The Proprioceptive Neuromuscular Facilitation Concept in Parkinson Disease: A Systematic Review and Meta-Analysis

Iramaia Salomão Alexandre de Assis, MS,[a] Gustavo José Luvizutto, PhD,[b]
Ana Caroline Magrini Bruno, MS,[a] and Luciane Aparecida Pascucci Sande de Souza, PhD[b]

ABSTRACT

Objective: The aim of this review was to evaluate the effects of proprioceptive neuromuscular facilitation (PNF) in individuals with Parkinson disease.

Methods: This was a systematic review. We searched for articles with the keywords "Proprioceptive neuromuscular facilitation" and "Parkinson's disease." The databases searched were Scopus, ScienceDirect, Springer, Web of Science, LILACS (Latin American and Caribbean Health Sciences Literature), CINAHL (Cumulative Index to Nursing and Allied Health Literature), the Cochrane Library, PEDro (Physiotherapy Evidence Database), SciELO (Scientific Electronic Library Online), Ovid, and PubMed, in addition to reference lists of relevant articles. All scientific articles published before November 2019 that addressed rehabilitative outcomes of PNF for individuals with Parkinson disease were considered. Two investigators independently screened studies according to the eligibility criteria.

Results: Of the 674 articles found, 6 were selected. The PEDro scores of 2 articles were 3 points, and the others scored 7, 8, and 9 points. The meta-analysis investigated 3 articles with the same outcomes: walking speed, stride length, and cadence. We found a statistical difference between PNF and other therapies for gait speed (M = 0.28, 95% confidence interval = 0.21-0.34, $P < .001$).

Conclusion: Based on the meta-analysis, we found that PNF is similar or superior to other therapies as relates to gait speed. The efficacy of PNF for indications of Parkinson disease, however, requires further investigation, as a sufficient number of qualified, well-designed, randomized controlled studies is lacking. (J Chiropr Med 2020;19;181-187)

Key Indexing Terms: *Muscle Stretching Exercises; Parkinson Disease; Physical Therapy Modalities*

INTRODUCTION

Parkinson disease (PD) is a chronic and degenerative disorder of the central nervous system of idiopathic etiology. In this disease, there is a reduction of dopamine in the nigrostriatal pathway which is caused by the death of neurons of the substantia nigra in the midbrain and responsible for eye movement, motor planning, reward seeking, learning, and movement coordination.[1-3] Secondary complications of PD are associated with physical, mental, and emotional impairments, and these symptoms can be associated with level of disability and quality of life, contributing to a reduction in functional independence, which in turn is linked to changes in gait and increases the risk of falls.[4-6]

In a previous systematic review of physiotherapeutic interventions for PD[7], the authors analyzed general physical therapy, exercise, treadmill training, stimulation, dance, and martial arts. The "exercise" category had the highest number of allocations at 14 studies; among the subjects included in the category were strengthening, balance training, gait, fall prevention, proprioceptive neuromuscular facilitation (PNF), resistance exercises, aerobic training, education, and relaxation techniques.

Proprioceptive neuromuscular facilitation is a physiotherapeutic approach option for PD. It can be defined as promoting or hastening the response of the neuromuscular mechanism through stimulation of the proprioceptors.[8] This method aims to promote functional movement through the use of facilitation, inhibition, strengthening, and relaxation

[a] Physical Education Post Graduation Program, Federal University of Triângulo Mineiro, Uberaba, Minas Gerais, Brazil.
[b] Department of Applied Physical Therapy, Federal University of Triângulo Mineiro, Uberaba, Minas Gerais, Brazil.
Corresponding author: Luciane Aparecida Pascucci Sande de Souza, PhD, Universidade Federal do Triângulo Mineiro, Congonhas Street number 202, Damha Residential, Uberaba, MG 38042-284, Brazil.
(e-mail: *lucianesande@gmail.com*).
Paper submitted August 19, 2019; in revised form February 20, 2020; accepted July 13, 2020.
1556-3707

https://doi.org/10.1016/j.jcm.2020.07.003

of muscle groups. Concentric, eccentric, and static muscle contractions are used, combined with gradual resistance and appropriate facilitatory procedures, adjusted to the needs of each individual, and applied on diagonal movements.

