Original Article

Anteroposterior Stability: A Determinant of Gait Dysfunction and Falls in Spinocerebellar Ataxia

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Abstract

Background: Establishing an association between gait variability and direction specific balance indices may help in identifying the risk of falls in patients with spinocerebellar ataxia (SCA) which may help in developing an appropriate intervention. This study is intended to identify the association between balance and gait parameters especially gait variability in these patients. **Methods:** Patients with genetically confirmed SCA ($n = 24$) as well as controls ($n = 24$) who met the study criteria were recruited. Gait was assessed using the GAITRite system and balance was assessed using dynamic posturography (Biodex) to record direction-specific dynamic balance indices. Disease severity was assessed using international cooperative ataxia rating scale (ICARS). **Results:** The mean age of the SCA group (38.83 ± 13.03 years) and the control group (36.38 ± 9.09 years) were comparable. The age of onset of illness was 32 ± 10.62 years and duration of 5.67 ± 3.62 years. The mean ICARS was 45.10 ± 16.75. There was a significant difference in the overall balance index (OBI), anterior–posterior index (API), medial/lateral index (MLI) between SCA patients (4.56 ± 2.09, 3.49 ± 1.88, 2.94 ± 1.32) and the controls (2.72 ± 1.25, 2.08 ± 0.85, 1.85 ± 0.97). However, correlation was observed only between gait stability and balance parameters in API direction. **Conclusions:** There was an increased anteroposterior oriented balance deficit in patients with SCA, which was significantly correlating with the gait parameters. The balance training intervention may focus on improving anteroposterior direction to prevent falls and improving walking efficiency.

Keywords: Balance, balance index, dynamic posturography, gait, gait stability, GAITRite, spinocerebellar ataxia

Introduction

Spinocerebellar ataxia (SCA) is an autosomal dominant heterogeneous neurodegenerative disorder of the central nervous system.[1] It is a progressive disorder with the rate of functional decline that depends on the age of onset, gender, type, genetic defect, etc.[2] Patients with SCA are more prone to falls and with greater episodes of near falls, 75% of these falls often lead to injuries,[3] and subsequent prolonged hospitalization. Further, fall and fear of fall (FOF) may impose severe "mobility restriction" and be more dependent on family members or caregivers.[4-6] On some occasion, mobility restriction has been imposed upon by the family members to avoid the patients getting a fatal fall and its consequences on themselves. Overall, this shall lead to a poor quality of life for patients and their caregivers.[7]

The body tends to adapt to the postural instability during locomotion by modifications in the gait patterns, which helps in reducing the risk of falls in them.[8] This can be in accordance with the trial and error adaptation of the motor behavior for which cerebellum plays a crucial role. Cerebellum helps in postural stability and also plays a vital role in control of movements through its connections with reticular formation as well as the vestibular system.[9]

Studies have identified the increased variability of gait as a clinical marker for falls in patients with dementia and the oldest-old population. While progressive disturbances in coordination, balance, and gait are characteristic features of SCA, gait variability and fall has been reported as well.[10] As the risk and incidence of falls during walking have a direct relationship with the balance deficits and variability of gait, identifying the relationship between specific balance indices with various spatiotemporal gait characteristics including gait variability in terms of coefficient variation of step length and step time may add information on planning "fall prevention" strategies. Many works of literature have identified the relationship between the motor performances of the individuals and the severity and prognosis of the disease,[11,12] but hardly any of them have identified the relationship between the gait and balance variables. It is of demand to study the specific balance parameters associate with the gait parameters with special interest on gait variability in these patient populations to optimize rehabilitation strategies accordingly. This study measures the balance and gait characteristics of SCA patients

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and to identify the correlation between the balance and gait parameters. The influence of specific balance parameter on gait variability in cerebellar pathology shall thus be explored. The correlation may reveal the relationship between balance sub-component and major gait characteristics and may not be considered as a causative effect of one on another.

Methods

Patients with genetically confirmed SCA were recruited from the Neurology OPD and Movement Disorders clinic of the department of Neurology, National Institute of Mental Health and Neuro Sciences (NIMHANS), Bangalore. Ethical clearance was obtained from the institutional review board before recruitment. Patients in the age group of 20–70 years of both gender and who were able to ambulate independently or with assistive devices for a minimum of 10 m were included in the study after obtaining well informed consent. Patients who were unable to undergo the tests because of severe mobility disturbance, presence of concomitant other neurological illness, or significant medical or orthopedic problems and significant vision problems were excluded. The control group consisted of healthy volunteers who were willing to participate in the study and were recruited from within the institution. Healthy adult individuals of both genders within the age group of 20–70 were considered as controls. Signed informed consent was obtained from the participants prior to the data collection process. Patients underwent gait assessment followed by balance assessment.

