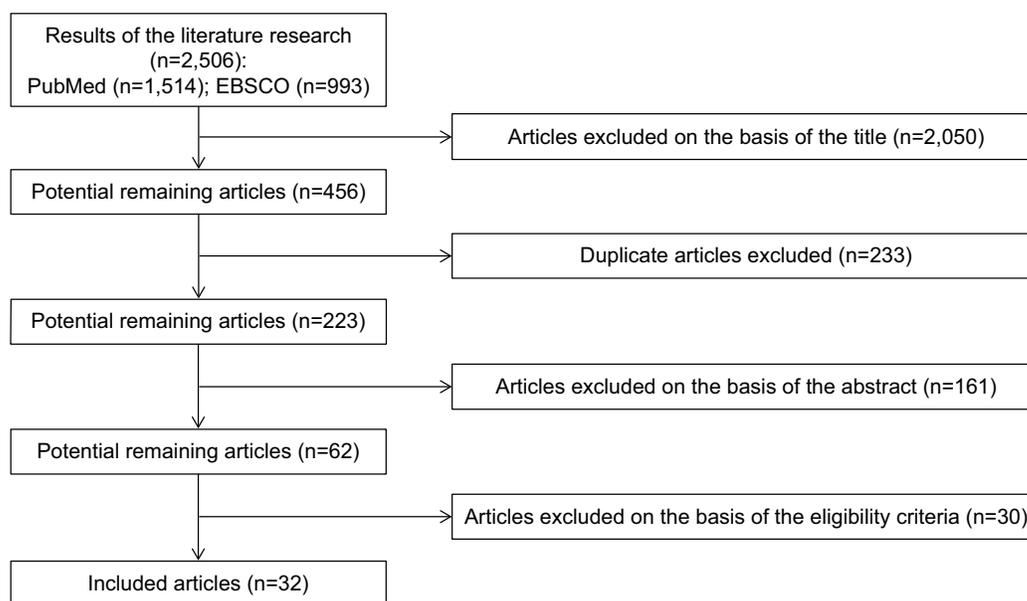
## Methods

### Search strategy

A comprehensive systematic literature search was performed using the following databases: PubMed and EBSCO. We mainly selected articles that were published between 2000 and 2017. Combinations of the following key terms were used for each database: “body balance” OR “postural control” OR “posturography” OR “gait initiation” OR “crossing obstacle” AND “Parkinson’s disease”. The search was limited to articles published in English and full-text original articles.

### Study selection

Early screening of the articles based on titles and abstracts was performed by two authors (AB and MP). The full-text articles were independently assessed by two authors (AK and JM) using the following study inclusion criteria: 1) the participants of the studies had to suffer from PD, 2) the outcome measures had to be a force platform and/or a video camera and/or clinical tests, and 3) the posturographic procedure was described. Studies were excluded if 1) there was no control group, 2) the Physiotherapy Evidence Database (PEDro) scale was lower than 4, and 3) there was a treatment intervention. The results of the study selection procedure are summarized in the flowchart. In total, 32 studies met the inclusion criteria for the review (Figure 1).



**Figure 1** Flowchart for the study search and selection.

## Methodological quality

The quality of the included articles was assessed by three reviewers (AK, JM, and AB) using the standardized and validated PEDro tool. The PEDro scale is an 11-item scale that has been previously used in systematic reviews.<sup>19,20</sup> Any disagreements were resolved via discussion or consultation with the fourth author (KJS).

## Data extraction

Two reviewers (AK and MP) extracted the following information independently from the included studies: study design, assessment protocols, outcome measures, and study conclusion. The data were collated and organized in Tables 1 and 2.

## Results

### Data synthesis

The initial search retrieved a total of 2,506 articles from the databases. After exclusion on the basis of the title and removal of duplicate articles, 223 potential articles were identified. After the abstract review, 62 full-text articles were assessed for the eligibility criteria. Finally, 32 articles met all the inclusion criteria and were included in our systematic review. Figure 1 presents a flowchart of the literature search process.

### Participants' characteristics

The total pooled sample size of all of the included studies was 791 participants, including 383 males and 228 females. The mean age of the subjects ranged between 40 and 90 years among the included studies. A summary of the included studies is presented in Table 3.

### Quality assessment

All of the included studies had a quality score ranging from 5 to 7 points. Of the included studies, 8 were graded as fair and 24 were graded as good. Table 3 illustrates the PEDro points of all the included studies.

### Assessment of balance in PD

#### Subjective assessment of balance and motor abilities

In our review, we found that the H&Y scale was commonly used to assess disease progression from stage 0 (absence of disease symptoms) to stage 5 (wheelchair mobility).<sup>10</sup> In almost all of the studies, individuals with PD had H&Y stage I–III (n=27), suggesting a mild to moderate stage of the disease. In addition, the most widely used (n=24) scale was the Unified Parkinson's Disease Rating Scale (UPDRS),<sup>21</sup>

**Table 1** The characteristics of the measurements procedures and conditions in static and dynamic balance

Reference	Subjective assessment	Objective assessment	Measurements procedure	Measurements duration	Foot position	Measurements condition	Variables	Main findings
Adkin et al <sup>51</sup>	ABC UPDRS	FP	QS	60 s 20 s	Double leg Feet together Single leg	EO/EC EO/EC with the threat of a push or pull EO/EC on foam support	Area COP (mm <sup>2</sup> ), single-leg stance duration	FOF was significantly associated with a qualitative estimate of postural control in PD; individuals with PD who had a greater degree of posture impairment reported greater FOF.
Marchese et al <sup>27</sup>	Tinetti UPDRS	FP (QFP Medicapteurs)	QS	8×51, 2 s	Double leg	EO/EC cognitive task	Area COP (mm <sup>2</sup> ), lenCOP (mm)	No difference of COP parameters between patients and controls, but visual deprivation induced a worsening of postural stability in both groups.
Horak et al <sup>67</sup>	UPDRS	FP moveable platform + 6 video cameras	LOS	8× each direction	Double leg	EO 8 directions: F, FR, R, BR, B, BL, L, FL	The peak COM displacement, the time-to-peak COM, COP displacement	Significant differences between PD and controls. PD subjects had smaller than normal postural stability margins in all directions, but especially for backward sway.

