Tandon *et al.*
Bulletin of the National Research Centre (2023) 47:76
https://doi.org/10.1186/s42269-023-01052-7

Bulletin of the National Research Centre

RESEARCH **Open Access**

Gait analysis of patients with Parkinson-plus syndromes: a research article

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Abstract

Background Aim of the observational study was to assess which of the gait and balance parameters are most affected in Parkinson-plus syndromes patients with falling tendencies as compared to healthy individuals.

Methods Authors studied levodopa-responsive patients of multiple system atrophy (MSA) and progressive supranuclear palsy (PSP) who had falling tendencies early in the disease and healthy controls and evaluated the spatiotemporal gait parameters using BTS G WALK and balance parameters by Limits of Stability test on BIODEX Balance system SD in the Gait and Motion Analysis Lab.

Results In comparison to controls, Parkinson-plus syndromes patients had significantly different gait and balance parameters, apart from stride time and stance time, pelvic obliquity and pelvic tilt, cadence, hip abduction–adduction and hip rotation, foot progression, gait profile score, gait variable hip abduction–adduction, rotation, gait variable flexion–extension and gait deviation index (p-values < 0.05). Also, in comparison to MSA patients, PSP patients had significantly greater values of all static parameters except for swing time, step width, pelvic tilt and rotation, hip rotation and ankle dorsiflexion-plantarflexion, gait profile score of right limbs and all gait variable parameters except for pelvic tilt and hip flexion–extension, foot progression and gait deviation index of right limb. However, balance parameters were similar in MSA and PSP. Duration of disease and duration since falls may not significantly affect gait and balance parameters in Parkinson-plus syndromes patients.

Conclusions Hence, gait differentiates between Parkinson-plus patients and healthy controls and between MSA and PSP patients with falling tendencies and gait and balance parameters may also help in planning rehabilitative strategies.

Keywords Gait, Balance, Multiple system atrophy, Progressive supranuclear palsy, Parkinson plus syndromes

Background

In the recent times, the researchers have been employing wearable technology, accelerometers, sensors, optical cameras and machine learning to analyze the gait patterns of patients of Parkinson's disease and Parkinson plus syndromes (Hatanaka et al. 2016; Raccagni et al. 2018; Matsushima et al. 2017; Schlachetzki et al. 2017). Additionally, they have compared Parkinson plus syndromes' gait to Parkinson's disease gait using various methods (Raccagni et al. 2018; Vos et al. 2020; Ricciardi et al. 2019). However, the studies comparing different Parkinson plus patients among each other are relatively rare.

In the past, the clinicians have also assessed and compared the balance parameters of Parkinson's Disease patients to those of Parkinson plus patients (Baston et al. 2014), though there are not many studies comparing the balance parameters of different Parkinson plus syndrome

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patients like multiple system atrophy and progressive supranuclear palsy patients.

This study, therefore, aimed to compare the gait patterns and balance parameters of patients of different Parkinson plus syndromes, especially those having multiple system atrophy (MSA)-Parkinsonian variant (MSA-P) and progressive supranuclear palsy (PSP) with predominant parkinsonism (PSP-P) or PSP with Richardson's syndrome (PSP-RS) in the early stage (within 5 years of disease onset) when they may experience falls but can still walk independently. This may help in diagnosis, and in future rehabilitation and prognostication.

Methods

We recruited the patients of Parkinson-plus syndromes visiting the Out Patient department (OPD)s and admitted to the wards of the department of Neurology, of the institute between 2020 and 2023.

Firstly, the authors carried out this observational study on Parkinson plus patients, which included MSA and PSP patients and age and sex matched healthy controls from among the attendants of the patients and secondly, for this study, we included all the MSA patients fulfilling the 'Second consensus statement' criteria for probable or possible MSA-P (MSA with predominant Parkinsonism) and the PSP patients fulfilling the 'Movement Disorders Society (MDS)-PSP' criteria for probable or possible PSP-P (PSP with predominant Parkinsonism) and PSP-RS (PSP with Richardson's syndrome) (Gilman et al. 2008; Hoglinger et al. 2017). Moreover, we included MSA and PSP individuals, in the early stage of disease (within 5 years of disease onset) who were able to walk unaided after taking their medications but had a history of falls due to abnormal balance. We excluded the patients with vestibular system disorders, visual impairment, symptoms of neuropathy and those with mechanical disorders like gonarthrosis and osteoarthritis, which could affect their gait. The investigators took a written informed consent from all the study participants and included all those who gave their consent. Then, the study investigators took history, performed clinical examination and laboratory tests like hemogram, renal, liver and thyroid function tests, coagulation parameters, X-ray chest and vitamin B12 and folic acid levels and excluded those with abnormal results. We also did an MRI head on the patients to exclude those who did not fit in the diagnostic criteria for PSP or MSA.

All the procedures of this observational study are in accordance with the ethical standards of the Institutional Ethics committee. After ethical approval, the authors asked all the participants to walk barefoot at self selected speed in a 10-m-long walkway in the 'Gait and Motion Analysis Lab', using 'BTS G—Walk', BTS Bioengineering, Italy machine to analyze the gait parameters of the patients. Previously, the clinicians instructed the patients to take their usual medications of anti-Parkinsonian drugs and excluded those with a history of freezing while on medicines. BIODEX Balance System SD, Biodex Medical Equipments, Inc, USA, evaluated the balance of the patients and this evaluation involved fall risk test, postural stability and limits of stability test by standing on a platform and trying to tilt in various directions as instructed by the pointer on the screen of the machine. After analysis, we obtained the results of limits of stability test for balance analysis.