Measurement of gait

The gait parameters were assessed using the GAITRite® Electronic Walkway System (CIR Systems Inc., Clifton, New Jersey) with an input frequency of 30 Hz. GAITRite composed of a 7 m mat with embedded sensors that collects the spatial and temporal parameters of gait. A trial (3 trials) on GAITRite was provided for the participants for familiarization and to bring out their casual walking pattern. Spatial and temporal parameters were recorded from the Walkway system by asking the patient to walk on the mat from one end to another at their comfortable speed. To elicit comfortable speed, patients were asked to start to walk from 1 m ahead and beyond the gait mat. A minimum of four steps was recorded to assess the variability of gait parameters. No commands were given at the time of assessment to reduce the bias. Parameters such as functional ambulation profile (FAP), velocity, cadence, and step time, step length, stride time, stride length, and heel to heel base of support (H-H BOS) of left and right leg were obtained. H-H BOS is considered as the vertical distance from the mid-heel point of one foot to the line of progression formed by two footprints of the other foot. Gait variability was assessed as the coefficient of variation (CV) of spatial and temporal variables of step and stride.

Measurement of balance

The balance parameters were assessed using the Biodex Balance System (Biodex Medical Systems Inc., Shirley, New York). This system is equipped with a circular platform that can move freely in anteroposterior and medio-lateral axes simultaneously allowing a 20 degrees tilting from horizontal in all directions. The amount of stiffness of the platform is controlled mechanically by hydraulic springs. Assessment of overall balance index (OBI) as well as anteroposterior and medio-lateral sway index (API and MLI) were recorded. Foot position coordinates were to establish the ideal foot position of the subject for the test and recorded. For this, the person is made to stand over the locked platform, after which it is unlocked whereby the subject has to adjust his foot position to maintain platform stability. The platform is locked again and the new foot positions are recorded. Subjects are then asked to maintain this foot positions throughout the test procedure. Testing begins by releasing the platform and asking the subjects to maintain upright standing for 20 s without any support. A trial of 20 s was provided for the subjects after which three test trials were done, and the average of the three was recorded. A high score recorded in various sway index parameters indicates increased sway and poor balance in individual direction as well as on an overall balance index. A safety harness was provided to ensure protection from a fall.

Statistical analysis

Descriptive analysis was used for the demographic variables of participants. Independent *t*-test was performed to identify the difference between means of the baseline characteristics of SCA and control group. Mann–Whitney U test was applied to identify the differences in balance and gait parameters between the SCA and the control group. The level of significance was kept at $P < 0.05$. Spearman's rank correlation was performed separately within the groups to identify the correlation between the gait and balance parameters. The analysis was done using SPSS (IBM SPSS Statistics for Windows, Version 22.0, Armonk, NY: IBM Corp. Released 2013).

Results

A total of 48 individuals participated in the study; with 24 participants in each group. The duration of illness in SCA group was 5.67 ± 3.62. The demographic details of two groups are provided in Table 1. Independent *t*-test analysis demonstrated homogeneity between the two groups for the demographic measurements. There were four patients with SCA1, 12 SCA2, 5 SCA3, and 3 SCA12. There was a significant difference between the balance indices of the two groups upon analyzing using independent *t*-test with SCA group demonstrated significant balance deficits than that of controls ($P < 0.01$). Both groups expressed higher API when compared to MLI. The mean values of OBI, API, and MLI of SCA was 4.56 ± 2.09, 3.49 ± 1.88 and 2.94 ± 1.32, and the control group was 2.72 ± 1.25, 2.08 ± 0.85, and 1.85 ± 0.97, respectively [Table 2].

The mean step count of SCA group was 7.92 ± 1.79 (Min: 5, Max: 12), whereas the mean step count of control group was 5.62 ± 1.17 (Min: 4, Max: 8). Mann–Whitney U test analysis

demonstrated significant difference in balance and most of the gait parameters including coefficient of variation, between both groups [Table 3]. There was a significant increase in CV of Step Length of SCA group (Lt: 11.9 ± 11.48, Rt: 8.04 ± 6.59) when compared with the control group (Lt: 3.46 ± 2.35, Rt: 3.73 ± 2.56) ($P < 0.01$).