(Continued)

Table 1 (Continued)

Reference	Subjective assessment	Objective assessment	Measurements procedure	Measurements duration	Foot position	Measurements condition	Variables	Main findings
Schmit et al <sup>38</sup>	–	FP (Berotec 4060-NC) + monitor	QS	30 s	Double leg	EO/EC cognitive task	SD COP AP/ML (cm), lenCOP (cm), entropy AP/ML	Significant differences between PD and controls. AP and ML COP SD and COP path length were greater for PD. AP entropy was higher for PD patients than control participants. There were no effects of the cognitive task.
Błaszczyk et al <sup>15</sup>	UPDRS	FP (QFP)	QS	2×30 s	Double leg	EO/EC	lenCOP AP/ML (mm), area COP (mm <sup>2</sup> ), range COP (mm), mean COP (mm)	Significant differences between PD patients and healthy elderly in sway area, sway ranges, and path lengths. These measures had increased in PD group.
Chastan et al <sup>35</sup>	UPDRS	FP (Satel) VICON system	QS	51.2 25.6	Double leg	EO/EC	Total lenCOP (mm), lenCOP AP/ML (mm), area COP (mm <sup>2</sup> )	Under static conditions, early-stage PD patients had a larger sway area than the control subjects. Under dynamic conditions, the PD patients' sway area was greater than control subjects in the AP position. Oscillations of the mobile platform were not different between the two groups.
Termoz et al <sup>29</sup>	–	FP (AMTI)	QS	5×10 s	Double leg, 45° foot position, side-by-side foot with stooped posture	EO	COM lenCOP, vCOP, COP-COM, RMS amplitude	Similar postural control mechanisms in all groups. However, the PD subjects showed significant smaller RMS amplitudes compared to the elderly people in the 45° foot position and in the stooped posture.
Mancini et al <sup>52</sup>	UPDRS	FP + 6 video cameras	QS LOS	3×60 s 1×15 s	Double leg	EO forward and backward leaning	Mean COP AP/ML, maximal forward leaning, functional LOS, COP-COM peak	Functional LOS were significantly smaller in subjects with PD compared to control subjects.
Ganesan et al <sup>42</sup>	UPDRS	Biodex Balance System	LOS	3×20 s	Double leg	EO 8 directions: F, FR, R, BR, B, BL, L, FL	LOS balance index	The dynamic balance indices and total LOS scores did not differ significantly between PD and controls. Direction-wise analysis of LOS showed significantly lower scores in PD compared to controls only in FR and BL directions.

Ebersbach et al <sup>22</sup>	Pull test tandem walk	FP (T&T medilogic GmbH)	QS	60 s	Double leg	EO	lenCOP (mm)	No significant differences were found between controls and patients with impaired pull test for static and dynamic posturography. Patients with normal pull test had lower sway values than controls in dynamic posturography.
Suarez et al <sup>29</sup>	–	FP (BRU)	LOS	NR	Double leg	EO SVF moving field (OK)	Area COP LOS	COP with SVF showed no difference between PD and controls. While LOS with SVF and COP for OK stimulation showed a significant difference. PD patients presented significant differences in the area COP and the balance functional reserve values between static visual field and optokinetic stimulation.
Stylianou et al <sup>30</sup>	UPDRS	FP (advance medical technology)	QS	3×30 s	Double leg	EO/EC	Total lenCOP (mm), lenCOP AP/ML (mm), rangeCOP AP/ML (mm), area COP (mm <sup>2</sup> )	Significant differences between the PD and the two control groups were found in sway path length, area, and ranges in AP/ML directions.
Błaszcyk and Orawiec <sup>33</sup>	UPDRS	FP (QFF)	QS	3×30 s	Double leg	EO/EC	Range COP AP/ML (mm), total lenCOP (mm), lenCOP AP/ML (mm), area COP (mm <sup>2</sup> ) SR	Both the AP/ML SRs were significantly increased in PD patients when compared to the control group.
Ickenstein et al <sup>34</sup>	UPDRS	FP (GK-1000)	QS	2×30 s	Double leg	EO/EC	vCOP (m/s), range COP (m), mean radius (m), area COP (m <sup>2</sup> )	Significant differences between the PD and controls. PD showed a significantly greater mean range, mean radius, speed, and area of COP.
Vervoort et al <sup>41</sup>	UPDRS	SMART balance, test system	LOS	3×20 s	Double leg	EO, the RWS test, the SOT	Equilibrium score and postural strategy, latency time and response strength, directional control	Freezers performed poorer directional postural control compared to nonfreezers and control groups.
Johnson et al <sup>24</sup>	BBS UPDRS	FP (AccuSway Plus)	QS LOS	2×60 s	Double leg	EO/EC	lenCOP AP/ML (cm), area COP (cm <sup>2</sup> )	Static posturography discriminated between PD fallers and controls but not between PD fallers and

(Continued)

Table 1 (Continued)

