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The Effects of Tai Chi Based Exercise on Dynamic Postural Control of Parkinson's Disease Patients while Initiating Gait

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Abstract. [Purpose] The purpose of this study was to investigate the effects of Tai Chi (TC) based exercise on dynamic postural control when people with mild or moderate Parkinson's disease (PD) initiate gait. [Subjects] Ten people with PD, who ranged in age from 70 to 84 years, volunteered to participate in a 12-week intervention of TC exercise. [Methods] Participants with PD were tested pre- and post-intervention in a task in which they were instructed to initiate gait from the position of quiet stance. Participants with PD were trained with TC exercise that emphasizes a shift in weight bearing from bilateral to unilateral support, challenging postural stability, three times per week over a period of 12 weeks. Differences between pre- and post-test in COP displacement in the anteroposterior (A-P) and mediolateral (M-L) directions were assessed using two force plates. [Results] After practicing the TC exercise, participants with PD significantly increased A-P and M-L displacement of the COP. [Conclusion] TC exercise increased COP displacement in the A-P and M-L directions, thereby improving participants' ability to generate momentum to initiate gait and maintain lateral stability. The findings of this study support the use of TC exercise as an effective and safe rehabilitation strategy for some individuals with PD.
Key words: Parkinson's disease, Tai Chi exercise, Aging

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INTRODUCTION

As the elderly population is rapidly increasing throughout the world, control of gait in people with Parkinson's disease (PD) has attracted growing interest among researchers and clinicians[1)]. Up to 4.6 million people over the ages of 50 years were estimated to suffer from PD in Western Europe's five most populous nations in 2005, and this number is expected to increase to 9.3 million by 2030[2)]. Incidence rates of annual falls in people with PD have been reported to range from 50% to 68 %, and approximately 27% of people with PD suffer from serious fall related injuries, including hip fractures, in the first 10 years following diagnosis PD[3–6)].

PD is defined as a chronic, progressive, central nervous system disorder resulting from dysfunction of the basal ganglia that is responsible for motor control of skilled voluntary movements[1)]. PD primarily affects the elderly, resulting in difficulty in performance of functional and skilled motor tasks, such as walking, writing, and speaking[1)]. It is characterized by gradual development of hypokinesia (reduced speed of movement), akinesia (absence of movement or impaired initiation of movement), resting tremor, rigidity, disturbed balance, freezing gait, and cognitive impairment, as well as age related impairments, such as decreased muscle strength of lower extremities[7,8)]. In general, all of these signs and symptoms can in various degrees affect the automaticity of motor tasks, such as the gait of the individual. In PD, difficulty in performing transitional movements, such as initiating gait, ending gait, or turning are a very common clinical manifestation[9–11)]. People with PD also have problems in performing simultaneous motor or cognitive tasks, crossing obstacles, or when attempting to walk in complex environmental settings[12–14)].

Previous studies[15–18)] have demonstrated that the strength of the lower extremity muscles of PD patients and regular exercise are associated with their capacity to perform of functional tasks, such as walking and sit-to-stand. They emphasized the importance of appropriate intervention for people with PD to improve and/or maintain functional levels. Several intervention strategies, including general exercise, high-intensity resistance training, and sensory

cueing training have been suggested for improvements of balance, strength, and freezing gait of people with PD[19–22].

Tai Chi (TC) exercise has recently received growing attention as a strategy for enhancement of human well-being, including balance impairment and disability related to aging and age related diseases such as PD. TC is an ancient Chinese martial art that consists of a series of slow, continuous, and gentle movements dynamically shifting body weight from double-limb to single-limb support and it may be effective for addressing impairment in postural control during gait. People with PD who practiced TC improved physical aspects of general well-being and scores of functional assessment scales, including the 50-ft speed walk, Timed Up-and-Go, Functional Reach Test, Unified Parkinson's Disease Rating Scale (UPDRS) motor subscale 3, Berg Balance Scale (BBS), Tandem Stance, and Six-Minute Walk[23–25]. While previous studies have demonstrated that TC exercise is beneficial for improving balance and the functional ambulation profile, none has reported on the potential mechanisms underlying the benefits of TC exercise such as improvement of movement dysfunction and reduction of falls among PD sufferers.

