THE MEDICAL BULLETIN OF
SISLI ETFAL HOSPITAL

DOI: 10.14744/SEMB.2023.79990
Med Bull Sisli Etfal Hosp 2023;57(2):232–237

Original Research

Comparative Assessment of Gait and Balance in Patients with Parkinson's Disease and Normal Pressure Hydrocephalus

Ozgur Oztop Cakmak,[1] Kardelen Akar,[2] Hussein Youssef,[2] Mustafa Yavuz Samanci,[3] Sibel Ertan,[1] Atay Vural[1,2]

[1]Department of Neurology, Koc University Faculty of Medicine, Istanbul, Türkiye
[2]Motion Analysis Laboratory, Koc University, KUTTAM, Istanbul, Türkiye
[3]Department of Neurosurgery, Koc University Faculty of Medicine, Istanbul, Türkiye

ABSTRACT

Objectives: We aim to compare balance and gait parameters in patients diagnosed with Parkinson's disease (PD) and normal pressure hydrocephalus (NPH).

Methods: A total of 13 patients with NPH, 20 with PD, and 13 healthy controls (HC) recruited in the study. Three IMU sensors (Ambulatory PD Monitoring Inc., OR, USA) were placed on the lumbar area and the feet of the participants. The balance evaluations comprised eight successive standing tasks; the modified clinical test of sensory interaction on balance test. These tasks involved standing with feet apart and eyes open as well as eyes closed on a firm and foam surface, standing with feet together and eyes open as well as eyes closed, and tandem stance with the right foot front and the left foot front. Functional evaluations of gait were conducted using the 10-M Walk Test (10 MWT), the 2 min-Walk Test (2 MWT), and the timed-up and go (TUG). Parameters of the gait and balance were analyzed and then compared.

Results: NPH patients displayed a notable decrease in both stride length and gait speed as compared with both PD patients and healthy participants. The balance tests revealed that the NPH group demonstrated significantly poorer performance, specifically in the feet-apart eyes-closed foam-surface test, and the tandem stance test. During the tasks while eyes were open on firm and foam surfaces, PD and NPH groups showed an increase in root mean square sway, range, and mean velocity ($p<0.05$) of sway in the anteroposterior plane. In addition, during the TUG test, the NPH group exhibited a significant prolongation in the time needed to complete the task and a decline in turning velocity as compared to PD, but no notable difference was seen in comparison to the HC group.

Conclusion: Our study indicated that the patients with NPH exhibited notably worse gait and balance measurements in comparison to both the PD patients and HC groups. These findings emphasize the significance of monitoring and managing gait and balance impairments in NPH patients. Sensor-based technologies may offer objective parameters for a more precise and efficient follow-up of these patients in terms of gait and balance.

Keywords: Ambulatory PD monitoring, balance, gait analysis, normal pressure hydrocephalus, Parkinson's disease

Please cite this article as "Cakmak OO, Akar K, Youssef H, Samanci MY, Ertan S, Vural A. Comparative Assessment of Gait and Balance in Patients with Parkinson's Disease and Normal Pressure Hydrocephalus. Med Bull Sisli Etfal Hosp 2023;57(2):232–237".

Address for correspondence: Ozgur Oztop Cakmak, MD. Department of Neurology, Koç University Faculty of Medicine, Istanbul, Türkiye
Phone: +90 535 868 36 73 **E-mail:** ooztop@ku.edu.tr

Submitted Date: May 09, 2023 **Revised Date:** May 17, 2023 **Accepted Date:** May 17, 2023 **Available Online Date:** June 20, 2023

Patients diagnosed with idiopathic normal pressure hydrocephalus (NPH) and Parkinson's disease (PD) often exhibit gait problems that are characterized by a reduced speed of walking, shortened stride length, and poor balance control.[1]

Although balance impairment is typically observed with in the late stages of PD, patients may report subtle balance problems in the earlier stages, alongside other Parkinsonian symptoms. In addition, Parkinsonian symptoms occurred in other neurological disease may complicate the management of the disease.[2] Distinguishing between NPH and PD can present a challenge, particularly when the assessment concentrates primarily on gait and balance performance.[3]