Reference	Subjective assessment	Objective assessment	Measurements procedure	Measurements duration	Foot position	Measurements condition	Variables	Main findings
Zawadzka-Kunikowska et al <sup>16</sup>	TUG Retropulsion test	FP (PROMED)	QS	2×32 s	Double leg	EO/EC	Area COP (mm <sup>2</sup> ), lenCOP (mm), vCOP AP/ML (mm/s), mean vCOP (mm/s)	nonfallers, whereas dynamic posturography (reaction time, velocity, and target hit time) also discriminated between fallers and nonfallers. No significant differences in any stabilographic parameters were observed between healthy elderly subjects and PD patients.
Fukunaga et al <sup>13</sup>	–	FP (Tetrax)	QS	32 s	Double leg	EO/EC 45° of head rotation to the right/left on a firm surface, head tilted 30° backward on a firm surface, head tilted 30° forward on a firm surface EO/EC on a unstable surface on a cushion	Stability index, weight distribution index, left/right and toes/heel synchronization index, postural oscillation frequency (F1, F2–F4, F5–F6, and F7–F8), fall index	PD showed a significantly higher weight distribution index, fall index, Fourier transformation at low-medium frequencies (F2–F4), and significantly lower right/left and toe/heel synchronization vs controls.
Oude Nijhuis et al <sup>28</sup>	UPDRS Tinetti ABC scale	FP (dual-axis platform) + 18 IREDs + Optotrak motion analysis system	QS	24×	Double leg	EO/EC Platform tilts at velocities 60°/s (fast); 30°/s (medium); 3.8°/s (slow)	Area COM, COM displacement (mm), AP ankle torque	The amplitude of COM displacement was significantly larger for PD patients, compared with controls. Patients were significantly more unstable than controls following fast perturbations, but not following slow perturbations.
Ferrazzoli et al <sup>16</sup>	UPDRS BBS	FP (Prokin 254)	QS	2×30 s	Double leg	EO/EC cognitive task	SD COP (mm), SD COP AP (mm), SD COP ML (mm), area COP (mm <sup>2</sup> )	Significant differences in the SD of body sway between PD and controls. PD patients showed higher values of total SD COP during EO and EC and along the ML axis with EO. Area COP with EO and EC was not significantly different across groups.

Fernandes et al <sup>37</sup>	UPDRS	FP (Emed-AT25)	QS	60 s	Double leg	EO/EC cognitive task	Range COP (cm), vCOP (cm/s)	The COP displacement was significantly higher for the individuals with PD, both in AP and ML directions. The effect of performing a more complex task (standing with eyes closed), or an additional task (enunciating words while standing), on standing balance was not significantly different between the individuals with PD and controls.
Barbosa et al <sup>25</sup>	BBS MBT	FP (AMTI)	QS	3×60 s	Double leg	EO/EC cognitive task	COP (mm/s), SD-AP COP (mm), SD-ML COP (mm), area COP (mm <sup>2</sup> )	Posturographic data showed that PD patients performed worse than controls in all evaluations. In general, balance on dual task was significantly poorer than balance with eyes closed.
Barbieri et al <sup>32</sup>	UPDRS	FP (AccuGait)	QS	3×30 s	Double-leg tandem stance, single-leg stance	EO	Mean vCOP (mm/s), rmsCOP AP/ML (mm), area COP (mm <sup>2</sup> ), asymmetry index (%)	Individuals with PD in the bilateral stage presented higher postural control asymmetry than those in the unilateral stage. In addition, the bilateral group also presented higher postural control asymmetry than neurologically healthy individuals in the tandem adapted and unipedal adapted standing conditions.
Doná et al <sup>40</sup>	UPDRS ADL DGI	FP (BRU)	QS LOS	NR	Double leg	EO/EC	LOS (cm), area COP (cm <sup>2</sup> )	PD had significantly lower LOS area and balance functional reserve values and greater body sway area in all posturographic conditions compared with healthy subjects.

**Abbreviations:** –, not applicable; ABC, The Activities-specific Balance Confidence Scale; ADL, activities of daily living; AP, anteroposterior direction; B, backward; BBS, Berg Balance Scale; BL, backward-left; BR, backward-right; COM, center of mass; COP, center of foot pressure; DGI, Dynamic Gait Index; EC, eyes closed; EO, eyes open; F, forward; FL, forward-left body sway; FP, force platform; FOF, fear of falling; FR, forward-right; IRED, infrared emitting diodes; L, left; lenCOP, length of COP; LOS, limits of stability; MBT, MiniBest test; ML, mediolateral direction; NR, no reported; OK, optokinetic stimulation, moving field; PD, Parkinson's disease; QS, quiet stance; R, right; RMS, root mean square; rmsCOP, root mean square COP; RWS, rhythmic weight shift; SOT, sensory organization test; SR, sway ratio; SVF, stable visual field; TUG, Timed Up and Go test; UPDRS, Unified Parkinson's Disease Rating Scale; vCOP, velocity of COP.

**Table 2** The characteristics of the measurements procedure in different gait constraints

Reference	Subjective assessment	Objective assessment	Measurements procedure	Measurements condition	Variables	Main findings
Rocchi et al <sup>44</sup>	UPDRS	FP infrared cameras	Two steps, starting with the right foot, at normal, comfortable pace 3× step initiation	Feet parallel, narrow stance, wide stance	APA magnitude, APA timing, length of the first step, velocity of the first step	PD subjects had much more difficulty initiating a step from a wide stance than from a narrow stance. Preparation for step initiation from wide stance was associated with a larger lateral and backward COP displacement than from narrow stance.
Lewek et al <sup>23</sup>	UPDRS BBS	3D motion analysis system (VICON) +25-foot walkway	5× each condition	Normal velocity, fastest possible velocity walking on the heels	Gait velocity, arm swing, trunk rotation, stride time asymmetry	PD group showed significantly greater arm swing asymmetry compared to the control group. Both groups had comparable gait velocities, and there was no significant difference between the groups in the magnitude of arm swing in all walking conditions for the arm that swung more.
Vitório et al <sup>50</sup>	UPDRS	Two digital camcorders (JVCTM and GR-DVL9800) +8-m walkway	Walk to the obstacle at preferred speed, step over it, and to keep walking until the end of the pathway 5× each condition	No obstacle, ankle height obstacle, obstacle set at half of the knee height	Stride length, stride duration, stance phase duration, swing phase duration, step length, leading and trailing foot placement in front of the obstacle, leading and trailing toe clearance, leading foot placement after crossing the obstacle	PD demonstrated shorter stride length and greater stride duration than controls. PD also increased their stance phase durations for both obstacle conditions, while the CG maintained comparable step durations for all conditions. For the crossing phase, people with PD demonstrated shorter step length over the obstacle. Leading limbs were closer to the obstacle before and after crossing.
Brown et al <sup>46</sup>	UPDRS	Six-camera motion analysis system (Pulnix TM-670 I/AN and VICON) +10-m walkway	Walk at a self-determined pace in six different testing conditions 6× obstacle trials	Music accompaniment (no music/music), concurrent arithmetic task (single task/dual task), obstacle (no obstacle/obstacle)	Step length, toe-obstacle distance, heel-obstacle distance, step height of lead foot, trail foot, crossing velocity of the lead limb, trail limb, whole-body COM	PD crossed the obstacle slower than CTRL subjects and that concurrent music differentially altered obstacle crossing behaviors for the CTRL subjects and subjects with PD. Subjects with PD further decreased obstacle-crossing velocities and maintained spatial parameters in the music condition. In contrast, CTRL subjects maintained all spatiotemporal parameters of obstacle crossing with music.
Rogers et al <sup>45</sup>	UPDRS	FP (AMTI) infrared cameras	Three steps forward "as fast as possible" beginning at any self-selected time 6× trials	Unperturbed stepping (base condition), perturbed stepping (drop condition, elevate condition)	APA onset time, APA duration, peak displacement time, amplitude, step onset time, step duration, step length, step speed, step clearance, step width	PD patients demonstrated a longer APA duration, longer time to first step onset, and slower step speed than controls. In both groups, the DROP perturbation reinforced the significant reduction in APA duration, increase in peak amplitude, and earlier time to first step onset compared