Results of gait and balance testing yielded the study variables. The study utilized SPSS version 20 for statistical analysis and calculated the means for various balance and gait parameters. We compared the means using Mann–Whitney U test. Upon analyzing the p-values between Parkinson plus patients and controls and between MSA and PSP subgroups, we considered p-values < 0.05 to be significant. The study investigators found out relation between parameters and duration of disease and between parameters and duration since falls by means of regression analysis and considered a coefficient greater than ± 0.6 and p-value < 0.05 to be significant. We recruited patients in the first and second year and analyzed the data in the last 6 months.

Since, the institute is a tertiary care center, hence, we get around 5 new cases of Parkinson plus syndromes every month. So, we would get around 60 cases in one year. However, due to affordability issues, we could test 30 cases and 18 controls (with same ratio of sex and age < 60 and > 60 years) with a ratio of 5:3 between cases and controls.

Results

We examined 50 patients for the study and only 30 gave consent for the study due to time constraints and were hence, included. Also, due to affordability issues, we could take 18 controls. There were 24 men (75%) and 6 (25%) women in the cases group and 14 men (77.78%) and 4 women (22.22%) in the control group. Among cases, 14 people (46.67%) were in the age range between 40 and 59 years and 16 people (53.33%) in the range between 60 and 80 years and among controls, 9 persons (50%) were in between 40 and 59 years and 9 persons (50%) in between 60 and 80 years of age.

In comparison to controls, among static scores, stride time and stance time of the limbs, pelvic obliquity and pelvic tilt of the limbs, number of steps taken in a minute, hip abduction–adduction and hip rotation of the limbs, foot progression of the limbs and gait profile scores of the limbs and among the variable scores, hip abduction–adduction, rotation and flexion–extension of the limbs, were the parameters which did not change much in patients of Parkinson plus syndromes and all the other parameters changed significantly. The disease also did not significantly affect the Gait deviation index of both the limbs (Tables 1, 2).

In comparison to MSA patients, PSP patients had significantly greater values of all the static parameters except for mainly swing time of the limbs, step width, pelvic tilt and rotation, hip rotation and ankle dorsiflexion-plantarflexion of the limbs, gait profile score of right limbs and of all the gait variable parameters except for mainly pelvic tilt and hip flexion–extension of the limbs, foot progression of both the limbs and gait deviation index of right limb (Tables 3, 4).

However, the authors found no significant relation (coefficient greater than ± 0.6; p-value < 0.05) between the duration of disease and the gait and balance parameters and also between the duration of falls and various gait and balance parameters in patients of Parkinson plus syndromes. Number of steps in one minute decreased as the duration of disease increased significantly (coefficient 0.639; p-value < 0.001).

As the duration of disease increased, the stride time (right limb coefficient -0.811; p-value < 0.001; left limb coefficient -0.928; p-value < 0.001) and stance time (right limb coefficient -0.718; p-value 0.001; left limb coefficient -0.814; p-value < 0.001) of left and right limb decreased; however, number of steps per minute (coefficient 0.897; p-value < 0.001) and pelvic obliquity (right limb coefficient 0.689; p-value 0.004; left limb coefficient -0.690; p-value 0.004), knee flexion extension of left and right limb (deg) (right limb coefficient 0.698; p-value < 0.001; left limb coefficient 0.819; p-value < 0.001) and ankle dorsiflexion plantarflexion of left limb (deg) (coefficient 0.620; p-value 0.005) increased significantly in individuals with multiple system atrophy. As the duration since first fall increased, step width (coefficient 0.581; p-value 0.010), ankle dorsiflexion plantarflexion of right limb (coefficient 0.615; p-value < 0.001), foot progression of left limb (coefficient 0.832; p-value < 0.001) and gait variable foot progression of right limb (coefficient 0.698; p-value 0.003) also increased and pelvic obliquity of left limb (coefficient -0.733; p-value 0.002) and right limit of balance (coefficient -0.684; p-value 0.005) decreased in these patients.

In patients of PSP, stride length (right limb coefficient 0.724; p-value 0.001; left limb coefficient 0.708; p-value 0.005), step length (right limb coefficient 0.772; p-value 0.004; left limb coefficient 0.724; p-value 0.005) and gait deviation index of right limb (coefficient 0.521; p-value 0.067) increased with increasing disease duration, while step width (coefficient -0.809; p-value 0.004), gait variable pelvic rotation of right and left limb (right limb coefficient -0.983; p-value < 0.001; left limb coefficient -0.961; p-value < 0.001), gait variable hip flex-extension of right limb (coefficient -0.610; p-value 0.035), gait variable knee flex-extension of right limb (coefficient -0.731; p-value 0.015) and left limit of stability (coefficient -0.676; p-value 0.023) decreased with increasing disease duration. With increasing duration since first fall, stride length (right limb coefficient -0.729; p-value 0.001; left limb coefficient -0.666; p-value 0.007), swing time of left limb (coefficient -0.788; p-value 0.002), step length of left limb (coefficient -0.637; p-value 0.009), hip abduction adduction of left limb (coefficient -0.694; p-value 0.011), hip rotation of left and right limb (left limb -0.842; p-value 0.002; right limb -0.685; p-value 0.026), gait profile score of right limb (coefficient -0.642; p-value 0.011), gait variable hip rotation of right limb (coefficient -0.771; p-value 0.009), gait variable gait deviation index of left limb (coefficient -0.635; p-value 0.030) decreased while double support phase of right limb (coefficient 0.648; p-value 0.034), gait variable hip abduction adduction of left limb (coefficient 0.658; p-value 0.036), gait variable hip flex-extension of left limb (coefficient 0.680; p-value 0.003) increased. Forward limit of balance (coefficient 0.564; p-value 0.067), forward right limit of balance (coefficient 0.607; p-value 0.036), backward right limit of balance (coefficient 0.717; p-value 0.017) and overall stability limit (coefficient 0.876; p-value < 0.001) showed a positive correlation with duration since falls in these patients.