Theoretical mechanisms for the action of PNF include autogenic inhibition (decreased agonist excitability during stretching or maximal contraction by Golgi tendon organs), reciprocal inhibition (decreased antagonist muscle activity during agonist contraction), and stress relaxation (applied constant stress in the muscles and the connected tendons).[9] These mechanisms hypothetically could be used to treat rigidity in PD, but there are few studies reporting them in PD.[10,11]

The International PNF Association defines the PNF philosophy under 5 subheadings: positive approach (mental engagement in therapy), functional approach (integrating real tasks from daily life), mobilizing reserves (irradiation principle), treating the whole person, and using motor learning and motor control principles. Altogether, PNF fits into the International Classification of Functioning, Disability and Health with its components of impairments, activity limitations, and participation restrictions in the personal and environmental context of the patient involved.[12]

The use of PNF in PD is justified because it may help individuals achieve efficient motor function and promote benefits with respect to clinical condition and physical aspects such as tremor, rigidity, bradykinesia, and balance impairments.[8,11] Looking to the importance of this concept, we saw a necessity of performing a systematic review to enable mapping of the main scientific findings. Thus, the aim of this study was to review current evidence for the effectiveness of PNF in individuals with PD.

Methods

For this review, we included randomized controlled trials, quasi-randomized controlled trials, and nonrandomized controlled trials up to November 2019. The review was registered in the International Prospective Register of Systematic Reviews (PROSPERO, CRD42017077529).

Types of Participants

All participants were individuals with PD confirmed by the Unified Parkinson's Disease Rating Scale or Movement Disorder Society PD criteria.[13]

Types of Interventions

We included trials that compared PNF versus any other interventions in individuals with PD.

Strategy

The eligibility criteria followed the PICO strategy (participants, interventions, comparisons, outcomes, and study design) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and formulated by Moher et al.[14] In this way, we included the following: participants—individuals with PD; interventions—exercises using PNF; comparisons—any other treatment protocols; and outcomes—description and interpretation of results obtained, regardless of the measures used or parameters evaluated.

Excluded were review articles, case reports, articles not available in full, articles off the topic, and articles that did not meet the inclusion criteria.

Search Methods for Identification of Studies

The databases searched were Scopus, ScienceDirect, Springer, Web of Science, LILACS (Latin American and Caribbean Health Sciences Literature), CINAHL (Cumulative Index to Nursing and Allied Health Literature), the Cochrane Library, PEDro (Physiotherapy Evidence Database), SciELO (Scientific Electronic Library Online), Ovid, and PubMed, in addition to reference lists of relevant articles. The combination of descriptors was "Parkinson's Disease" AND PNF OR "Proprioceptive Neuromuscular Facilitation" OR stretching OR contract-relax OR contract-relax-antagonist-contract. This combination was used for all scientific databases, but for Ovid and Springer a refinement was necessary: in OVID the options "original articles" and "articles with abstracts" were used, and in Springer the "articles" option.

Data Collection and Analysis

Two of the authors (I.S.A.A., A.C.M.B.) independently screened titles and abstracts of records obtained through electronic database searches and excluded obviously irrelevant reports. We retrieved full-text articles for the references that remained; 2 of the authors then independently screened the articles to identify studies for inclusion and recorded the reasons for exclusion of ineligible studies. We resolved disagreements through discussion or, if required, consulted a third person. We collated multiple reports on the same study, so that each study, not each reference, was the unit of interest in the review. We recorded the selection process and completed a PRISMA flow diagram. The selected articles were classified based on the PEDro scale.[15]

Data Synthesis and Statistical Analysis

All outcomes were analyzed as continuous variables. The results were presented as the mean of differences (MD) along with 95% confidence intervals (CIs), using fixed-effects models. The unit of analysis was each participant recruited for review.