Vitório et al <sup>49</sup>	UPDRS	Three-dimensional system (OPTOTRAK) +8-m walkway	Walk along a pathway at preferred speed and to step over an obstacle 3× trial	Obstacle crossing	Leading and trailing foot placement in front of the obstacle, leading and trailing toe clearance, leading foot placement after crossing the obstacle	There were no significant differences between patients with mild PD and healthy individuals. Patients with moderate PD exhibited shorter distances for leading toe clearance and leading foot placement after the obstacle than did healthy individuals. Patients with moderate PD tended to exhibit a lower leading horizontal mean velocity during obstacle crossing than did healthy individuals.	with other conditions. During ELEVATE trials that opposed the intended weight transfer forces, both groups rapidly adapted their stepping to preserve standing stability by decreasing step length and duration and increasing step height and foot placement laterally.
Doan et al <sup>47</sup>	UPDRS	FP (Kistler) 4.7-m walkway vision-occluding goggles (PLATO)	Walk at a self-selected speed along the walkway in each of the high and low conditions 18× each condition	High conditions (walkway was 0.7 m above the ground), low conditions (walkway was outlined on the floor)	Trail foot precrossing clearance, lead foot postcrossing clearance, lead foot crossing step length, trail foot crossing step length, averaged step length, COM crossing velocity, vertical toe clearance	PD patients making shorter crossing steps, with decreased initiation and crossing velocities. Compared to CTRL participants, PD used a smaller precrossing margin. PD off and PD on used significantly slower whole body COM obstacle crossing velocity in the high condition. PD off had a high frequency of obstacle contacts in the high condition.	
Galna et al <sup>48</sup>	UPDRS	FP three-dimensional motion analysis system (VICON) +10-m walkway	Walk at preferred pace. For obstacle crossing trials, the starting position was calculated to be 10 steps away from the obstacle 8× each condition	Level ground walking Obstacle crossing	Mediolateral excursions of the COM, COM-COP inclination angle, peak medial and lateral velocity of the COM	People with PD had greater sideways sway than healthy older adults when walking, particularly when walking over obstacles. People with PD also maintained their COM more medial to their stance foot throughout the swing phase of gait compared to controls. The severity of motor symptoms in people with PD, measured using the UPDRS-III, was associated with faster sideways COM motion but not increased COM excursions.	

**Abbreviations:** APA, anticipatory postural adjustment; BBS, Berg Balance Scale; CG, control group; COM, center of mass; COP, center of foot pressure; CTRL, control; FP, force platform; PD, Parkinson's disease; UPDRS, Unified Parkinson's Disease Rating Scale.