In comparison to controls, the patients of Parkinson plus syndromes scored significantly less on all the balance parameters (Fig. 1). Most of the balance parameters did not differ significantly between MSA and PSP groups. When compared to the controls, the values of MSA and PSP patients were significantly lower except for forward left limit in MSA and right limit in PSP affected individuals (Fig. 2).

Discussion

Gait

'BTS bioengineering' technology can test the gait of PD patients and PD alters the gait parameters like cadence, stride duration, stance duration, swing phase, swing duration, velocity, step width, stride length and swing velocity in comparison to healthy controls (Pistacchi et al. 2017). In the past also, the researchers have compared Parkinson plus syndromes to PD. A published study compared the gait of patients of PSP and PD, while the patients were walking on gait platform using 'BTS bioengineering' technology, similar to the one we employed and found differences among the gait patterns of these two groups of patients (Amboni et al. 2021). In another study, employing 10-m walk test, patients of

Table 1 Various static parameters of gait in patients of Parkinson plus syndromes

Gait parameters	Mean values of patients of Parkinson-plus syndromes	Mean values of controls	*p*-values comparing Parkinson-plus patients with controls using Mann–Whitney *U* test
Stride time of right limb	1.21 ± 0.26	1.16 ± 0.14	0.890
Stride time of left limb	1.25 ± 0.26	1.17 ± 0.17	0.360
Stance time of right limb	0.86 ± 0.27	0.75 ± 0.15	0.190
Stance time of left limb	0.86 ± 0.24	0.75 ± 0.12	0.099
Swing time of right limb	0.35 ± 0.07	0.42 ± 0.09	< 0.001
Swing time of left limb	0.35 ± 0.06	0.40 ± 0.06	0.005
Stance phase of right limb (%)	70.93 ± 7.12	63.50 ± 8.34	< 0.001
Stance phase of left limb (%)	69.31 ± 5.61	65.05 ± 4.23	0.009
Swing phase of right limb (%)	29.95 ± 6.15	36.33 ± 8.39	< 0.001
Swing phase of left limb (%)	29.16 ± 4.94	34.62 ± 5.24	0.001
Single support phase of right limb (%)	29.96 ± 4.66	35.07 ± 4.79	0.001
Single support phase of left limb (%)	29.48 ± 6.19	36.82 ± 8.67	< 0.001
Double support phase of right limb (%)	22.51 ± 5.24	16.87 ± 4.51	< 0.001
Double support phase of left limb (%)	21.35 ± 3.65	16.20 ± 4.25	< 0.001
Mean velocity (m/s)	0.62 ± 0.31	0.98 ± 0.30	< 0.001
Mean Velocity (% height/s)	36.03 ± 17.83	61.51 ± 17.21	< 0.001
Cadence (steps/min)	102.66 ± 17.36	104.71 ± 13.36	0.890
Stride length of right limb (m)	0.68 ± 0.30	1.11 ± 0.21	< 0.001
Stride length of left limb (m)	0.69 ± 0.30	1.10 ± 0.21	< 0.001
Stride length of right limb (% height)	41.04 ± 17.37	68.87 ± 12.94	< 0.001
Stride length of left limb (% height)	42.04 ± 16.79	69.01 ± 12.33	< 0.001
Step length of right limb (m)	0.34 ± 0.14	0.56 ± 0.10	< 0.001
Step length of left limb (m)	0.33 ± 0.15	0.54 ± 0.11	< 0.001
Step width (m)	0.16 ± 0.06	0.12 ± 0.04	0.012
Pelvic obliquity of right limb (deg)	0.70 ± 2.82	1.45 ± 4.82	0.915
Pelvic obliquity of left limb (deg)	− 0.72 ± 2.80	− 1.43 ± 4.83	0.932
Pelvic tilt of right limb (deg)	12.67 ± 9.35	8.63 ± 8.37	0.086
Pelvic tilt of left limb (deg)	12.66 ± 9.34	8.63 ± 8.38	0.086
Pelvic rotation of right limb (deg)	− 4.33 ± − 11.60	7.19 ± 15.69	0.011
Pelvic rotation of left limb (deg)	4.34 ± 11.62	− 5.93 ± 16.24	0.074
Hip ab-adduction of right limb (deg)	− 3.39 ± 4.85	− 0.22 ± 6.90	0.166
Hip ab-adduction of left limb (deg)	− 5.15 ± 5.78	− 3.46 ± 5.46	0.327
Hip flex-extension of right limb (deg)	13.22 ± 12.44	1.02 ± 13.10	0.002
Hip flex-extension of left limb (deg)	11.55 ± 12.32	5.16 ± 9.84	0.103
Hip rotation of right limb (deg)	− 5.38 ± 19.53	− 19.59 ± 28.75	0.187
Hip rotation of left limb (deg)	− 5.21 ± 22.70	− 3.76 ± 33.57	0.476
Knee flex-extension of right limb (deg)	8.96 ± 9.32	− 0.22 ± 7.84	0.002
Knee flex-extension of left limb (deg)	7.84 ± 9.78	0.46 ± 8.32	0.004
Ankle dorsi–plantarflexion of right limb (deg)	6.49 ± 5.01	1.23 ± 4.89	0.002
Ankle dorsi–plantarflexion of left limb (deg)	7.41 ± 4.96	0.41 ± 5.72	< 0.001
Foot progression of right limb (deg)	− 15.97 ± 11.12	− 9.98 ± 18.65	0.766
Foot progression of left limb (deg)	− 7.14 ± 13.01	− 8.78 ± 18.17	0.282
Gait profile score of right limb (deg)	11.40 ± 2.95	11.33 ± 4.30	0.489
Gait profile score of left limb (deg)	13.01 ± 7.07	10.57 ± 2.10	0.163