The variability in results across studies was checked by using the I^2 statistic and the P value for the χ^2 test of heterogeneity provided by Review Manager (RevMan, version 5.3; Nordic Cochrane Centre, Copenhagen, Denmark), which was used for all analyses.

Owing to the small number of studies identified, sensitivity tests (eg, low versus high risk of bias) were not performed and subgroups were not applied.

Results

We identified a total of 674 article citations through database searches (301 from ScienceDirect, 214 from Scopus, 53 from PubMed, 52 from Ovid, 18 from Springer, 16 from LILACS, 12 from the Cochrane Library, 4 from SciELO, 2 from PEDro, and 1 each from Web of Science and CINAHL). After screening by title and then by abstract, we obtained full-text copies for 10 citations that were potentially eligible for inclusion in the review. We excluded 4 studies for the reasons described in Figure 1. The remaining 6 studies, with a total of 153 participants with PD, met the minimum methodological requirements, and we included them in this review. The search results are shown in Figure 1.

Regarding PEDro scores, 2 articles scored 3 points, another 2 articles scored 8 points, and the others scored 7 and 9 points (Table 1).[16-21]

The main theme explored by the authors of the studies reviewed was gait. Two studies used the Vicon 250 system for kinematic gait analysis[16,17]; the others used the GAITRite system for temporospatial gait analysis,[18] the Qualysis ProReflex,[19] reaction force analysis by a segmented platform walkway,[20] and the Smart-DX 500 8-camera infrared optoelectronic motion analysis system[21] to measure kinematic variables during gait.

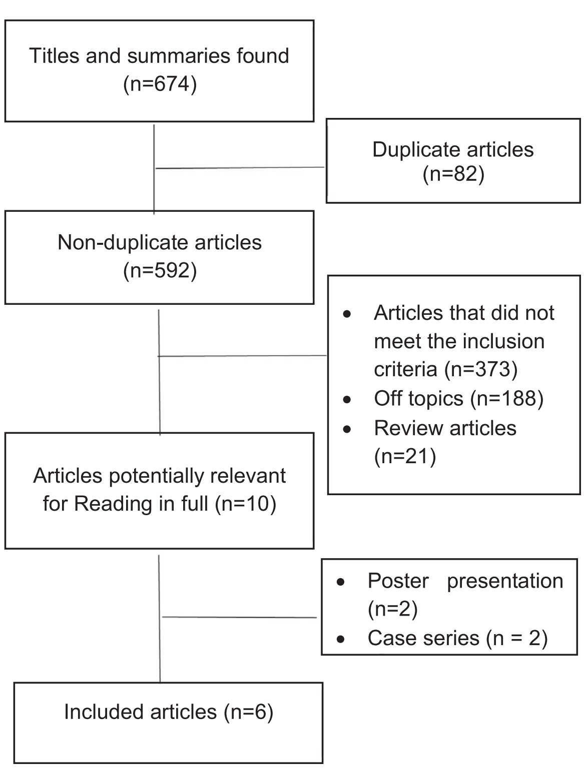

Fig 1. *Flowchart of the article selection process.*

The 2 studies that used the Vicon 250 system with an optoelectronic 3-dimensional gait recorder were by the same group of researchers. They analyzed angular changes of the pelvis in all planes and of the hip joint in the sagittal plane and modifications in the length of the iliac and biceps femoral muscles and in biomechanical parameters, and showed better pelvis alignment and higher muscle strength after PNF was applied in individuals with PD.[16,17]

Picelli et al[18] compared 3 different interventions for gait rehabilitation in individuals with PD: robotic walking, treadmill walking, and conventional physiotherapy based on PNF. The robotic gait and treadmill training were more effective than physical therapy based on PNF, and showed beneficial results regarding stride length, balance control, and fatigue.

El-Tamawy et al[19] compared treadmill training associated with vibratory stimuli and techniques with conventional physiotherapy based on low-intensity exercises, weight change, and active exercises graded for axial muscles. Both groups presented a significant improvement in the parameters evaluated, and the group that trained with the treadmill associated with vibratory stimuli and PNF showed better results than the group with conventional physiotherapy.