**Table 3** A summary of the included studies – group characteristics

Reference	PD					Control		PEDro
	n (F/M)	Age (years), mean $\pm$ SD	H&Y scale	Disease duration (years), mean $\pm$ SD	UPDRS	n (F/M)	Age (years), mean $\pm$ SD	
Adkin et al <sup>51</sup>	58 (19/39)	66.2 $\pm$ 9.3	NR	6.5 $\pm$ 4.9	NR	30 (16/14)	66.7 $\pm$ 8.1	6
Marchese et al <sup>27</sup>	24 (8/16)	66.4 $\pm$ 7.9	II–III	8.9 $\pm$ 3.3	NR	20 (7/13)	60.9 $\pm$ 7.4	5
Horak et al <sup>57</sup>	7 (NR)	67.0 $\pm$ 2.0	III–IV	17.6 $\pm$ 5.0	56.5 $\pm$ 6.0	7 (NR)	66.3 $\pm$ 2.2	6
Schmit et al <sup>38</sup>	6 (4/2)	70.8 $\pm$ 15.9	III	6.2 $\pm$ 1.1	NR	6 (4/2)	70.17 $\pm$ 4.71	6
Błaszczyk et al <sup>15</sup>	55 (20/35)	64.6 $\pm$ 8.9	I–III	5.5 $\pm$ 4.4	NR	55 (20/35)	64.3 $\pm$ 7.9	6
Chastan et al <sup>35</sup>	9 (4/5)	61.7 $\pm$ 8.4	I	3.2 $\pm$ 2.0	10.3 $\pm$ 2.0	18 (8/10)	60.6 $\pm$ 7.4	6
Termoz et al <sup>29</sup>	10 (NR)	60.2	II–III	5.0 $\pm$ 3.3	NR	10 (NR)	60.4	5
Mancini et al <sup>52</sup>	13 (6/7)	60.3 $\pm$ 8.5	I–II	12.5 $\pm$ 5.1	28.5 $\pm$ 14.5	10 (NR)	64.9 $\pm$ 8	6
Ganesan et al <sup>42</sup>	20 (NR)	58.3 $\pm$ 8.7	II	3.6 $\pm$ 2.0	28.3 $\pm$ 5.0	20 (NR)	57.9 $\pm$ 8.5	5
Ebersbach et al <sup>22</sup>	58 (23/35)	65.9 $\pm$ 7.8	I–III	9.5 $\pm$ 6.3	16.1 $\pm$ 12.0	29 (15/14)	66.8 $\pm$ 6.4	6
Suarez et al <sup>39</sup>	24 (NR)	66.5 $\pm$ 8.5	I–II	NR	NR	19 (NR)	62.3 $\pm$ 12.7	5
Stylianou et al <sup>30</sup>	19 (NR)	65.0 $\pm$ 9.7	I–III	5.2 $\pm$ 4.7	21.3 $\pm$ 8.5	14 (NR)	67.8 $\pm$ 9.6	5
Błaszczyk and Orawiec <sup>33</sup>	55 (20/35)	64.6 $\pm$ 8.9	I–III	5.4 $\pm$ 4.4	23.3 $\pm$ 12.1	55 (20/35)	64.3 $\pm$ 7.9	6
Ickenstein et al <sup>34</sup>	12 (6/6)	71.9 $\pm$ 5.8	I–III	NR	NR	10 (6/4)	72.0 $\pm$ 6.9	6
Vervoort et al <sup>41</sup>	19 (2/17)	58–75	II–IV	9.0 $\pm$ 4.0	25.5	10 (7/3)	63–74	6
Johnson et al <sup>24</sup>	48 (28/21)	65.0 $\pm$ 8.0	II–III	4.6 $\pm$ 0.6 7.2 $\pm$ 0.9	12.7 $\pm$ 1.7 17.5 $\pm$ 1.9	17 (10/7)	64 $\pm$ 7	7
Zawadka-Kunikowska et al <sup>36</sup>	15 (NR)	73.5 $\pm$ 9.7	I–III	NR	NR	24 (NR)	42–90	5
Fukunaga et al <sup>43</sup>	30 (12/18)	59.8 $\pm$ 10.3	I–III	NR	NR	29 (18/11)	58.9 $\pm$ 9.8	6
Oude Nijhuis et al <sup>28</sup>	7 (1/6)	56.1 $\pm$ 68.6	II–III	5.0 $\pm$ 1.8	41.0 $\pm$ 17.1	8 (1/7)	53.4 $\pm$ 67.0	6
Ferrazzoli et al <sup>26</sup>	29 (17/12)	69.2 $\pm$ 8.8	II–III	10.6 $\pm$ 5.2	18.6 $\pm$ 5.5	12 (9/3)	66.5 $\pm$ 6.3	6
Fernandes et al <sup>37</sup>	50 (NR)	68.3 $\pm$ 7.3	II	NR	19.1 $\pm$ 7.9	60 (NR)	68.9 $\pm$ 10.1	6
Barbosa et al <sup>25</sup>	40 (16/24)	67.2 $\pm$ 4.3	II–III	NR	NR	27 (17/10)	68.37 $\pm$ 3.7	6
Barbieri et al <sup>32</sup>	19 (NR)	72.7 $\pm$ 5.9	I–III	NR	13.6 $\pm$ 2.8 27.5 $\pm$ 7.7	11 (5/6)	69.18 $\pm$ 7.37	6
Doná et al <sup>40</sup>	41 (12/29)	40–80	I–III	8.0 $\pm$ 6.0	27.0 $\pm$ 14.0	41 (19/22)	62 $\pm$ 12	6
Rocchi et al <sup>44</sup>	21 (5/16)	61.7 $\pm$ 7.8	II–III	16.2 $\pm$ 9.2	22.4 $\pm$ 11.2	24 (6/18)	62.4 $\pm$ 7.4	5
Lewek et al <sup>23</sup>	12 (9/3)	68.0 $\pm$ 8.0	I	2.0 $\pm$ 0.8	11.2 $\pm$ 5.5	8 (3/5)	61 $\pm$ 12	6
Vitório et al <sup>50</sup>	12 (4/8)	67.0 $\pm$ 6.2	I–III	7.1 $\pm$ 5.5	30.9 $\pm$ 19.0	12 (4/8)	67 $\pm$ 6.44	6
Brown et al <sup>46</sup>	10 (3/7)	67.2 $\pm$ 6.1	II–III	4.2 $\pm$ 7.3	27.3 $\pm$ 5.3	10 (7/3)	65.9 $\pm$ 6.0	6
Rogers et al <sup>45</sup>	8 (3/5)	72.9 $\pm$ 9.3	II	4.3 $\pm$ 3.2	16.8 $\pm$ 4.5	8 (3/5)	73.3 $\pm$ 9.1	6
Vitório et al <sup>49</sup>	30 (16/14)	70.8 $\pm$ 6.9	I–III	NR	18.2 $\pm$ 5.6 28.9 $\pm$ 6.9	15 (8/7)	70.7 $\pm$ 5.1	6
Doan et al <sup>47</sup>	10 (5/5)	69.7 $\pm$ 10.3	NR	8.2 $\pm$ 6.6	18.1 $\pm$ 10.5	10 (NR)	68.8 $\pm$ 8.4	5
Galna et al <sup>48</sup>	20 (7/13)	65.6 $\pm$ 7.7	I–III	NR	12.6 $\pm$ 5.1	20 (7/13)	65.3 $\pm$ 8.0	6

**Abbreviations:** F, female; H&Y, Hoehn and Yahr; M, male; NR, not reported; PD, Parkinson's disease; PEDro, Physiotherapy Evidence Database; UPDRS, Unified Parkinson's Disease Rating Scale.

which has been developed to assess the disability of patients and has become the gold standard in the clinical judgment of PD patients. The scale consists of four main elements: the state of intellectual and mood disorders (Part I), activities of daily life (Part II), motor symptoms and balance disorders

(Part III), and complications of treatment (Part IV). The UPDRS is predominantly used in clinical settings and in research on Parkinson's disease.<sup>22</sup>

The most conventional clinical tests to assess the balance in PD are the Berg Balance Scale (BBS);<sup>23–26</sup> Timed Up and

Go (TUG) Test,<sup>24</sup> Tinetti test,<sup>27,28</sup> and pull-test, tandem walk, and single-leg standing tests.<sup>11,18</sup>