Table 2 Various dynamic parameters of gait in patients of Parkinson plus syndromes

Gait variable scores	Mean values of patients of Parkinson-plus syndromes	Mean values of controls	*p*-values comparing Parkinson-plus patients with controls using Mann–Whitney U test
Pelvic obliquity of right limb (deg)	3.60 ± 1.25	3.41 ± 0.99	0.864
Pelvic obliquity of left limb (deg)	3.96 ± 1.74	3.16 ± 1.42	0.050
Pelvic tilt of right limb (deg)	8.70 ± 5.31	6.15 ± 4.62	0.051
Pelvic tilt of left limb (deg)	8.56 ± 5.35	6.18 ± 4.66	0.105
Pelvic rotation of right limb (deg)	7.12 ± 3.28	4.82 ± 2.20	0.011
Pelvic rotation of left limb (deg)	6.90 ± 3.49	4.66 ± 2.34	0.017
Hip ab-adduction of right limb (deg)	5.11 ± 2.46	5.47 ± 2.84	0.941
Hip ab-adduction of left limb (deg)	5.94 ± 4.25	5.12 ± 2.59	0.958
Hip flex-extension of right limb (deg)	12.17 ± 4.47	13.95 ± 6.82	0.322
Hip flex-extension of left limb (deg)	11.68 ± 5.04	11.76 ± 6.28	0.966
Hip rotation of right limb (deg)	18.36 ± 9.83	18.48 ± 15.45	0.594
Hip rotation of left limb (deg)	17.62 ± 11.30	18.26 ± 8.89	0.371
Knee flex-extension of right limb (deg)	12.72 ± 4.17	12.05 ± 4.27	0.418
Knee flex-extension of left limb (deg)	14.44 ± 5.12	10.86 ± 4.65	0.035
Ankle dorsi–plantarflexion of right limb (deg)	18.31 ± 28.75	7.51 ± 2.07	0.002
Ankle dorsi–plantarflexion of left limb (deg)	15.57 ± 20.46	7.72 ± 2.94	0.008
Foot progression of right limb (deg)	10.01 ± 7.15	5.47 ± 2.90	0.005
Foot progression of left limb (deg)	9.34 ± 5.53	6.86 ± 3.38	0.148
Gait deviation index of right limb	75.00 ± 11.49	74.16 ± 16.28	0.655
Gait deviation index of left limb	70.86 ± 13.86	72.47 ± 10.75	0.898

PSP showed a decrease in velocity, step length, cadence and mean acceleration. Our study, however, showed no significant difference in cadence in patients of PSP in comparison to controls (Hatanaka et al. 2016). A previous study showed increased stance time variability, swing time variability, stride time variability, and stride length variability in Parkinson-plus syndrome patients in comparison to PD patients (Gabner et al. 2019). Our study, however, compared among Parkinson plus patients (MSA and PSP) and found these parameters to be different among MSA and PSP patients as well, apart from some other parameters like single support phase of right limb, double support phase of both the limbs, mean velocity, cadence, step length of left limb, pelvic obliquity of both the limbs, hip flex-extension of left limb, knee flex-extension of left limb, foot progression of right limb, gait profile score of left limb, gait variable pelvic obliquity of left limb, gait variable pelvic rotation of left limb, gait variable hip abduction–adduction of both the limbs, gait variable hip rotation of left limb, gait variable knee flexion–extension of left limb, gait variable ankle dorsiplanter-plantarflexion of left limb and gait deviation index of left limb, which were also different in MSA and PSP groups.

A previous study did not find differences among gait patterns of MSA and PSP patients in contrast to our study, which found many significant differences in between these two groups of patients, as mentioned (Raccagni et al. 2018).

On comparing between patients of MSA and controls, in a published study, researchers have noticed differences in gait variability except for stride time (Sidoroff et al. 2021). In our study, among the dynamic scores, gait deviation index of both the limbs were not significantly altered, though other dynamic scores like foot progression of right limb and hip rotation of left limb were significantly different in patients of MSA in comparison to the controls.