Spearman rank correlation was performed to identify the relationship between gait and balance parameters. It was observed that there was significant correlation between the gait parameters and balance measures such as OBI and API in patients with SCA. MLI was not correlating significantly with any of the gait parameters in this group ($P > 0.05$). On analyzing gait variability, only coefficient of variation (CV) of step length of left leg showed a moderate positive correlation with OBI (Spearman $\rho = 0.423$, $P = 0.040$) and API (Spearman $\rho = 0.463$, $P = 0.023$). The control group showed significant correlation between balance parameters and most of the gait parameters. Figures 1 and 2 depicts the correlation of balance indices and gait variability in SCA and control

Table 1: Demographic characteristics of the study participants

Characteristic	SCA Group ($n=24$)	Control Group ($n=24$)	*t*-test	Significance ($P<0.05$)
Gender (M:F)	16:8	16:8		
Age (years) (Mean±SD)	38.83±13.03	36.38±9.09	0.76	0.45
Age at onset (years) (Mean±SD)	32±10.62	-	-	-
Duration of illness (years) (Mean±SD)	5.67±3.62	-	-	-
Mean ICARS score (Mean±SD)	45.10±16.75	-	-	-
Height (cm)	166.67±10.42	169.04±10.14	0.80	0.43
Weight (kg)	69.39±14.49	74.64±11.96	1.37	0.18
BMI (kg/m^2)	24.94±4.41	26.14±3.82	1.00	0.32

BMI: Body mass index; ICARS: International Cooperative Ataxia Rating Scale

Table 2: Comparison of balance indices between the two groups

Balance indices	SCA Group ($n=24$)	Control Group ($n=24$)	Mean Difference	*t*-test	Significance ($P<0.05$)
OBI	4.56±2.09	2.72±1.25	1.84	3.69	0.001
API	3.49±1.88	2.08±0.85	1.42	3.36	0.002
MLI	2.94±1.32	1.85±0.97	1.09	3.28	0.002

API: Antero-posterior index; MLI: Mediolateral index; OBI: Overall balance index

Table 3: Comparison of gait parameters of the two groups

Variables	Side	SCA Group (Mean±SD)	Control Group (Mean±SD)	Mann-Whitney *U*	Significance ($P<0.05$)
FAP	-	80.13±15.44	95.46±3.71	60.50	<0.001
Velocity (cm/sec)	-	75.05±19.82	112.95±22.61	59.00	<0.001
Cadence (steps/min)	-	97.2±11.64	106.19±7.0	143.50	0.003
Step Time (cm)	Lt	0.62±0.09	0.57±0.04	152.00	0.005
	Rt	0.63±0.07	0.57±0.04	144.50	0.003
Step Length (cm)	Lt	45.76±9.74	63.38±9.78	45.00	<0.001
	Rt	47.11±8.44	63.38±9.71	52.00	<0.001
Stride Time (sec)	Lt	1.23±0.14	1.13±0.75	153.00	0.005
	Rt	1.25±0.15	1.13±0.71	146.50	0.004
Stride Length (cm)	Lt	93.51±19.66	127.45±19.66	52.00	<0.001
	Rt	92.69±18.88	127.49±19.09	43.00	<0.001
H-H BOS (cm)	Lt	15.81±7.13	11.15±3.91	163.00	0.010
	Rt	15.73±7.04	11.29±3.73	166.00	0.012
CV Step Time (%)	Lt	26.63±85.41	3.06±2.37	82.00	<0.001
	Rt	8.11±3.9	3.69±2.99	111.00	<0.001
CV Step Length (%)	Lt	11.9±11.48	3.46±2.35	81.00	<0.001
	Rt	8.04±6.59	3.73±2.56	137.00	0.002
CV Stride Time (%)	Lt	5.08±3.26	2.48±2.03	141.00	0.002
	Rt	5.99±3.96	2.45±1.85	126.00	0.001
CV Stride Length (%)	Lt	6.89±6.75	2.51±1.89	154.00	0.006
	Rt	7.18±6.24	2.36±2.11	110.00	<0.001

*Significant at $P<0.05$ level; **significant at $P<0.001$ level. CV: Coefficient of variation; FAP: Functional ambulation profile; H-H BOS: Heel-heel base of support; Lt: Left; Rt: Right

group, respectively. The correlation analysis is summarized in Table 4.