### Objective assessment of balance

Beyond all these clinical assessments, there is computerized posturography, which has been widely used to quantify the postural control by analyzing the displacement of the center of foot pressure (COP). In our review, almost all the authors used different types of force platforms. Most of the authors assessed static balance on stable platforms: AMTI AccuGait, AccuSway,<sup>24,25,29–32</sup> QFP Medicapture platform,<sup>15,27,33</sup> GK-1000,<sup>34</sup> SATEL platform,<sup>35</sup> and PROMED.<sup>36</sup> In some articles, the following pressure platforms were used: T&T Medilogic GmbH<sup>17</sup> and Emed AT25;<sup>37</sup> in other articles, platforms were connected to monitors and virtual reality was used: Bertec 4060-NC,<sup>38</sup> the BRU™ Balance Rehabilitation Unit,<sup>39,40</sup> and the Smart Balance Master System.<sup>41</sup> Researchers sometimes applied a system designed to test balance and stability that provided balance training for patients; the system used was a mobile platform: the Biodex Balance System,<sup>42</sup> Tetrax System,<sup>43</sup> Prokin 254,<sup>26</sup> and a dual-axis platform.<sup>28</sup>

In addition to the objective assessment of static balance, there were many scientific articles that evaluated dynamic balance in PD. The authors mainly examined step initiation<sup>44,45</sup> and gait with<sup>46–49</sup> or without crossing an obstacle.<sup>23</sup> In most cases, the authors used an optoelectronic three-dimensional system with a walkway,<sup>23,46,49</sup> sometimes these systems were used together with a force platform,<sup>45,48</sup> but sometimes the force platform was used only with a walkway.<sup>44,47</sup>

### Posturographic measurement procedures used in PD

Postural instability is one of the most common problems for people with PD and is extensively diagnosed by force plate posturography. In reviewing the literature, we noticed that there were many different measurement procedures. The most standard procedures were the quiet stance (QS) test (n=20) and the limits of stability (LOS) test (n=7). In most cases, the duration of barefoot standing was 30 seconds (n=7), 32 seconds (n=2), and 60 seconds (n=6), and in one case, the trial lasted for 10 seconds. However, there was also a test in which the trial lasted for 51.2 or 25.6 seconds.<sup>27,35</sup> The duration of the single-leg stance test was 20 seconds,<sup>51</sup> and the duration of the LOS test was 20 seconds<sup>41,42</sup> or 15 seconds.<sup>52</sup> Each trial was repeated one time or two to eight times, but the trial was mostly repeated three times. Postural instability was also measured at several positions of the foot: double leg (n=17), single leg (n=2), and tandem stance (n=2). The detailed characteristics of the measurement procedures and conditions are shown in Table 3.

The ability to maintain balance depends on the integration of the proprioceptive, vestibular, and visual systems.<sup>53</sup> Therefore, the researchers assessed the balance under various conditions. Static balance was measured with the eyes open and closed (n=20) and on both stable and unstable surfaces. In some articles, the authors investigated standing balance in individuals with PD under single- and dual-task conditions, such as counting or talking<sup>25,26,37,38</sup> and with the support of surface perturbation.<sup>28</sup>

Impaired balance control is also associated with gait disturbance in PD patients. Comparing to standing the gait is a big challenge for maintaining balance, and it is well known that the postural instability increases dramatically as the BOS changes from a double-leg stance to a single-leg stance during a step.<sup>54</sup> Patients with PD exhibit a deficit in maintaining balance during transition between states of static and dynamic equilibrium, such as gait initiation. PD can perform straight line walking task relatively easily, but they experience severe problems during more demanding tasks such as crossing obstacles.<sup>55</sup> Therefore, in this review, we included studies that consider the most demanding gait constrains in PD.

The researchers used different procedures to assess these aspects of dynamic balance; two of them investigated only gait initiation.<sup>44,45</sup> Rocchi et al<sup>44</sup> tested step initiation when the initial stance changed from narrow to wide. In this study, the subjects were instructed to take two steps, starting with the right foot at their comfortable rate and step initiation trials were performed three times, whereas Rogers et al<sup>45</sup> examined the effect of perturbations of ground support on postural control during step initiation in PD.

Some authors<sup>48,49</sup> examined gait along a walkway at their preferred speed and crossing an obstacle. Vitória et al<sup>49</sup> measured obstacle avoidance three times, and the participants were also informed to step over the obstacle with their right leg. Galna et al<sup>48</sup> tested four trials for level-ground walking and eight trials for walking with obstacle avoidance. In another study, Brown et al<sup>46</sup> explored whether a concurrent task affected obstacle crossing. In their study, subjects walked along a walkway at a self-determined pace under six different testing conditions: music accompaniment (no music/music), a concurrent arithmetic task (single task/dual task), and walking without or with crossing an obstacle. In our review, we also found that some authors recorded gait under three conditions: preferred gait velocity, fastest possible gait velocity and walking on the heels. All of these trials were performed five times.<sup>23</sup>

Furthermore, in Doan et al,<sup>47</sup> the researchers tested patients with PD during stepping over an obstacle in a threatening

context. Participants walked under two separate conditions: on the gait path with the obstacle raised above the floor and on the gait path with the obstacle at floor level. Each trial was repeated 18 times. The detailed characteristics of the measurements procedures and conditions are shown in Table 1.

## Postural instability in PD: results of objective methods

### Static balance

Many researchers have investigated the postural instability in patients with PD. Postural sway can be measured by a force platform that registers displacements of the COP. Alterations in body sway can be described by numerous variables, such as the area, range, velocity, frequency, path length, root mean square, and SD of the COP.<sup>56</sup> All these COP measures and the range of the LOS were estimated in the reviewed articles.

The searched literature that performed an objective posturographic assessment provided contradictory results. A large majority of the studies revealed that PD patients exhibited body sway at higher rates than that of healthy aged-matched subjects ( $n=12$ ), whereas other findings showed similar ( $n=4$ ) and smaller ( $n=2$ ) body sway.