Pohl et al[20] compared 4 different interventions: speed-dependent treadmill training, limited progressive treadmill training, PNF-based physical therapy, and the control intervention (resting for 30 minutes in a reclining and comfortable position). Speed and stride length improved in the groups with speed-dependent treadmill training and limited progressive treadmill training. In our meta-analysis we used group 3 (PNF-based physical therapy) versus group 4 (control intervention).

Serrao et al[21] compared 2 different interventions—a PNF-derived rehabilitation approach combined with suggestion of sensory-visual tips versus conventional physical therapy—and concluded that the PNF-derived rehabilitation approach plus sensory-visual tips could be used to improve gait function.

The information of the studies is presented in Table 2.

The meta-analysis was performed with 3 studies owing to the variability of their outcomes: Picelli et al,[18] who compared PNF with robotic walking and treadmill training; El-Tamawy et al,[19] who compared PNF with gait training associated with vibratory stimuli; and Serrao et al,[21] who compared a PNF-derived rehabilitation approach combined with suggestion of sensory-visual tips with conventional physical therapy. For these studies,[18,19,21] the outcomes included in the meta-analysis were gait speed (MD = 0.28, 95% CI = 0.21 to 0.34, *P*

Table 1. *Articles Included in This Review*

Article	Participants	Study Design	PEDro Score
Pohl et al[20]	n = 17 (PD) 4 groups: STT; LTT; CGT; control intervention	Nonrandomized clinical trial	7
Rutowicz et al[16]	n = 3 (PD) n = 35 healthy (CG)	Nonrandomized clinical trial	3
Rutowicz et al[17]	n = 3 (PD) n = 35 healthy (CG)	Nonrandomized clinical trial	3
El-Tamawy et al[19]	n = 30 (PD) 2 groups: G1; G2 (control)	Randomized clinical trial	9
Picelli et al[18]	n = 60 (PD) 3 groups: robotic gait; treadmill with the same intensity; conventional physiotherapy based on PNF	Randomized clinical trial	8
Serrao et al[21]	n = 40 (PD) 2 groups: PNF-derived rehabilitation approach combined with suggestion of sensory-visual tips; conventional physical therapy	Randomized clinical trial	8

CG, control group; *CGT*, conventional gait therapy; *G1*, group 1; *G2*, group 2; *LTT*, limited progressive treadmill training; *PD*, Parkinson disease; *PEDro*, Physiotherapy Evidence Database; *PNF*, proprioceptive neuromuscular facilitation; *STT*, structured speed-dependent treadmill training.

$< .00$; Fig 2A), stride length (MD = 0.14, 95% CI = 0.10 to 0.18, $P < .00$; Fig 2B) and cadence (MD = 5.19, 95% CI = −3.03 to 13.41, $P = .22$; Fig 2C). In these outcomes, there was no significant difference between PNF and the other interventions.

Discussion

This systematic review offers up-to-date but limited evidence supported by only 6 studies, 3 being randomized controlled trials, on the effectiveness of PNF in individuals with PD. Regarding the content of the studies included, the outcome observed in all of them was gait. Gait in individuals with PD is characterized by reduced speed and step length, increased axial rigidity, and impaired rhythmicity.[22-24] The meta-analysis in our study shows a statistical difference comparing PNF with other techniques for gait speed but not for cadence. Based on the minimal clinically important difference for gait speed in PD (larger minimal clinically important different = 0.22),[25] we can assume that PNF promotes a clinically significant increase in gait speed. For stride length, we observed a statistical difference, but we highlight the greater weight of the El-Tamawy et al study in the meta-analysis. These gait problems in PD increase the incidence of falls and the risk of bone fracture.[26-28]

Mirek et al[29] show differences in values for spatiotemporal parameters (such as walking speed and frequency, stride length, and time of single-limb support) between individuals with and without PD. Westwater-Wood et al[30] show that PNF is effective for functional rehabilitation and increasing range of movement in neurologic and nonneurologic patients. The improvement in PD gait parameters in the El-Tamawy et al study[19] has a potent effect from external cues linked to proprioceptive inputs by PNF and vibration. Such inputs can activate an alternate pathway involving the cerebellum, sensorimotor cortex, and lateral premotor cortex.[31,32] This means that the recruitment of these structures can compensate for an inefficient basal ganglia in PD. This is an interesting alternative for the gait training of individuals with PD, both for its efficacy and its low cost, because the vibration devices can be put on individuals' shoes.