The utilization of sensor-based technologies for measuring gait and balance is becoming increasingly popular. These user-friendly technologies provide objective and reproducible measurements in the assessment of movement disorders.[4] The wearable system, called ambulatory PD monitoring (APDM) inertial sensor (Opals and Mobility Lab), consists of three-axis accelerometers, gyroscopes, and a magnetometer.[5,6] Assessment of the postural sway provides information on postural instability. Measurements, such as area, velocity, frequency, and jerk, can be employed to describe postural sway. These metrics can provide valuable insights into the underlying mechanisms of postural control and balance impairment and can be useful in the assessment of various clinical populations.[7-9] Force platforms are common tools for evaluating posture in a quantitative manner. Several studies have used force platforms to assess postural sway in PD or NPH patients and have reported abnormalities.[10-12] However, few studies have compared balance problems and gait impairment in these patients. The primary aim of our study is to compare gait and balance in newly diagnosed NPH patients, PD patients, and healthy subjects using sensor-based technologies. The secondary aim is to investigate the role of sensor-based technologies as an additional tool to complement neurological findings with objective measurements.

Methods

Twenty patients diagnosed with PD based on the internationally recognized diagnostic criteria,[13] 13 patients with a diagnosis of probable NPH according to the guidelines,[14] and 13 healthy individuals as a control group were enrolled. Patients were recruited from the Departments of Neurology and Neurosurgery at the Koc University Hospital (Istanbul, Turkey). All the participants gave informed consent. The demographic characteristics of all cases, such as age and gender, were recorded. The disease severity and stage in Parkinson's patients were determined using the MDS-UPDRS Part 3 and Hoehn and Yahr (H and Y) scale. All participants were invited to the motion analysis laboratory for gait and balance assessments. All assessment parameters were recorded following the APDM Mobility Laboratory System (APDM Inc., Portland, OR, USA) Guidelines. During the gait task, three IMU sensors were attached to the participants' feet and lumbar area to evaluate spatiotemporal parameters, trunk angles, and turning angles as well as velocity. All the participants performed the 10-M Walk Test (10MWT) and the 2-min Walk Test (2MWT). Balance assessment included the modified clinical test of sensory interaction on balance with the feet together and eyes open or closed, tandem stance on the right or left foot front, and the TUG test. The duration of stance tasks was recorded with a maximum duration of 30 s.

Measurements began only after the participant had a stable and appropriate position. Participant was asked to complete a task. The test was terminated if the participant moved to regain balance, and the duration was recorded.

Statistical Analysis

Categorical data were shown as numbers and percentages, whereas continuous variables were reported as the median (interquartile range). Scales and gait metrics underwent correlation analysis. GraphPad program Inc., La Jolla, California, USA, GraphPad Prism program 8.4.3., the Anderson-Darling, and D'Agostino and Pearson tests were used to assess the normality assumptions. The correlation between the dependent gait data and UPDRS, and H and Y were performed with the Pearson correlation test.

Chi-square analysis was conducted for eight balance tasks between the groups, and the numbers of patients who completed and did not complete the balance tests are detected.

In the IMU-based sensor analysis for balance, gait, and the TUG test, a t-test was utilized to compare the groups, and a one-way ANOVA was performed to assess overall group differences.

Ethical Approval

The Ethics Committee of Koç University (Date: November 12, 2020, number: 2020.418, IRB1, 157) approved the study. All procedures were performed in accordance with the ethical standards set by the Declaration of Helsinki, and all participants provided written informed consent.

Results

This study included 20 Parkinson's patients (12 males and eight females) with a mean age of 69.1 (range 68–76), 13 NPH patients (seven males and six females) with a mean age of 69.71 (range 60–70), and 13 healthy participants (seven males and six females) with a mean age of 69.71 (range 60–70).

The demographic characteristics and clinical details of the patients are reported in Table 1.

Table 2 summarizes all the gait parameters. Table 3 shows the analysis of the TUG parameters.

Comparing the NPH group to both PD patients and healthy subjects revealed that they had substantially slower gait speed (p=0.001) and reduced stride length (p=0.0004). The PD group did not reveal any notable differences in stride length or gait speed compared to controls.