According to some researchers,<sup>15,25,30,33–35,40</sup> patients with PD, during a QS both with eyes open and eyes close, presented a significantly greater spontaneous sway area than elderly people without neurodegenerative problems. In addition, the total anteroposterior (AP) and mediolateral (ML) sway path lengths were higher in PD.<sup>15,30,33,35</sup> Also, the mean velocity of the COP oscillation was significantly different between PD patients and the aged-matched control groups.<sup>25,34</sup> On the other hand, in some articles, analysis of the COP area and path COP (length and velocity) during QS showed a lack of significant differences between PD patients and elderly people without neurodegenerative problems.<sup>24,27,36</sup> Moreover, the mean values of the AP and ML sway range measured in the PD group were significantly higher compared to those of the control group.<sup>15,33,34,37</sup> Similarly, in other studies, the SDs of the COP were significantly greater in PD patients.<sup>25,26</sup> Furthermore, Ebersbach and Gunkel<sup>17</sup> compared PD patients (with a normal pull-test and with pull-test score of 1 or 2) and healthy controls. In this study, they observed that patients with a normal pull-test had lower sway than the control group in static and dynamic posturography. Termoz et al<sup>29</sup> compared the postural control mechanisms of young, elderly, and PD patients. These authors suggested similar postural control mechanisms in young, elderly, and PD

subjects. However, PD subjects showed significantly smaller root mean square amplitudes compared to the elderly people. These findings imply that PD patients use a stiffening strategy to control their balance.

The visual system yields central nervous system information regarding the position of the body relative to the environment. In the abovementioned studies, the authors found that all of the recorded variables increased after visual deprivation.

Another very important aspect is falling, which is very common in PD patients who has a high risk of falling.<sup>43</sup> In comparison to the control group, PD patients showed significantly less confidence in maintaining their balance and preventing falls during the performance of daily activities, which was associated with the increasing area of the COP.<sup>51</sup> In addition, Johnson et al<sup>24</sup> used posturography to assess postural stability and discriminate between fallers and nonfallers in PD. Their results indicated that the static posturography variables measured allowed discrimination of fallers from elderly people without neurodegenerative problems, while none of these variables discriminated fallers from nonfallers. Regarding dynamic balance, fallers exhibited significantly slower reaction times than nonfallers and controls and also had a significant slowing of their movement velocity compared to nonfallers and controls.

Many studies found effects of cognitive tasks and a simple motor task in static balance disturbance in PD.<sup>25–27,37,38</sup> Some authors<sup>26,27</sup> found that the COP area and the SD of the COP were significantly increased in PD patients during dual task performance, whereas no difference of the COP path was observed. Similarly, Barbosa et al<sup>25</sup> showed that balance in the dual task was significantly poorer than balance with eyes closed. However, Fernandes et al<sup>37</sup> and Schmit et al<sup>38</sup> found that the influence of performing an additional task on COP displacement was similar for both the PD and elderly groups.

Under clinical conditions, balance disorders are diagnosed with a score of stage 3 or higher on the H&Y scale. In our review, we noticed that some studies examined the PD population in the early stages of PD<sup>30,35,37</sup> and compared them to those with moderate and high disease severity.<sup>32</sup> Stylianou et al<sup>30</sup> claimed that ML sway path length, sway area, and sway range are sensitive to the effects of PD even in mild to moderate severity patients. Similarly, Chastan et al<sup>35</sup> investigated sway path length and sway area, but they noticed significant difference between groups only in sway area. Also Fernandes et al<sup>37</sup> noticed that the AP and ML sway range were significantly greater in early stage PD than control subjects. In addition, individuals with PD in H&Y stage II–III

presented higher postural control asymmetry than those in H&Y stage I. In addition, PD in II–III also presented higher postural control asymmetry than neurologically healthy individuals.<sup>32</sup> According to all these results, postural instability exists in the early stages of PD before clinical symptoms. Moreover, Błaszczyk et al<sup>15</sup> and Błaszczyk and Orawiec<sup>33</sup> performed a significant correlation between H&Y stage and sway range under both eyes open and closed conditions and ML sway path length under eyes open condition. H&Y stages are also associated with risk of falls.

Most of reviewed studies reported disease duration, but not everyone correlate it with results. Błaszczyk and Orawiec<sup>33</sup> found that in the PD patient, both AP and ML sway ranges recorded with eyes closed correlated with the duration of the disease. Also the ML sway ratio correlated with PD duration. However, Johnson et al<sup>24</sup> revealed no correlation between disease duration and static and dynamic posturography.

Many authors investigated the LOS in different directions.<sup>31,39–42,52,57</sup> The LOS values were significantly lower (suggesting impaired balance and increased risk of falling) in PD patients compared to controls.<sup>40,42,52</sup> PD subjects had smaller postural stability margins in all directions than elderly people, but PD patients maintained greater stability in the forward direction compared to the backward direction.<sup>40,56</sup> Moreover, Bonnet et al<sup>31</sup> tested impairments in ML body shifts. In this study, PD patients showed a significantly lower contribution of the ML postural control mechanisms compared with elderly control subjects. In addition, Vervoort et al<sup>41</sup> analyzed the ability to move the COP ML and AP in a group of PD patients (freezers and nonfreezers) and age-matched controls. This study revealed that freezers performed poorer in a directional postural control task compared to nonfreezers and control subjects.

Some authors correlated posturographic and clinical variables.<sup>24–27,33</sup> The authors most commonly investigated relationships between posturography and BBS, TUG test, Tinetti test, and UPDRS. Johnson et al<sup>24</sup> noticed the strong correlations with the BBS and TUG time, which were linearly related to falls and which were significantly positive correlated with the sway area. However, in some studies, there was only a weak correlation between ML SD of the COP and BBS in eyes open condition.<sup>25</sup> Also, Ferrazzoli et al<sup>26</sup> show a significant negative correlation between BBS scores and ML SD of the COP and sway area. But the same authors pointed no significant correlation between posturographic parameters and disease severity evaluated with UPDRS. Similarly, Marchese et al<sup>27</sup> presented no significant correlation among

UPDRS, Tinetti test, and mean values of COP area and COP path under both visual conditions. But in other study, there was a significant positive correlation between the ML sway ratio under eyes open conditions and the UPDRS.<sup>33</sup>