It might be possible to differentiate between multiple system atrophy and progressive supranuclear palsy patients even in the stage when they both have a tendency to fall but they are still walking on the basis of gait.

Balance

A previous study assessing balance of patients of PSP in comparison to controls, while standing on a moveable plate, showed that PSP affects the balance of patients and that they employ ankle movement to resist falls.[7] Even while walking, the ankle scores were more affected in our patients of atypical Parkinsonism in comparison to the controls. As such, our patients of Parkinson plus syndromes demonstrated a significantly impaired balance measured in terms of limits of stability in all the

Table 3 Various static parameters of gait in patients of multiple system atrophy and progressive supranuclear palsy

Gait parameters	Mean values of patients of multiple system atrophy	*p*-values comparing MSA and controls using Mann–Whitney U test	Mean values of patients of progressive supranuclear palsy	*p*-values comparing PSP and controls using Mann–Whitney U test	*p*-values comparing MSA and PSP using Mann–Whitney U test
Stride time of right limb	1.12 ± 0.13	0.342	1.35 ± 0.34	0.122	0.032
Stride time of left limb	1.18 ± 0.15	0.800	1.36 ± 0.35	0.138	0.409
Stance time of right limb	0.75 ± 0.13	0.962	1.03 ± 0.34	0.008	0.003
Stance time of left limb	0.76 ± 0.10	0.716	1.01 ± 0.32	0.005	0.010
Swing time of right limb	0.35 ± 0.08	0.001	0.34 ± 0.05	0.005	0.639
Swing time of left limb	0.35 ± 0.05	0.011	0.34 ± 0.07	0.026	0.340
Stance phase of right limb (%)	67.53 ± 6.40	0.016	76.04 ± 4.78	< 0.001	< 0.001
Stance phase of left limb (%)	65.89 ± 3.60	0.467	74.46 ± 3.86	< 0.001	< 0.001
Swing phase of right limb (%)	32.34 ± 6.58	0.016	26.38 ± 3.09	< 0.001	0.002
Swing phase of left limb (%)	31.37 ± 3.98	0.048	25.85 ± 4.45	< 0.001	0.001
Single support phase of right limb (%)	32.49 ± 3.09	0.058	26.18 ± 4.06	< 0.001	< 0.001
Single support phase of left limb (%)	31.52 ± 6.80	0.009	26.43 ± 3.56	< 0.001	0.057
Double support phase of right limb (%)	20.32 ± 4.14	0.015	25.79 ± 5.13	< 0.001	0.025
Double support phase of left limb (%)	19.62 ± 2.82	0.014	23.96 ± 3.23	< 0.001	0.001
Mean velocity (m/s)	0.72 ± 0.33	0.025	0.46 ± 0.18	< 0.001	0.030
Mean Velocity (% height/s)	42.23 ± 19.37	0.007	26.73 ± 10.03	< 0.001	0.022
Cadence (steps/min)	108.56 ± 13.44	0.411	93.83 ± 19.31	0.169	0.036
Stride length of right limb (m)	0.77 ± 0.34	0.001	0.53 ± 0.15	< 0.001	0.026
Stride length of left limb (m)	0.79 ± 0.32	0.001	0.55 ± 0.16	< 0.001	0.022
Stride length of right limb (% height)	46.21 ± 19.51	0.001	33.29 ± 9.92	< 0.001	0.051
Stride length of left limb (% height)	47.37 ± 18.35	0.001	34.05 ± 10.36	< 0.001	0.028
Step length of right limb (m)	0.37 ± 0.15	< 0.001	0.29 ± 0.10	< 0.001	0.090
Step length of left limb (m)	0.37 ± 0.16	0.002	0.26 ± 0.08	< 0.001	0.022
Step width (m)	0.16 ± 0.05	0.049	0.17 ± 0.06	0.018	0.373
Pelvic obliquity of right limb (deg)	− 0.39 ± 2.80	0.506	2.34 ± 1.98	0.498	0.003
Pelvic obliquity of left limb (deg)	0.37 ± 2.79	0.527	− 2.35 ± 1.97	0.498	0.003
Pelvic tilt of right limb (deg)	14.79 ± 8.76	0.018	9.48 ± 9.65	0.799	0.117
Pelvic tilt of left limb (deg)	14.78 ± 8.75	0.018	9.48 ± 9.65	0.799	0.112
Pelvic rotation of right limb (deg)	− 5.70 ± 12.45	0.009	− 2.27 ± 10.38	0.108	0.866

Table 3 (continued)