Difficulty in initiating gait is the one of the most common movement disorders in PD and an important sign in diagnosis of akinesia. Initiation of gait is defined as the transition from quiet stance to steady state gait, a voluntary movement that challenges the balance control system as it moves from a condition of stable static balance to continuously unstable posture[9,11,26–28]. In addition, since initiation of gait involves a stereotyped pattern of muscle activity in the lower extremities, problems or subtle age-related changes with gait initiation can easily be exaggerated in pathologies associated with the elderly[27]. Furthermore, many falls by the elderly often occur during postural transitions, such as initiation and termination of gait and changing direction. Given these circumstances, initiation of gait can be used as a functionally appropriate investigative tool to provide insight into motor control and measurement of the mechanisms of pathological gait patterns or age-related changes of gait.

The center of pressure (COP) is defined as the point of application of the ground reaction forces (GRFs) on the force plates, and is commonly used as an indicator of balance and postural control[29]. For example, the elderly have a significantly reduced ability to generate a COP shift while initiating gait compared to young adults[27]. Thus, examination of COP trajectory variables when subjects perform motor tasks would provide useful information for understanding of the mechanisms of balance impairment related to PD, since COP represents the response of the central nervous system to movement of the whole body center of mass[11]. Therefore, the purpose of the current study was to investigate the effects of TC based exercise on dynamic postural control when people with mild or moderate PD initiate gait.

SUBJECTS AND METHODS

Ten patients (mean age: 78.5 years) with idiopathic PD participated in this study. All patients had Hoehn & Yahr (H&Y) disability[30] scores ranging from 2 to 4 and were able to walk independently at least 5 m without ambulatory aids. All participants were tested in the "on" state approximately 1.5 hours following administration of dopaminomimetics when they were showing full response to their PD medications, usually a time of good performance during a day. Exclusion criteria were as follows: 1) dementia (a Mini Mental Status Examination (MMSE)[31] score < 24); 2) inability to complete the 12-week period of TC exercise due to a physical illness; 3) previous history or evidence of neurological impairment other than PD which could interfere with locomotion; 4) previous training in any form of TC exercise or current involvement in any type of regular exercise program; or 5) inability to walk independently. Each participant was informed of the study protocol and gave his or her written consent to participate. This study was approved by the University Institutional Review Board prior to the start of data collection. Table 1 summarizes participants' demographic and clinical characteristics.

Table 1. Demographic and clinical characteristics of the participants with PD

Participant details	Mean (SD)
Age (years)	78.5 (5)
Male/female	1/9
Height (cm)	154.4 (2.5)
Weight (kg)	52.6 (3.6)
MMSE score/30	27.8 (2.1)
PD duration (months)	40.2 (28.9)
Hoehn and Yahr score/range	2.95 (0.5)/2–4
UPDRS motor score/56	19.4 (8.3)

Note. Values represent mean ± standard deviation (SD). Abbreviations: PD, Parkinson's disease; MMSE, Mini Mental Status Examination; UPDRS, Unified Parkinson's Disease Rating Scale.

Throughout the training period, an experienced TC instructor taught 12 modified forms of Yang style TC[32] exercise, a standard and popular TC routine, to people with PD. A 10-minute period of warm-up exercise, followed by a 40-minute period of 12 easy-to-learn and easy-to-perform Yang style TC movements, and a 10-minute period of cool-down exercises was performed three times per week over a period of 12 weeks. Warm-up exercise included slow and gentle flexibility exercises sequentially targeting the shoulders, neck, arms, and legs, followed by a trunk stretching exercise that coordinated weight shift with trunk rotation and active arm swinging, as well as static isolated TC movements. TC exercise consisted of a series of slow, gentle, smooth, relaxed, continuous, rhythmic, coordinated, and flowing movements of different body parts, which emphasized increasing the magnitude of trunk and arm rotation with a shift in weight bearing from bilateral to unilateral support, challenging the postural stability. The cycle of 12 movements was repeated approximately 6 times during the training sessions. Cool-down exercises included gentle and slow range of motion exercises of ankles, knees, and hips, as well as the back, and a meditation that

Table 2. Mean values (±SD) of the COP variables pre- and post-intervention of the swing and stance limb