### Dynamic balance during gait initiation and walking

Gait initiation is a motor task that involves alternating from a QS in double-limb support to a dynamic balance that allows forward body movement; gait initiation consists of a preparatory phase and stepping phase.<sup>58</sup> The preparatory phase is associated with anticipatory postural adjustments (APAs) in which the COP shifts backward and toward the swing limb to move the body center of mass (COM) forward and over the stance limb prior to stepping.<sup>58</sup> Some studies have indicated that in comparison with healthy control subjects, APA in PD patients may be abnormal. In the patients with PD, self-initiated steps were characterized by a longer APA duration, longer time to first step onset, and slower step speed than those of controls.<sup>45</sup> Sometimes, APAs were tested during step initiation from a narrow-stance and wide-stance BOS. The results indicated that the preparation for gait initiation from a wide stance was associated with a larger lateral and backward COP displacement than that from a narrow stance, and PD patients had much more difficulty starting to step from a wide stance.<sup>44</sup>

Gait in PD is a topic of growing interest for researchers. Many authors examined straight line walking and more demanding tasks for PD patients, such as crossing an obstacle. Lewek et al<sup>23</sup> performed an examination of arm swing magnitude and asymmetry in individuals with early PD, and their results indicated that there were no significant differences in arm swing magnitude between the PD and control groups. Considering obstacle avoidance, subjects with PD crossed the obstacle slower than healthy subjects.<sup>46,47</sup> Some people with PD walked with greater and faster ML sway than control subjects, particularly when walking over obstacles. In addition, PD patients maintained their COM more medial to their COP compared to the control group when transferring the lead limb over the obstacle. These results suggest that PD reduces the risk of lateral falls.<sup>48</sup>

## Discussion

A systematic review was conducted on the different methods and various posturographic procedures and standard measures of postural sway variability used in studies on balance disorders in individuals with PD. This analysis identified many potentially important differences in the included studies.

The postural changes in PD are widely described by different authors, but the results are often dissimilar and contradictory. Some reviewed articles showed that patients with PD have higher values of the COP variables than people without neurological deficits.<sup>15,30,33–35,38</sup> However, other studies shown that COP variables are lower in patients with PD than in healthy subjects,<sup>17,29</sup> and Zawadka-Kunikowska et al<sup>36</sup> noted no significant differences between groups, and also Fernandes et al<sup>37</sup> and Marchese et al<sup>27</sup> obtained similar results. This might be due to the sample size. Although seven articles had fewer than 15 participants in each of their groups,<sup>28,29,34,35,38,52,57</sup> out of the 24 studies focused on static balance included in this review, none reported the sample size calculation results. In addition, some studies have not equinumerous patients and control groups.<sup>17,24,25,27,36</sup> Although it is important to emphasize that a large sample size is not always required, reporting the outcome of an appropriate statistical power calculation could be beneficial for reported findings.

Furthermore, postural difficulties are different during PD progression and at each stage of PD. According to the H&Y scale, the balance disorders occur only in the third stage.<sup>10</sup> However, it has been reported that postural instability may appear already in the early stages of the disease, even before the onset of clinical symptoms.<sup>11</sup> The current knowledge about changes in postural control in mild to moderate PD is limited and unclear, but it is known that the early stage PD patients had a larger sway area,<sup>35</sup> COP displacement, and COP velocity<sup>37</sup> than the control subjects. This systematic review indicated that there are only few articles that consider balance dysfunction in early stages of the disease, and the majority of authors assess postural control in the entire PD population (H&Y stage I–III) without dividing into mild to moderate stages. These issues can negatively affect the future interpretations of results and give contradictory information about postural control in people with PD.

Another issue that was noticed in the review is different duration of QS and various numbers of repetitions of each trial. It is known that in most cases of common COP measures, it will be enough to average three 30 seconds trials or one to two 60 seconds trials to achieve acceptable reliability ( $R=0.7$ ).<sup>59</sup> Within the included studies, we have noticed that some authors employed different measurements procedures. Termoz et al<sup>29</sup> applied five 10 seconds trials; other authors used one to two 32 seconds trials,<sup>36,43</sup> 8 of 51 2 seconds trials,<sup>27</sup> or one to two 30 seconds trials;<sup>34,38</sup> and two studies did not report information about duration and

repetitions of trials.<sup>39,40</sup> These are articles where we noticed different results compared to other studies. Moreover, what is also significant in research planning, another potential reason regarding discrepancy in the results is that the authors use diverse equipment and sampling frequency leading to different outcome measures. Of the 24 reviewed studies, 14 articles reported sampling frequency that ranged from 10 to 200 Hz.

Although it was not the primary goal of our review to evaluate the effects of PD-related parameters (eg, UPDRS), disease duration or antiparkinsonian medications on measures of standing balance and walking stability, they are important factors that should be considered. It is widely recognized that levodopa reduced rigidity and improved bradykinesia and gait speed,<sup>60</sup> but it have little impact on balance.<sup>61</sup> However, in most included studies, the PD patients were tested in the “ON” state after the intake of dopaminergic drugs. Only one of the reviewed articles investigated the levodopa effect on postural control. We also noticed that most studies reported disease duration, but the authors of only two articles compared this aspect with their results.<sup>24,33</sup> Therefore, there is a clear need for further research in this area.

## Conclusion

PD is the most common neurodegenerative disease and has been widely investigated by many researchers. It is well known that PD patients have numerous balance and motor disorders, and investigators have examined many different aspects of these disabilities. In our review, we found that tests of both static and dynamic balances in PD were performed and that the authors used various subjective and objective methods. Regarding the objective methods, we found that there were many dissimilar procedures in posturography. There were various measurement durations, conditions, variables, and equipments used. In our opinion, to better assess postural control in PD, reliable procedures to measure balance should be established. Future researchers in this topic should precisely define the reliability and validity of the measures and methods, duration and number of repetitions of trials, sample size, and sampling frequency. Furthermore, future studies should take account of specific PD-related characteristics such as the stage of the disease. Thereby, it is possible to create a gold standard in posturography measures in PD. In addition, we suggest using objective methods (for example, force plate) to assess balance, with standard clinical tests as supplementary procedures.

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## Disclosure

The authors report no conflicts of interest in this work.

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