Gait parameters	Mean values of patients of multiple system atrophy	*p*-values comparing MSA and controls using Mann–Whitney U test	Mean values of patients of progressive supranuclear palsy	*p*-values comparing PSP and controls using Mann–Whitney U test	*p*-values comparing MSA and PSP using Mann–Whitney U test
Pelvic rotation of left limb (deg)	5.72 ± 12.46	0.016	2.27 ± 10.38	0.271	0.866
Hip ab-adduction of right limb (deg)	− 3.15 ± 4.75	0.342	− 3.74 ± 5.19	0.138	0.525
Hip ab-adduction of left limb (deg)	− 3.68 ± 5.95	0.962	− 7.36 ± 4.95	0.060	0.066
Hip flex-extension of right limb (deg)	15.91 ± 14.69	0.004	9.18 ± 6.67	0.018	0.062
Hip flex-extension of left limb (deg)	16.79 ± 12.58	0.006	3.68 ± 6.54	0.672	0.007
Hip rotation of right limb (deg)	− 9.56 ± 18.65	0.486	0.88 ± 19.91	0.090	0.310
Hip rotation of left limb (deg)	− 7.15 ± 18.89	0.704	− 2.29 ± 28.14	0.363	0.539
Knee flex-extension of right limb (deg)	9.62 ± 10.26	0.006	7.97 ± 8.02	0.011	0.832
Knee flex-extension of left limb (deg)	10.88 ± 10.18	0.001	3.29 ± 7.36	0.176	0.054
Ankle dorsi–plantar-flexion of right limb (deg)	6.45 ± 5.48	0.017	6.54 ± 4.44	0.004	0.611
Ankle dorsi–plantar-flexion of left limb (deg)	6.36 ± 5.84	0.007	8.99 ± 2.76	< 0.001	0.175
Foot progression of right limb (deg)	− 20.13 ± 10.69	0.146	− 9.72 ± 8.84	0.176	0.025
Foot progression of left limb (deg)	− 7.32 ± 14.04	0.289	− 6.88 ± 11.90	0.472	0.657
Gait profile score of right limb (deg)	11.24 ± 3.25	0.646	11.63 ± 2.54	0.446	0.865
Gait profile score of left limb (deg)	10.29 ± 3.51	0.612	17.10 ± 9.07	0.001	0.007

directions, as expected. We also found that PSP and MSA patients did not differ significantly in balance parameters in most of the directions. However, MSA patients, who may fall sideways as well, did not demonstrate difference in sideward balance parameters in comparison to PSP patients.

In MSA patients in comparison to PD, the previous research found out balance impairment (postural instability) and an increased sway (Na et al. 2019; Panyakaew et al. 2019). A previous study did not find any difference in the sway parameters of patients of PD compared to those of PSP but they were different in comparison to controls (Kammermeier et al. 2018). Our study, on the other hand, found out significant impairment of balance (limits of stability) in patients of Parkinson plus syndromes (both MSA and PSP patients) in comparison to controls and on comparing between PSP and MSA patients, the balance parameters were almost similarly affected. Other previous studies, which had compared limits of stability of PSP patients with controls and PD patients found a greater impairment in balance, especially backward balance in patients of PSP (Pasha et al. 2016; Ondo et al. 2000), but they had not compared MSA patients with PSP patients, like in our study.

Another study on patients of PSP showed preserved limits of stability scores in the left and forward left direction (Ganesan et al. 2012). Our PSP patients, however, had impaired balance in all the directions, in comparison to the controls, but right direction values were not significant. Our MSA patients also had imparted balance in all the directions, though forward left direction values were not within significant limits.

Also, the previous investigators assessed decreased walking speed, lesser cadence, shorter step and stride length, and greater pelvis motion to be the risk factors for falls in PD patients (Creaby and Cole 2018). Here,

Table 4 Various dynamic parameters of gait in patients of multiple system atrophy and progressive supranuclear palsy

Gait variable scores	Mean values of patients of multiple system atrophy	*p*-values comparing MSA and controls using Mann–Whitney U test	Mean values of patients of progressive supranuclear palsy	*p*-values comparing PSP and controls using Mann–Whitney U test	*p*-values comparing MSA and PSP using Mann–Whitney U test
Pelvic obliquity of right limb (deg)	3.33 ± 1.05	0.447	4.02 ± 1.46	0.497	0.175
Pelvic obliquity of left limb (deg)	3.36 ± 1.31	0.456	4.88 ± 1.95	0.004	0.038
Pelvic tilt of right limb (deg)	9.83 ± 6.34	0.058	7.00 ± 2.62	0.182	0.512
Pelvic tilt of left limb (deg)	9.68 ± 6.42	0.114	6.88 ± 2.58	0.271	0.409
Pelvic rotation of right limb (deg)	6.17 ± 3.20	0.178	8.55 ± 2.95	0.001	0.051
Pelvic rotation of left limb (deg)	5.81 ± 3.26	0.242	8.54 ± 3.27	0.001	0.023
Hip ab-adduction of right limb (deg)	4.52 ± 2.71	0.342	5.99 ± 1.81	0.156	0.013
Hip ab-adduction of left limb (deg)	3.84 ± 2.51	0.029	9.09 ± 4.47	0.005	< 0.001
Hip flex-extension of right limb (deg)	13.27 ± 4.71	0.862	10.53 ± 3.65	0.028	0.156
Hip flex-extension of left limb (deg)	11.59 ± 5.82	0.899	11.82 ± 3.81	0.933	0.719
Hip rotation of right limb (deg)	16.78 ± 11.07	0.728	20.73 ± 7.43	0.127	0.117
Hip rotation of left limb (deg)	13.59 ± 7.77	0.023	23.68 ± 13.29	0.204	0.034
Knee flex-extension of right limb (deg)	12.12 ± 3.84	0.704	13.63 ± 4.63	0.271	0.385
Knee flex-extension of left limb (deg)	13.10 ± 4.96	0.268	16.45 ± 4.88	0.007	0.040
Ankle dorsi–plantar-flexion of right limb (deg)	22.73 ± 36.71	0.058	11.68 ± 4.05	< 0.001	0.397
Ankle dorsi–plantar-flexion of left limb (deg)	9.61 ± 3.41	0.150	24.51 ± 30.67	0.001	0.013
Foot progression of right limb (deg)	10.73 ± 7.55	0.004	8.93 ± 6.67	0.079	0.320
Foot progression of left limb (deg)	9.56 ± 4.91	0.094	9.03 ± 6.56	0.525	0.553
Gait deviation index of right limb	76.65 ± 12.93	0.975	72.52 ± 8.84	0.397	0.352
Gait deviation index of left limb	76.92 ± 9.54	0.282	61.78 ± 14.68	0.090	0.003