Dependent variables	Time	TC participants
Swing limb		
A-P displacement (cm)*	Pre-intervention	11.56 (2.26)
	Post-intervention	14.33 (2.43)
M-L displacement (cm)*	Pre-intervention	2.98 (0.87)
	Post-intervention	3.96 (1)
Stance limb		
A-P displacement (cm)*	Pre-intervention	13.45 (1.72)
	Post-intervention	15.98 (2.58)
M-L displacement (cm)*	Pre-intervention	4.86 (1.34)
	Post-intervention	6.15 (3.03)

Note. Values represent mean ± standard deviation (SD). Abbreviations: TC, Tai Chi; COP, center of pressure; A-P, anteroposterior; M-L, mediolateral. *Significant difference ($p<0.05$) between pre- and post-intervention for the swing or stance limb.

emphasized diaphragmatic breathing exercise. The TC instructor explained and demonstrated how each form should be performed, and the group followed the motions.

Evaluation of participants was conducted a week before initiation of the TC exercise and a week after completion of the 12 weeks of TC exercise. Two experienced physical therapists collected the data. Participants were first evaluated using the UPDRS motor subscale 3[33] and MMSE. Two force plates (AMTI, Newton, MA, USA), embedded in a level walkway (5 m in length and 1.22 m in width), measured GRFs while participants initiated gait. Amplified force plate signals were sampled on-line at a rate of 1,000 Hz for 10 seconds (AMTI). GRFs collected from force plates were processed and COP data were analyzed using BioAnalysis v2.0 software (AMTI, Watertown, MA, USA). For each trial, participants stood quietly with their arms hanging at their sides in a predetermined position with each foot on a force plate. Participants were then instructed to initiate gait at a normal and comfortable pace using the right limb after receiving the verbal cue "Go" from one of the investigators, and continued to walk with the left limb. Each participant completed two practice trials and approximately five successful experimental trials. The feet of each participant on the force plates were traced and the tracings were used before the start of a new gait initiation trial to precisely position the feet on the force plate in order to increase between-trial consistency. All participants wore flat-soled shoes that are usually used for everyday walking or daily activities.

COP trajectory variables before and after TC exercise were compared using the paired t-test. Differences were considered statistically significant at $p<0.05$. Parameters selected for analysis included anteroposterior (A-P) and mediolateral (M-L) displacement of the COP. A-P (or M-L) displacement of the COP was defined as the total distance (or difference) between the minimum and maximum A-P (or M-L) COP location for the length of time either the left or right foot was in contact with the force plate. Statistical software SPSS 14.0 KO (SPSS, Chicago, IL, USA) was used for statistical analyses.

RESULTS

The paired t-test revealed a significant difference between before and after TC exercise in A-P and M-L displacement of the COP of the participants. All of these variables were significantly improved in post-test measurements, compared to pre-intervention measurements ($p<0.05$). TC participants showed a 122 % and 130 % increase in A-P and M-L displacement of the COP, respectively for both the swing and stance limbs. Mean values of the displacement of the COP in the A-P and M-L directions before and after TC are summarized in Table 2.

DISCUSSION

In this study, the effects of a TC exercise program on the ability to initiate gait by people with PD were investigated. Participants with PD demonstrated improvements in A-P and M-L displacement of the COP for both the swing and stance limbs. COP measures used in the current study represent muscle responses to maintain dynamic stability while initiating gait. Reduced displacement of the COP in either direction has been suggested to indicate instability[11] or perhaps the use of an alternate postural control strategy, that is possibly less efficient for the development of momentum for initiation of gait[34]. In the present study, the TC exercise program led to improvements in A-P and M-L displacement of COP while initiating gait. Mean A-P and M-L displacements of the COP of the TC participants increased by 22% and 30%, respectively, compared to pre-intervention. The improvements in COP variables were similar to those reported previously for older adults without PD who performed TC exercise[34,35]. In these earlier studies, the elderly subjects showed improvements in COP trajectory variables while initiating gait or crossing an obstacle.