An important contribution of this systematic review is to show that PNF can produce similar or superior effects relative to other therapies in spatiotemporal gait parameters, mainly in stride length and gait speed. Although stride length was greater in the intervention group in the meta-analysis, we highlight that those results are primarily based on the El-Tamawy et al study (weight = 97.1%). Proprioceptive neuromuscular facilitation is an inexpensive approach for rehabilitation with several benefits, but its application requires experience and practice.[33-35]

Limitations and Future Research

Some negative points were observed in the studies included. The studies by Rutowicz et al[16,17] also have heterogeneity of the control and PD groups regarding number of participants and their age, in addition to a lack of standardization in the interventions.

The main recommendation for future research based on our observations is an increase in the number of studies related to this subject, as well as a wider range of

Table 2. *Evaluations, Interventions, and Main Outcomes of the Articles Included in This Review*

Article	Evaluations	Interventions	Main Outcomes
Pohl et al[20]	Preintervention and postintervention. Speed (m/s), number of steps, and stride length; ground reaction force analysis by a segmented platform walkway.	LTT group: treadmill (0° inclination), 30 min; speed did not increase in relation to the initial walking speed. CGT group: PNF-based physical therapy gait. Control group: participants rested for 30 min in a reclining and comfortable position.	Basic gait parameters (overground walking speed and stride length) and parameters of gait analysis based on vertical ground reaction forces.
Rutowicz et al[16]	Preintervention and postintervention. Vicon 250 system. Task: walk in the normal rhythm, while the system recorded 15 complete cycles.	3 weeks, with 15 individual sessions of 45 min, based on PNF, for control group and intervention.	Limited mobility of the pelvis in all plans, for all participants with PD. Asymmetry of the lateral displacement of the pelvis found in all participants.
Rutowicz et al[17]	Preintervention and postintervention. Task: walk at normal speed for 20 m with passive markers on the skin. Evaluation of the effect of the therapy on the performance of the evaluated muscles (iliac and biceps femoris).	Intervention: 15 sessions of 45 min, using PNF, for control group and intervention.	Subject 2 showed no significant difference in muscle length, but there was improvement in the parameters evaluated after test 2. Subject 1 showed improvement of all parameters and elimination of asymmetry in pelvic deflection after rehabilitation. Subject 3 maintained the course of the length-change curves of the similar limbs.
El-Tamawy et al[19]	Preintervention and postintervention. Measurement of the cadence, stride length, and hip flexion and knee and ankle dorsiflexion.	G1: PNF + vibratory stimuli during treadmill walking + program done with group 2 (control). Sessions of 51-70 min, 3 times/wk, for 8 wk. G2: physiotherapy with low-intensity exercises, weight change, and active exercises graduated to increase strength. Sessions of 45 min, 3 times/wk, for 8 wk.	Significant increase in cadence, step length, distance, and walking speed (for both groups, being higher in G1). Improvement in the angle of hip flexion and knee and ankle dorsiflexion (for both groups, superior in G1).
Picelli et al[18]	Preintervention, immediately postintervention, 3 mo after. 10-m and 6-min walk tests, GAITRite system, Berg Balance Scale, Parkinson Fatigue Scale, and UPDRS.	12 sessions of 45 min, 3 d/wk (alternates), for a total of 4 wk. For RGT, sessions with static suspension system that provide a robot propulsion; for TT, training with body-weight support; and conventional walking training based on PNF.	10-m and 6-min test and step length—significant difference between RGT × PNF and TT × PNF. Cadence, ratio of duration of single and double support, and coefficient of variation of step time—no significant effect. Berg Balance Scale, UPDRS, and Parkinson Fatigue Scale—significant overall improvements between the RGN × PNF and TT × PNF groups in both evaluations.
Serrao et al[21]	A gait analysis by Smart-DX 500 8-camera infrared optoelectronic motion analysis system. Task: walk barefoot at comfortable speed along a catwalk. Five trials were recorded. Evaluated aspects: gait performance, gait balance, and trunk control.	8-week rehabilitation program. PNF-derived rehabilitation approach combined with suggestion of sensory-visual tips; conventional physical therapy.	Spatiotemporal gait parameters, joint kinematics, and trunk kinematics; UPDRS-III scale scores.