Discussion

The present study identified a significant correlation between the specific balance indices and gait parameters in patients with SCA. The API was higher in SCA group compared to MLI with a mean difference of 0.55 ± 0.47. When the MLI didn't correlate with any of the gait parameters, the API showed a significant correlation with 9 out of the 21 gait parameters analyzed for this study. The trend was identified to be a significant positive moderate correlation with temporal parameters, H-H BOS and CV of step length, and a moderate negative correlation with FAP, velocity, and cadence. Spatial parameters (step and stride length) didn't demonstrate a significant correlation.

Individuals in control group were homogenous with SCA group in terms of age, gender ratio, and BMI. On comparison with the control group, patients with SCA had significantly higher rate of balance deficits. All balance indices (OBI, API, and MLI) of control group were correlating significantly with 18 out of 21 gait parameters. It was noteworthy that control group data

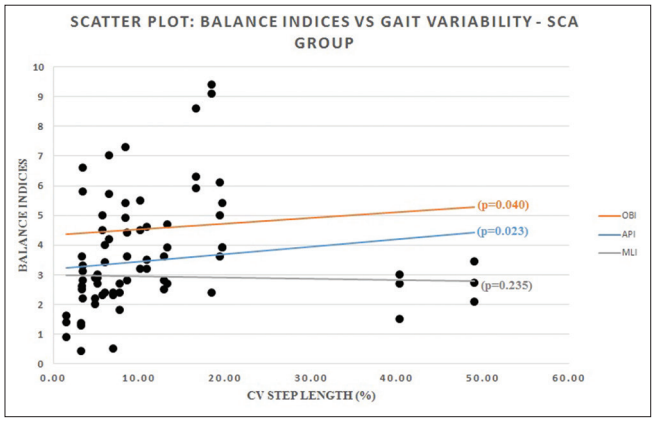

Figure 1: Positive correlation between balance indices (OBI&API) and gait variability (CV of Step length) in SCA group. No correlation was found in MLI vs Gait variability

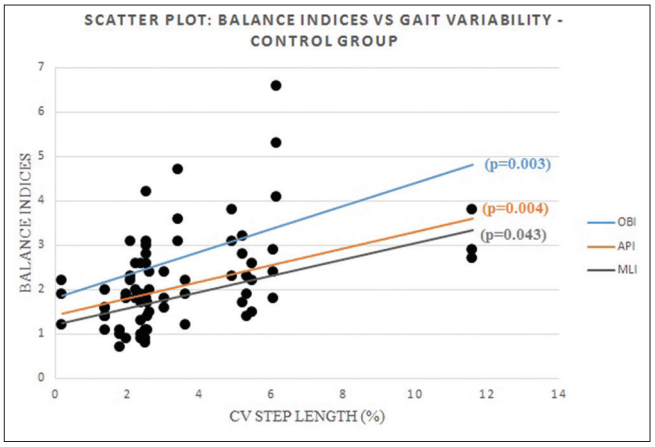

Figure 2: Positive correlation between balance indices (OBI, API&MLI) and gait variability (CV of Step length) in control group