The NPH group demonstrated increased values in the double support phase and stance phase, and lower values in the swing phase. However, no notable differences were seen in the gait phases of the patients within PD and healthy control (HC) groups. In the NPH group, the toe off angle was decreased compared to both HC and PD groups.

The results of the time to complete balance tests in 30 s are shown in Table 4. The NPH group exhibited significantly worse performance in balance tests, particularly in the feet-apart eyes-closed foam-surface test and the tandem stance test, both of which showed a decline in performance within 30 s.

Balance parameters are shown in Table 5. Both the PD and NPH groups exhibited significant increases in mean velocity in the transverse and sagittal planes (p<0.05). The NPH group showed significantly higher root mean square sway compared to the PD and HC groups.

Table 1. Demographics and clinical features of the patients and the healthy controls

	PD (n=20)	NPH (n=13)	HC (n=13)	p
Age, year Mean (SD)	69.10 (6.92)	71.92 (4.11)	69.23 (9.03)	ns 0.48
Sex (n) F:M	8:12	6:7	6:7	ns 0.91
Disease duration, years Mean (SD)	4.16 (3.53)	2.5 (1.50)	-	ns 0.21
UPDRS Mean (SD)	22.06 (10.80)	-	-	-

PD: Parkinson's disease; NPH: Normal pressure hydrocephalus; HC: Healthy control; SD: Standard deviation; n: Number; ns: Not significant.

Table 2. Gait parameters of participants

	PD (n=20)	NPH (n=13)	HC (n=13)	p t-test NPH versus PD	p t-test PD versus HC	p t-test NPH versus HC	p One-way ANOVA
Gait speed (m/s)	0.980±0.21	0.620±0.22	0.922±0.20	0.001	0.68	0.002	0.0001
Cadence (step/min)	103.3±13.27	98.86±16.17	104.1±6.95	0.39	0.85	0.29	0.52
Stride length (m)	1.01 (0.940–1.14)	0.771 (0.472–0.975)	1.09 (0.957–1.19)	0.001	0.37	0.001	0.001
Step time (s)	0.592±0.07	0.630±0.10	0.573±0.04	0.35	0.70	0.09	0.31
Stance phase (% GCT)	61.18 (59.62–62.90)	64.24 (62.99–67.10)	61.02 (60–61.83)	0.002	0.77	0.003	0.004
Swing phase (% GCT)	38.82 (37.10–40.38)	35.76 (32.83–37.01)	38.99 (37.99–39.84)	0.002	0.97	0.004	0.004
Double support phase (% GCT)	22.32 (19.20–25.95)	28.58 (26–34.37)	22.04 (20–23.60)	0.004	0.78	0.003	0.005
Elevation at midswing (cm)	1.95±1.01	1.66±0.77	1.72±0.62	0.38	0.47	0.83	0.58
Lateral step variability (cm)	2.61±0.66	2.30±0.87	2.97±0.89	0.25	0.20	0.06	0.11
Circumduction (cm)	2.54 (2.02–3.03)	1.41 (0.94–1.98)	2.75 (1.92–3.32)	0.0004	0.72	0.001	0.001
Foot strike angle (degree)	16.81±5.64	12.70±6.47	21.85±6.95	0.06	0.02	0.002	0.002
Toe off angle (degree)	34 (30.78–35.99)	24.94 (19.48–30.06)	33.92 (30.37–37.40)	0.0006	0.73	0.003	0.001
Toe out angle (degree)	12.21±5.16	12.85±9.44	11.23±8.56	0.80	0.68	0.65	0.85

PD: Parkinson's disease; NPH: Normal pressure hydrocephalus; HC: Healthy control; SD: Standard deviation; n: Number; ns: Not significant.