CGT, conventional gait therapy; *G1*, group 1; *G2*, group 2; *LTT*, limited progressive treadmill training; *PD*, Parkinson disease; *PNF*, proprioceptive neuromuscular facilitation; *RGT*, robotic gait; *TT*, treadmill training; *UPDRS*, Unified Parkinson's Disease Rating Scale.

topics and methodological proposals that include not only gait and the lower limbs but also the upper limbs and other related aspects. Similarly, we recommend the inclusion of studies with high methodological quality, with blinding of therapists and participants, and with long-term follow-up of participants.

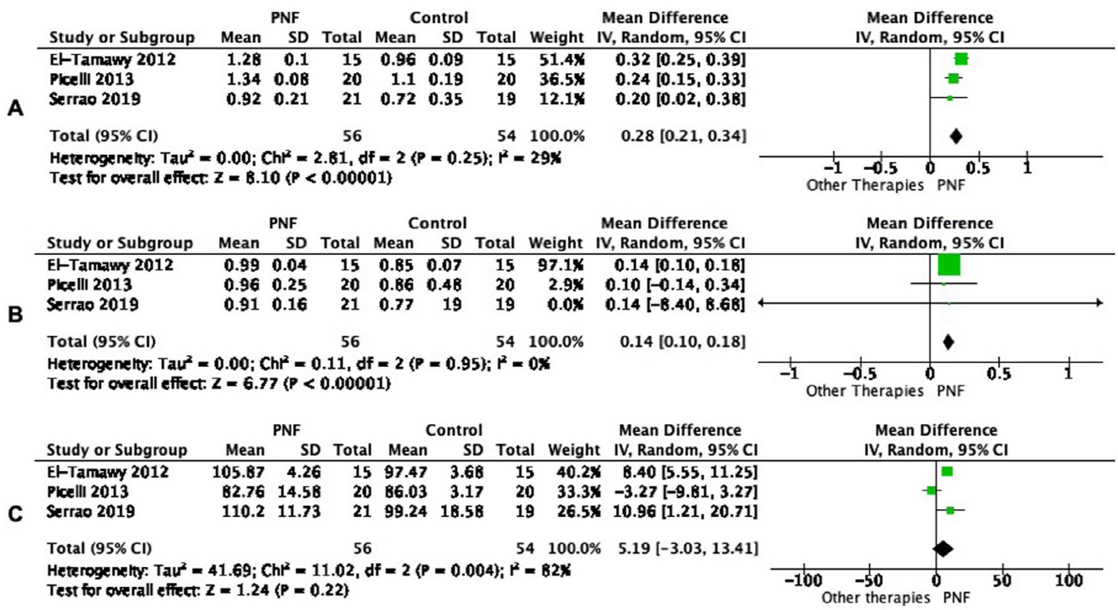

Fig 2. *Parameters evaluated in the meta-analysis: gait speed (A; m/s), stride length (B; m), and cadence (C; steps/min).*

Conclusion

There is a lack of studies of high methodological quality in the literature comparing PNF with other techniques. Based on our meta-analysis, we found that PNF is similar or superior to other therapies for gait speed. The efficacy of PNF for PD indications, however, requires further investigation, since a sufficient number of qualified, well-designed, randomized controlled trials is lacking.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): G.J. L., L.A.P.S.S.
Design (planned the methods to generate the results): I.S.A. A., G.J.L., L.A.P.S.S.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): G.J. L., L.A.P.S.S.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): I.S. A.A., A.C.M.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): I.S.A.A., A.C.M.
Literature search (performed the literature search): I.S.A. A., A.C.M.
Writing (responsible for writing a substantive part of the manuscript): I.S.A.A., G.J.L., A.C.M., L.A.P.S.S.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): G.J. L., L.A.P.S.S.