Control of the center of mass (COM), the net location of an individual's mass in three dimensional space[36], which is manipulated by the shift of the COP in the A-P and M-L directions while initiating gait, is an important consideration for dynamic postural control. Backward displacement of the COP in the initial phase of stepping generates the forward

moment necessary to initiate gait[27]. Thus, greater COP displacement in the posterior direction increases the moment arm by which the GRF can move the COP forward[34]. This COP shift mechanism in the A-P direction is mainly responsible for moving the body forward through subsequent steps. In the current study, 10 subjects with PD were able to improve A-P displacement of the COP an average of 15.2 cm, which is similar to that previously reported in a study of elderly individuals without PD who practiced TC[11]. Hass et al.[34] demonstrated that elderly subjects who performed TC exercise increased the magnitude of the backward displacement of A-P COP closer to that reported for more healthy older adults, whereas non-participants showed little change in displacement of A-P COP after a wellness education program.

The mean M-L COP displacement of the PD patients after the TC exercise was 5.1 cm, a 30% increase, compared to pre-intervention. This finding indicates that TC exercise positively influenced the magnitude of COP displacement in the M-L direction. It is believed that M-L displacement of the COP and its effects on COM motion contribute to maintenance of M-L stability during initiation of gait, and this COP variable may be compromised in people with PD as well as the elderly[11,37–39]. People with PD have reduced COP displacement in the M-L direction, compared with younger adults[11]. It has also been observed that older adults with disability and those transitioning to frailty have reduced M-L displacements of the COP, and people with PD who have greater M-L and A-P displacements of the COP and people who have a greater weight shift between the two limbs have a longer step during step initiation[11]. Moreover, pregnant women who reported falling demonstrated reduced movement of the COP when responding to translational perturbation while standing on a movable platform[40]. Further, children with autistic disorder who exhibit less age-related development and postural instability also have decreased COP shift in the M-L direction while initiating gait, compared to age-matched normally developing children[41]. Therefore, it is plausible that the significantly increased displacement of the COP seen in the present investigation is indicative of increased dynamic postural stability in the participants with PD who practiced the TC exercise.

Coordinated action of the hip abductor and adductor muscles has been suggested as being responsible for the M-L displacement of the COP[42], and a reduced M-L COP displacement in elderly people with disability may be a result of decreased hip muscle function. This explanation is in agreement with a previous study[43] which reported that age-related differences in muscle power were found at proximal locations of the body, such as the hip, rather than at the ankle. Previous studies[44–46] have also reported that reduced strength of the lower extremity extensors and hip abductors in the elderly contributes to falls.

While initiating gait or crossing an obstacle, the COP created by the swing limb hip abductors moves laterally toward the swing limb and generates momentum toward the stance limb[47]. Thus, muscle activity at the ankle and hip tend to propel the COM forward and toward the intended stance limb. In the present study, increased COP displacement in the M-L direction following TC exercise may be the result of improved coordinated action of the hip abductor and adductor muscles[42].

Several limitations of the current study have to be considered. The sample size of people with PD was relatively small, and no control group was included in the current study. In addition, the TC exercise was performed for a 12-week period, which is a relatively short duration for providing the full benefit of Tai Chi exercise to people with PD. Moreover, participants in the current study were recruited from communal living facilities, which may not be representative of people with PD living in the community. No follow-up information to indicate whether the improvements were temporary or permanent was included in the study. Furthermore, the exact timing and spatial events of gait parameters after TC exercise were not investigated because only two force plates were used in the current study. Thus, collective analysis of kinematic and kinetic data would provide better insight into the effects of the TC exercise on PD patients than the separate analysis of kinetic data.

In conclusion, the current study shows that participants with PD who participated in a 12-week program of TC exercise increased A-P and M-L displacement of the COP, thereby improving their ability to generate momentum in initiation of gait and maintenance of balance and lateral stability. Thus, the findings of this study support the use of TC exercise as an effective and safe rehabilitation strategy for some individuals with PD. Finally, the primary disadvantage of using the COP alone for assessment of postural stability is that it measures the secondary consequences of swaying movements, such as the position of the body (i.e., COM movement), not the movements themselves. Recent studies[48–52] have suggested that examination of the movements of the COM and its relationship to the COP during initiation of gait provides more information about the influence of TC exercise on people with PD as an assessment of dynamic balance performance rather than COP and COM variables taken separately. Therefore, it is necessary that a well designed randomized controlled trial using a larger population of patients with PD and combined analysis of the movements of the COM and COP be performed in order to further our understanding of the effectiveness of TC exercise as a fall prevention program for people with PD.

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