Table 3. The timed up and go test parameters between groups

	PD (n=20)	NPH (n=13)	HC (n=13)	p t-test PD versus NPH	p t-test PD versus HC	p t-test NPH versus HC	p One-way ANOVA
Total duration, s Mean (SD)	10.81 (2.92)	14.78 (4.04)	11.67 (2.85)	0.003	0.50	0.054	0.01
Sit-to-stand duration, s Mean (SD)	1.17 (0.39)	1.12 (0.10)	0.99 (0.12)	0.21	0.21	0.36	0.10
Stand-to-sit duration, s Mean (SD)	0.92 (0.25)	0.99 (0.26)	0.87 (0.13)	0.50	0.61	0.26	0.56
Turn angle, degree Mean (SD)	179.1 (11.73)	165.1 (26.64)	180.5 (11.66)	0.09	0.74	0.16	0.19
Turn duration, s Mean (SD)	2.31 (0.54)	2.77 (0.54)	2.46 (0.60)	0.02	0.50	0.21	0.08
Turn velocity, degree/s Mean (SD)	166.1 (40.21)	128.1 (43.51)	161.0 (43.11)	0.009	0.74	0.07	0.03

TUG: Timed up and go; PD: Parkinson's disease; NPH: Normal pressure hydrocephalus; HC: Healthy control.

Table 4. Achieving balance tests in 30 s

	HC (n) Able to: Unable to	PD (n) Able to: Unable to	NPH (n) Able to: Unable to	p HC versus NPH	p PD versus NPH	p HC versus PD	p overall
FA_EO_Firm	13:0	20:0	13:0	na	na	na	na
FA_EC_Firm	13:0	20:0	13:0	na	na	na	na
FA_EO_Foam	13:0	20:0	13:0	na	na	na	na
FA_EC_Foam	13:0	19:1	9:4	0.02	0.04	0.41 ns	0.02
FT_EO	13:0	20:0	13:0	na	na	na	na
FT_EC	13:0	19:1	11:2	0.14 ns	0.31 ns	0.41 ns	0.26 ns
Tandem Right_EO	13:0	17:3	6:7	0.002	0.01	0.14 ns	0.002
Tandem Left_EO	13:0	17:3	5:8	0.0007	0.005	0.14 ns	0.0005

FA_EO_Firm: Feet apart eyes open on firm surface; FA_EC_Firm: Feet apart eyes closed on firm surface; FA_EO_Foam: Feet apart eyes open on foam surface; FA_EC_Foam: Feet apart eyes closed on foam surface; FT_EO_Firm: Feet together eyes open; FT_EC_Firm: Feet together eyes closed; na: Not applicable; ns: Not significant.

Table 5. Balance parameters between patients and healthy controls during feet apart eyes open on foam surface task

	PD (n=20)	NPH (n=13)	HC (n=13)	p t-test PD versus NPH	p t-test PD versus HC	p t-test NPH versus HC	p One-way ANOVA
Sway area	0.110 (0.072–0.248)	0.231 (0.163–0.330)	0.161 (0.062–0.208)	0.01	0.84	0.052	0. 04
RMS sway	0.118 (0.097–0.188)	0.161 (0.141–0.197)	0.131 (0.084–0.154)	0.01	0.68	0.02	0.03
RMS sway (Sagittal)	0.098 (0.079–0.146)	0.125 (0.107–0.132)	0.096 (0.067–0.125)	0.04	0.35	0.009	0.02
Mean velocity	0.272±0.12	0.284±0.08	0.179±0.06	0.63	0.02	0.002	0.01
Mean velocity (Sagittal)	0.202±0.10	0.208±0.06	0.127±0.04	0.59	0.03	0.001	0.01
Path length	9.37 (6.95–13.66)	12.67 (10.03–13.49)	10.27 (7.86–12.59)	0.11	0.61	0.14	0.20
Path length (Sagittal)	7.23±3.24	8.86±2.26	7.67±3.03	0.14	0.70	0.28	0.34
Jerk	2.75 (1.10–4.84)	4.15 (2.73–4.51)	3.20 (1.34–4.37)	0.20	0.58	0.27	0.33
Jerk (Sagittal)	2.95 (1.16–5.71)	4.22 (2.84–6.42)	3.24 (1.54–5.33)	0.09	0.55	0.20	0.19
Range	0.616 (0.535–0.875)	0.923 (0.711–1.06)	0.747 (0.504–0.850)	0.03	0.98	0.12	0.10
Range (Sagittal)	0.539 (0.438–0.778)	0.644 (0.599–0.747)	0.558 (0.368–0.662)	0.13	0.47	0.03	0.09

PD: Parkinson's disease; NPH: Normal pressure hydrocephalus; HC: Healthy control; RMS: Root mean square.