Practical Applications

- Proprioceptive neuromuscular facilitation is a physiotherapeutic approach for Parkinson disease.
- It may be relevant for treatment of gait in individuals with Parkinson disease.
- Proprioceptive neuromuscular facilitation is not inferior to more technological treatments for stride length, gait speed, or cadence in individuals with Parkinson disease.

References

1. Jankovic J. Parkinson's disease: clinical features and diagnosis. *J Neurol Neurosurg Psychiatry*. 2008;79(4):368-376.
2. Kalia LV, Lang AE. Parkinson's disease. *Lancet*. 2015;386 (9996):896-912.
3. Berardelli A, Rothwell JC, Thompson PD, Hallett M. Pathophysiology of bradykinesia in Parkinson's disease. *Brain*. 2001;124(Pt 11):2131-2146.

4. Behari M, Srivastava AK, Pandey RM. Quality of life in patients with Parkinson's disease. *Parkinsonism Relat Disord*. 2005;11(4):221-226.
5. Grabli D, Karachi C, Welter ML, et al. Normal and pathological gait: what we learn from Parkinson's disease. *J Neurol Neurosurg Psychiatry*. 2012;83(10):979-985.
6. Lana RC, Álvares LMRS, Nasciutti-Prudente C, Goulart FRP, Teixeira-Salmela LF, Cardoso FE. Perception of quality of life in individuals with Parkinson's disease using the PDQ-39. *Rev Bras Fisioter*. 2007;11(5):397-402.
7. Tomlinson CL, Patel S, Meek C, et al. Physiotherapy intervention in Parkinson's disease: systematic review and meta-analysis. *BMJ*. 2012;345:e5004.
8. Voss DE, Jonta MK, Meyers BJ. *Proprioceptive Neuromuscular Facilitation: Patterns and Techniques*. 3rd ed. New York, NY: Harper & Row; 1985.
9. Hindle KB, Whitcomb TJ, Briggs WO, Hong J. Proprioceptive neuromuscular facilitation (PNF): its mechanisms and effects on range of motion and muscular function. *J Hum Kinet*. 2013;31:105-113.
10. Irwin-Carruthers SH. An approach to physiotherapy for the patient with Parkinson's disease. *S Afr J Physiother*. 1971;25(1):5-7.
11. Santos TB, Peracini T, Franco PM, Nogueira RL, Souza LAPS. Proprioceptive neuromuscular facilitation in Parkinson disease: report of therapeutic efficacy. *Fisioter Mov*. 2012;25(2):281-289.
12. Smedes F, Heidmann M, Schafer C, Fischer N, Stepién A. The proprioceptive neuromuscular facilitation-concept: the state of the evidence, a narrative review. *Phys Ther Rev*. 2016;21(1):1-15.
13. Postuma RB, Berg D, Stern M, et al. MDS clinical diagnostic criteria for Parkinson's disease. *Mov Disord*. 2015;30(12):1591-1601.
14. Moher D, Liberati A, Telzlaff J, Altman DG, PRISMA group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLOS Med*. 2009;6(7):1-6.
15. Schiwa SR, Costa LOP, Moser ADL, Aguiar IC, Oliveira LVF. PEDro: a base de dados de evidências em fisioterapia. *Fisioter Mov*. 2011;24(3):523-533.
16. Rutowicz B, Chwala W, Mirek E. Selected gait determinants in pelvic area in patients with Parkinsonian disease rehabilitated by means of PNF method. *Fizjoterapia*. 2006;14(1):65-71.
17. Rutowicz B, Mirek E, Chwala W. Effects of PNF exercises on patterns of changes of selected antagonistic hip joint muscles in patients with Parkinsonian disease. *Fizjoterapia*. 2006;14(1):72-77.