we found that Parkinson plus patients who were falling had a decreased swing time, swing phase, single support phase, stride length, mean velocity, step length, pelvic rotation of right limb and increased stance phase, double support phase, hip flex-extension of right limb, knee flex-extension, ankle dorsi–plantarflexion, gait variable pelvic rotation, gait variable ankle dorsi–plantarflexion in comparison to healthy people (who were not falling), similar to those of the study on PD with falls. However, we found that cadence was similar in the two groups, quite unlike the study on PD patients.

Main limitation of this study is lack of a larger sample size and this was due to lack of funds and inability to recruit more patients. Also, the investigators were aware of the fact that a person being tested was a case or a control and this might have resulted in a bias.

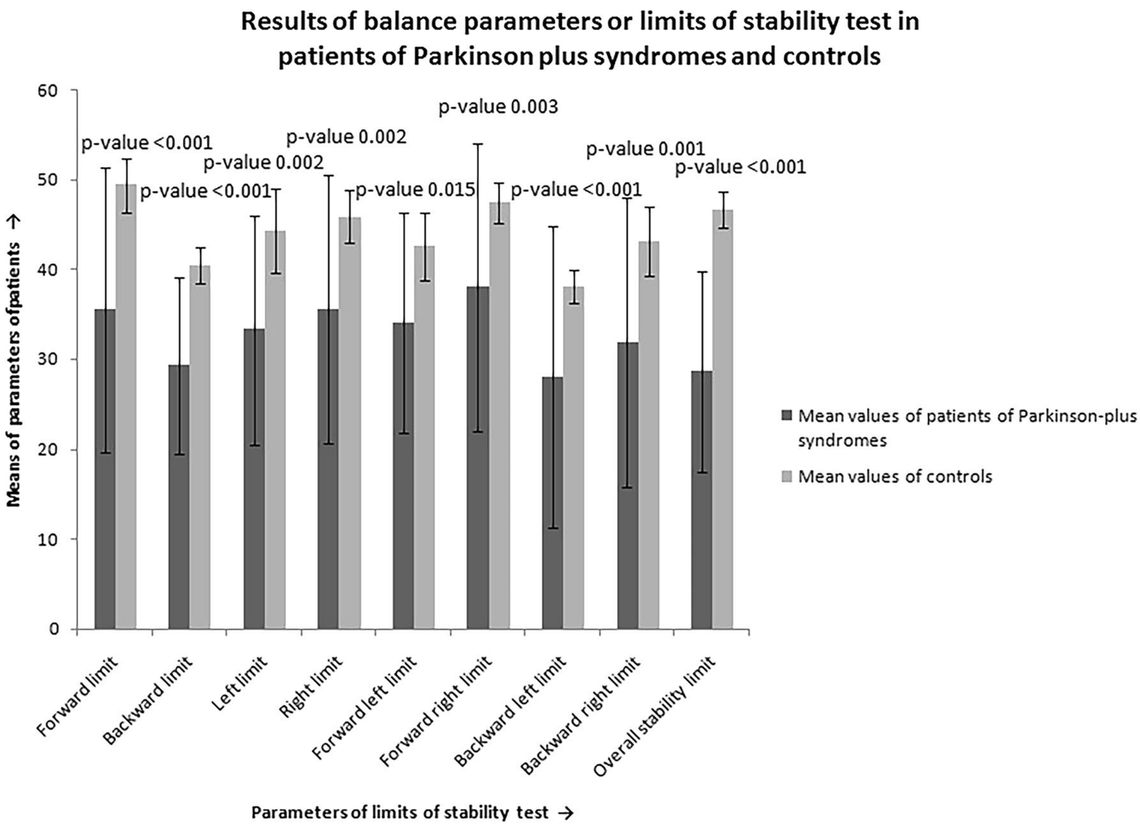
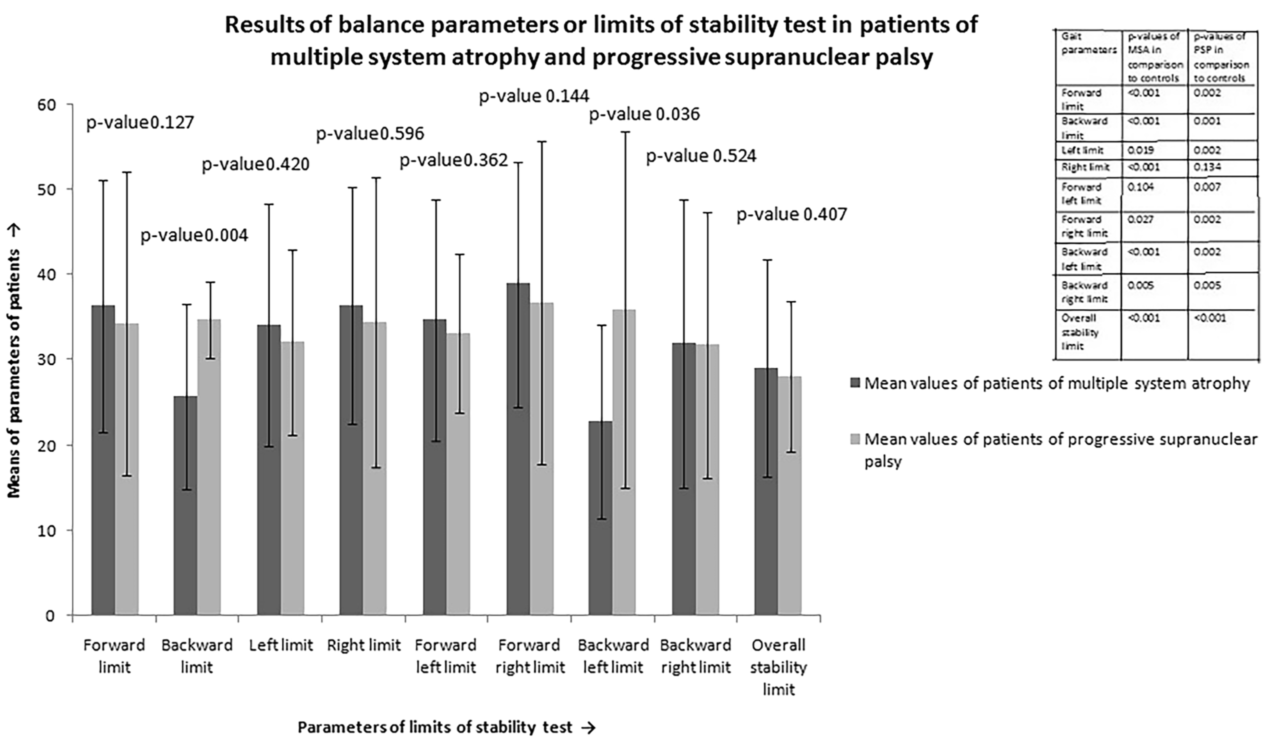