Discussion

Our study aimed to compare gait among patients with NPH, PD, and healthy participants using wearable sensors.

Gait impairments in PD are believed to be caused by underlying pathology in subcortical brain areas, while in NPH, both frontal and subcortical areas are hypothesized to be involved.[15,16] Our study found that patients with NPH had significantly lower gait speed and stride length when compared with both PD and healthy participants. However, the PD group did not display any notable differences in stride length or gait speed compared to controls.

Reduced gait speed as well as stride length in PD and NPH patients have been reported in previous studies.[1,17] Our results indicate that reduced length of stride and speed of gait were only evident in the NPH group. The lack of stride length and gait speed reduction in the PD group may be due to the fact that these patients were in the early stages of PD and receiving optimal medication. Moreover, our study found that the NPH group demonstrated an augmentation in the double support phase and stance phase and a reduce in the swing phase. In contrast, no notable differences were seen in the gait phases of the PD and HC groups. Furthermore, the toe-off angle was notably decreased in the NPH compared with both the control and PD groups. These alterations in gait phases are consistent with the clinical finding of NPH, which is commonly referred to as "magnetic gait."[1,18,19]

Every participant included in our study was capable of performing the eyes open on foam stance task. However, the use of IMU sensors revealed that both PD and NPH groups had significantly increased mean velocity in both transverse and sagittal planes (p=0.01) compared with the healthy participants. This finding suggests that the use of IMU sensors can provide sensitive measures of postural instability in patients with neurological conditions particularly in the early stages of PD, which may not be detected by clinical assessments alone.[20]

Furthermore, our results showed that the NPH group exhibited notably worse on balance tests as compared with the PD and HC groups. This finding is consistent with the augmented risk of falls observed in NPH, which may be attributed to the underlying balance and gait impairments related to the condition.[12,17,21,22]

The identification and quantification of gait and balance impairments through objective assessments, such as balance tests, can be valuable in guiding the advancement of effective management to decrease the risk of falls in NPH and PD. Further clinical studies are necessary to investigate the potential benefits of incorporating balance tests into the practical assessment and management of patients with NPH and PD.

The limitation of our study is the lack of PD patients in late stages who may have severe gait problems. Furthermore, all the PD patients were in a state of being "on." Future studies should expand to include late-stage PD patients and all PD patients in both "on" as well as "off" states to offer a more thorough comprehension of the disease progression.

Conclusion

Sensor-based gait analysis is a practical approach that can provide quantitative measurements. Tandem stance and eyes open tasks may be a valuable clue in assessing balance problems in NPH and PD patients. Additional studies are necessary to explore the potential differences in gait patterns and to enhance the diagnosis and treatment between different stages of PD and NPH.

Disclosures

Ethics Committee Approval: The study was approved by the Ethics Committee of Koç University (No: 2020.418, IRB1,157, dated 12.01.2020).

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Authorship Contributions: Concept – O.O.C., K.A., A.V., H.Y., S.E.; Design – O.O.C., K.A., A.V., H.Y., S.E.; Supervision – O.O.C., K.A., A.V., H.Y., S.E.; Fundings: A.V., K.A., H.Y.; Materials – O.O.C., A.V., Y.S., S.E.; Data collection &/or processing – O.O.C., K.A., A.V., H.Y., Y.S., S.E.; Analysis and/ or interpretation – O.O.C., K.A., A.V., H.Y., S.E.; Literature search – O.O.C., K.A., A.V., H.Y., Y.S., S.E.; Writing – O.O.C., K.A.; Critical review – O.O.C., K.A., A.V., H.Y., Y.S., S.E.

References

1. Stolze H, Kuhtz-Buschbeck JP, Drücke H, Jöhnk K, Illert M, Deuschl G. Comparative analysis of the gait disorder of normal pressure hydrocephalus and Parkinson's disease. J Neurol Neurosurg Psychiatry 2001;70:289-97.
2. Çiftci S, Kuran B, Duman Z, Yılmaz F, Mert C, Durlanık G, et al. The effect of associated parkinsonism on rehabilitation in stroke patients: a case series. Sisli Etfal Hastan Tip Bul 2018;52:64-9.
3. Mostile G, Contrafatto F, Terranova R, Terravecchia C, Luca A, Sinitò M, et al. Turning and sitting in early Parkinsonism: differences between idiopathic normal pressure hydrocephalus associated with Parkinsonism and Parkinson's disease. Mov Disord Clin Pract 2023;10:466-71.
4. Vanmechelen I, Haberfehlner H, De Vleeschhauwer J, Van Wonterghem E, Feys H, Desloovere K, et al. Assessment of movement disorders using wearable sensors during upper limb tasks: a scoping review. Front Robot AI 2023;9:1068413.
5. Mancini M, Horak FB. Potential of APDM mobility lab for the monitoring of the progression of Parkinson's disease. Expert Rev