18. Picelli A, Melotti C, Origano F, Neri R, Waldner A, Smania N. Robot-assisted gait training versus equal intensity treadmill training in patients with mild to moderate Parkinson's disease: a randomized controlled trial. *Parkinsonism Relat Disord*. 2013;19(6):605-610.
19. El-Tamawy MS, Darwish MH, Kallaf ME. Effects of augment proprioceptive cues on the parameters of gait of individuals with Parkinson's disease. *Ann Indian Acad Neurol*. 2012;15(4):267-272.
20. Pohl M, Rockstroh G, Rückriem S, Mrass G, Mehrholz J. Immediate effects of speed-dependent treadmill training on gait parameters in early Parkinson's disease. *Arch Phys Med Rehabil*. 2003;84(12):1760-1766.
21. Serrao M, Pierelli F, Sinibaldi E, et al. Progressive modular rebalancing system and visual cueing for gait rehabilitation in Parkinson's disease: a pilot, randomized, controlled trial with crossover. *Front Neurol*. 2019;10:902.
22. Dias NP, Fraga DA, Cacho EWA, Oberg TD. Treino de marcha com pistas visuais no paciente com doença de parkinson. *Fisioter Mov*. 2005;18(4):43-51.
23. Mirelman A, Bonato P, Camicioli R, et al. Gait impairments in Parkinson's disease. *Lancet Neurol*. 2019;18(7):697-708.
24. Crouse JJ, Phillips JR, Jahanshahi M, Moustafa AA. Postural instability and falls in Parkinson's disease. *Rev Neurosci*. 2016;27(5):549-555.
25. Hass CJ, Bishop M, Moscovich M, et al. Defining the clinically meaningful difference in gait speed in persons with Parkinson disease. *J Neurol Phys Ther*. 2014;38(4):233-238.
26. Goulart F, Santos CC, Teixeira-Salmela LF, Cardoso F. Análise do desempenho funcional em pacientes portadores de doença de Parkinson. *Acta Fisiatr*. 2004;11(1):12-16.
27. Williams DR, Watt HC, Lees AJ. Predictors of falls and fractures in bradykinetic rigid syndromes: a retrospective study. *J Neurol Neurosurg Psychiatry*. 2006;77(4):468-473.
28. Bloem BR, Hausdorff MJ, Visser EJ, Giladi N. Falls and freezing of gait in Parkinson's disease: a review of two interconnected, episodic phenomena. *Mov Disord*. 2004;19(8):871-884.
29. Mirek E, Chwała W, Longawa K, Rudzińska M, Adamkiewicz P, Szczudlik A. Proprioceptive neuromuscular facilitation method of therapeutic rehabilitation in the treatment of patients with Parkinson disease. *Neurol Neurochir Pol*. 2003;37(suppl 5):89-102.
30. Westwater-Wood S, Adams N, Kerry R. The use of proprioceptive neuromuscular facilitation in physiotherapy practice. *Phys Ther Rev*. 2010;15(1):23-28.
31. DeLong MR, Wichmann T. Circuits and circuit disorders of the basal ganglia. *Arch Neurol*. 2007;64(1):20-24.
32. Elsinger CL, Harrington DL, Rao SM. From preparation to online control: reappraisal of neural circuitry mediating internally generated and externally guided actions. *Neuroimage*. 2006;31(3):1177-1187.
33. Canning CG, Alison JA, Allen NE, Groller H. Parkinson's disease: an investigation of exercise capacity, respiration function, and gait. *Arch Phys Med Rehabil*. 1997;78(2):199-207.
34. Glendinning DS. A rationale for strength training in patients with Parkinson's disease. *Neurol Rep*. 1997;21(4):132-135.
35. Morris ME. Movement disorders in people with Parkinson disease: a model for physical therapy. *Phys Ther*. 2000;80(6):578-597.