Table 4: Summary of correlation analysis of two groups

Variables	Side	SCA Group (Spearman ρ)			Control Group (Spearman ρ)		
		OBI	API	MLI	OBI	API	MLI
FAP	-	-0.362, (*P*=0.082)	-0.506*, (*P*=0.012)	-0.062, (*P*=0.774)	-0.164, (*P*=0.444)	-0.034, (*P*=0.875)	-0.364, (*P*=0.080)
Velocity (cm/sec)	-	-0.352, (*P*=0.092)	-0.439*, (*P*=0.032)	-0.165, (*P*=0.442)	-0.497*, (*P*=0.014)	-0.496*, (*P*=0.014)	-0.436*, (*P*=0.033)
Cadence (steps/min)	-	-0.400, (*P*=0.053)	-0.514*, (*P*=0.010)	-0.360, (*P*=0.084)	-0.517**, (*P*=0.010)	-0.534**, (*P*=0.007)	-0.452*, (*P*=0.026)
Step Time (cm)	Lt	0.263, (*P*=0.215)	0.376, (*P*=0.070)	0.272, (*P*=0.199)	0.497*, (*P*=0.013)	0.513*, (*P*=0.010)	0.441*, (*P*=0.031)
	Rt	0.470*, (*P*=0.020)	0.548**, (*P*=0.006)	0.350, (*P*=0.094)	0.466*, (0.022)	0.506*, (0.012)	0.402, (*P*=0.052)
Step Length (cm)	Lt	-0.310, (*P*=0.140)	-0.355, (*P*=0.089)	-0.039, (*P*=0.856)	-0.462*, (*P*=0.023)	-0.452*, (0.027)	-0.430*, (*P*=0.036)
	Rt	-0.130, (*P*=0.545)	-0.154, (*P*=0.471)	-0.085, (*P*=0.693)	-0.438*, (*P*=0.032)	-0.423*, (*P*=0.040)	-0.376, (*P*=0.070)
Stride Time (sec)	Lt	0.386, (*P*=0.063)	0.513*, (*P*=0.010)	0.312, (*P*=0.137)	0.520**, (*P*=0.009)	0.537**, (*P*=0.007)	0.451*, (*P*=0.027)
	Rt	0.448*, (*P*=0.028)	0.533**, (*P*=0.007)	0.310, (*P*=0.140)	0.479*, (*P*=0.018)	0.508*, (*P*=0.011)	0.402, (*P*=0.052)
Stride Length (cm)	Lt	-0.154, (*P*=0.474)	-0.174, (*P*=0.416)	0.019, (*P*=0.929)	-0.451*, (*P*=0.027)	-0.438*, (*P*=0.032)	-0.421*, (*P*=0.040)
	Rt	-0.244, (*P*=0.251)	-0.249, (*P*=0.240)	-0.060, (*P*=0.782)	-0.421*, (*P*=0.041)	-0.409*, (*P*=0.047)	-0.379, (0.068)
H-H BOS (cm)	Lt	0.478*, (*P*=0.018)	0.590**, (*P*=0.002)	0.235, (*P*=0.268)	0.102, (*P*=0.636)	-0.012, (*P*=0.955)	0.222, (*P*=0.297)
	Rt	0.537**, (*P*=0.007)	0.632**, (*P*=0.001)	0.270, (*P*=0.202)	-0.008, (*P*=0.971)	-0.155, (*P*=0.471)	0.139, (*P*=0.517)
CV Step Time (%)	Lt	0.008, (*P*=0.971)	0.065, (*P*=0.763)	-0.094, (*P*=0.661)	-0.117, (*P*=0.586)	-0.185, (*P*=0.386)	-0.010, (*P*=963)
	Rt	0.223, (*P*=0.295)	0.315, (*P*=0.134)	0.140, (*P*=0.515)	0.442*, (*P*=0.031)	0.467*, (*P*=0.021)	0.328, (*P*=0.118)
CV Step Length (%)	Lt	0.423*, (*P*=0.040)	0.463*, (*P*=0.023)	0.252, (*P*=0.235)	0.573**, (*P*=0.003)	0.570**, (*P*=0.004)	0.417*, (0.043)
	Rt	0.071, (*P*=0.740)	0.128, (*P*=0.553)	-0.032, (*P*=0.883)	0.594**, (*P*=0.002)	0.654**, (*P*=0.001)	0.388, (*P*=0.061)
CV Stride Time (%)	Lt	0.101, (*P*=0.639)	0.271, (*P*=0.201)	0.122, (*P*=0.571)	0.483*, (*P*=0.017)	0.441*, (*P*=0.031)	0.447*, (*P*=0.028)
	Rt	0.166, (*P*=0.439)	0.304, (*P*=0.149)	-0.040, (*P*=0.851)	0.117, (*P*=0.586)	0.089, (*P*=0.680)	0.124, (*P*=0.563)
CV Stride Length (%)	Lt	0.025, (*P*=0.908)	0.142, (*P*=0.508)	-0.147, (*P*=0.493)	0.704**, (*P*<0.000)	0.678**, (*P*<0.000)	0.585**, (0.003)
	Rt	0.255, (*P*=0.229)	0.325, (*P*=0.122)	0.112, (*P*=0.603)	0.538**, (*P*=0.007)	0.511*, (*P*=0.011)	0.386, (*P*=0.062)

CV: Coefficient of variation; FAP: Functional ambulation profile; H-H BOS: Heel-heel base of support; Lt: Left; Rt: Right

demonstrated a significant moderate positive correlation with most of the temporal parameters (step time and stride time) and a moderate negative correlation with spatial parameters (step length and stride length) as well as with functional ambulation profile (FAP), velocity and cadence. Thus, the data showed an unforeseen result as there was significant correlation of all balance indices with gait parameters in the control group whereas the SCA group showed no significant correlation with MLI.