Med Devices 2016;13:455-62.
6. Fang X, Liu C, Jiang Z. Reference values of gait using APDM movement monitoring inertial sensor system. R Soc Open Sci 2018;5:170818.
7. Peterka RJ, Benolken MS. Role of somatosensory and vestibular cues in attenuating visually induced human postural sway. Exp Brain Res 1995;105:101-10.
8. Maurer C, Mergner T, Peterka RJ. Multisensory control of human upright stance. Exp Brain Res 2006;171:231-50.
9. Rocchi L, Chiari L, Cappello A. Feature selection of stabilometric parameters based on principal component analysis. Med Biol Eng Comput 2004;42:71-9.
10. Schlenstedt C, Muthuraman M, Witt K, Weisser B, Fasano A, Deuschl G. Postural control and freezing of gait in Parkinson's disease. Parkinsonism Relat Disord 2016;24:107-12.
11. Blomsterwall E, Frisén L, Wikkelsö C. Postural function and subjective eye level in patients with idiopathic normal pressure hydrocephalus. J Neurol 2011;258:1341-6.
12. Nikaido Y, Akisue T, Kajimoto Y, Tucker A, Kawami Y, Urakami H, et al. Postural instability differences between idiopathic normal pressure hydrocephalus and Parkinson's disease. Clin Neurol Neurosurg 2018;165:103-7.
13. Postuma RB, Berg D, Stern M, Poewe W, Olanow CW, Oertel W, et al. MDS clinical diagnostic criteria for Parkinson's disease. Mov Disord Off J Mov Disord Soc 2015;30:1591-601.
14. Ishikawa M, Hashimoto M, Kuwana N, Mori E, Miyake H, Wachi A, et al. Guidelines for management of idiopathic normal pressure hydrocephalus. Neurol Med Chir (Tokyo) 2008;48 Suppl:S1-23.
15. Griffa A, Bommarito G, Assal F, Herrmann FR, Van De Ville D, Allali G. Dynamic functional networks in idiopathic normal pressure hydrocephalus: Alterations and reversibility by CSF tap test. Hum Brain Mapp 2021;42:1485-502.
16. Peterson DS, Horak FB. Neural control of walking in people with Parkinsonism. Physiol Bethesda Md 2016;31:95-107.
17. Bugalho P, Alves L, Miguel R. Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. J Neural Transm 2013;120:1201-7.
18. Agostini V, Lanotte M, Carlone M, Campagnoli M, Azzolin I, Scarafia R, et al. Instrumented gait analysis for an objective pre-/postassessment of tap test in normal pressure hydrocephalus. Arch Phys Med Rehabil 2015;96:1235-41.
19. Williams MA, Thomas G, de Lateur B, Imteyaz H, Rose JG, Shore WS, et al. Objective assessment of gait in normal-pressure hydrocephalus. Am J Phys Med Rehabil 2008;87:39-45.
20. Horak FB, Mancini M. Objective biomarkers of balance and gait for Parkinson's disease using body-worn sensors: balance and gait biomarkers. Mov Disord 2013;28:1544-51.
21. Ravdin LD, Katzen HL, Jackson AE, Tsakanikas D, Assuras S, Relkin NR. Features of gait most responsive to tap test in normal pressure hydrocephalus. Clin Neurol Neurosurg 2008;110:455-61.
22. Marmarou A, Young HF, Aygok GA, Sawauchi S, Tsuji O, Yamamoto T, et al. Diagnosis and management of idiopathic normal-pressure hydrocephalus: a prospective study in 151 patients. J Neurosurg 2005;102:987-97.