Fig. 1 Results of balance parameters or limits of stability test in patients of Parkinson plus syndromes



Gait parameters	p-values of MSA in comparison to controls	p-values of PSP in comparison to controls
Forward limit	<0.001	0.002
Backward limit	<0.001	0.001
Left limit	0.019	0.002
Right limit	<0.001	0.134
Forward left limit	0.104	0.007
Forward right limit	0.027	0.002
Backward left limit	<0.001	0.002
Backward right limit	0.005	0.005
Overall stability limit	<0.001	<0.001

Fig. 2 Results of balance parameters or limits of stability test in patients of multiple system atrophy and progressive supranuclear palsy

Hence, one may use gait testing to differentiate between Parkinson-plus patients and healthy controls and between MSA and PSP patients with falling tendencies.

Worldwide, the clinicians are identifying many rehabilitative approaches for improving the gait and balance of people with PD like virtual reality, treadmill training and robot assisted gait training (Wang et al. 2019; Capecci et al. 2019; Schlenstedt et al. 2015). This data may further help in planning and innovating many rehabilitative approaches for improving gait of the patients of PSP including spinal cord stimulation, treadmill training and robot assisted gait training, which are being employed to some extent at several places in the world (Samotus et al. 2021; Sale et al. 2014; Suteerawattananon et al. 2002). Subsequently, it may facilitate rehabilitation of PSP and MSA patients based on balance (Zampieri and Fabio 2008; Lee et al. 2018; Silva-Batista et al. 2014).

Conclusions

In the present study, some gait parameters significantly differentiate between multiple system atrophy and progressive supranuclear palsy patients even in the stage when they both have a tendency to fall and few of these parameters are different from those in previous studies. The balance was however, equally affected in PSP and MSA patients. Knowledge about these similarities and differences may help in differentiating between these two entities clinically and may help in planning rehabilitative strategies in future.

Abbreviations

MSA	Multiple system atrophy
MSA-P	Multiple system atrophy-Parkinsonian variant
PSP	Progressive supranuclear palsy
PSP-RS	PSP with Richardson's syndrome
PSP-P	Progressive supranuclear palsy with predominant Parkinsonism
PD	Parkinson's disease
OPD	Out patient department
MDS	Movement Disorders Society

Acknowledgements

Not Applicable.

Author contributions

RT conceptualized the study and prepared the original draft, RT and GV worked out the methodology, formal analysis and investigations, RT, GV, BPS and AKG reviewed and edited the manuscript and AKG supervised the study. All the authors have read and approved the manuscript.

Funding

No funding was received.

Availability of data and materials

Data is available if needed by the journal.

Declarations

Ethics approval and consent to participate

This study was approved by the institutional ethics committee and certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Consent for publication

Patients signed informed consent regarding publishing their data and photographs.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Received: 10 April 2023 Accepted: 27 May 2023
Published online: 31 May 2023

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