Our study is in line with a few other studies which reported balance impairment in patients with SCA demonstrates a greater imbalance in AP than ML direction.[8,13-15] This unusual pattern of body oscillation may attribute to the reduction in ankle and knee flexion response and an increase in pelvis and trunk motions to perturbations.[16-19] The literature suggests various rationale for motor impairment in patients with SCA. Order reversal of motor unit recruitment, delayed recruitment of muscles responsible for proximal synergy control, agonist muscles co-activation, delay in postural response activation, reduction in amplitude of muscles responses, impaired control over automatic postural responses, and defects in adaptation to the environment, along with impaired connectivity between somatosensory and vestibular systems lead to the abnormal postural control and gait ataxia.[4,8,9,16,20]

Most importantly, this study has found correlation of API but not MLI with the gait parameters assessed in these patient populations. To the best of our knowledge, this is the first study to compare the relationship of balance and gait characteristics in SCA and controls using quantitative measurement. Human gait is a product of efficient static and dynamic balance measures. A reduction in balance performance may directly affect the ambulation of an individual. Our study identified that, in the balance performance measures under consideration, the API poses a significant relationship with the majority of the gait parameters, thus establishing an interaction between them. This may explain the gait dysfunction experienced by SCA patients. The ataxic gait in SCA manifest a reduction in gait velocity, cadence, step and stride length, swing phase, and an increment in the base of support, step and stride time, stance phase and double limb support phase, and increased variability of spatial and temporal parameters. The changes in gait parameters are speculated to arise due to trunk instability.[8,9,19,21]

Increased variability in gait parameters correlates positively with the severity of the disease and is related to gait instability and thus associated with the history of falls.[4,22] We identified that API contributes more to the gait variability in these patients with a significant positive correlation with the coefficient of variation of step length. Increased AP displacements have identified to be a strong predictor of incidence of falls in the elderly population whereas ML displacement was not.[23] This can be attributed to the increased reliance on the ankle and hip strategy for error correction in the sagittal plane. It's important to note that mediolateral instability is found to be predominant in subjects with cognitive impairment especially during dual task.[14,24,25] We suggest that exercise protocols with specific emphasis on anteroposterior stability may have a better impact on reducing gait variability and preventing falls in this population.

Cerebellum helps in scaling of the responses produced by the body to counteract for the postural perturbations. An inability to judge the magnitude of the responses for the preceding perturbation causes imbalance to the system with an overshooting of the responses.[17,21] Dysmetria in postural responses along with prolonged muscle activity are detected in individuals with cerebellar damage. This will be also accompanied by decomposition of movements causing an incoordination in combined multi-joint movements.[10] This may even have an impact on the coordination required between trunk and limb girdle in locomotion. Cerebellum also plays a vital role in motor learning and adaptations through a trial and error mechanism. A damage to cerebellar structures may also causes impaired adaptations to postural demands in terms of locomotion. Morton *et al*. suggested that direction-oriented balance deficits are seen in damage with cerebellar structures, with an anterior lobe lesion demonstrating an increased anteroposterior sway, localized vestibule–cerebellar lesion demonstrating an omnidirectional sway and lateral cerebellar damage showing only slight instability when compared to controls.

Our study poses a few limitations. This study included various sub-types of SCA hence the result cannot be generalized and lack of details regarding the number of falls from the participants. The number of subjects for each type of SCA was also less and hence subgroup analysis was not possible. As our study criteria filter the population with only mild to moderate symptoms, the findings may not be generalizable to severe category. Dual Task Paradigm was not used during balance and gait measurements. Safety harness was attached to the patient throughout the balance assessment, but caution was taken to rule out the impact of harness on the outcome. Although the gait and balance assessments provided various outcomes, the gait variability and balance indices were the topic of interest for this study. Future studies can focus on the analysis of other variables.

Conclusions

There is a significant relationship between the gait characteristics and the postural instability oriented to the anteroposterior direction than in the mediolateral direction in patients with SCA. However, generalization of the finding cannot be done as this study included various types of SCA genotypes. Gait variability which is the marker of fall found to be correlated with API. The results suggest the role of early screening of patients with neurological deficits to identify API oriented instability. Future studies can contemplate if the management protocols focussed on improving AP stability may improve gait parameters as well as reduction in falls.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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