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Ai Chi for Balance and Gait in Individuals with Parkinson's Disease: A Pilot Study

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Background and Purpose: Parkinson disease (PD) has effects on an individual's balance, and Ai Chi can be used to improve balance and gait performance. The aim of this study was to investigate the effectiveness of Ai Chi in improving the balance and gait of individuals with idiopathic PD.
Method: Ten individuals with PD at Hoehn and Yahr stages 1-3 were included in this 6-week study. Participants underwent a structured Ai Chi program (1 hour per session, twice weekly) for 6 weeks (12 sessions in total). Balance was assessed at baseline and week 6 using the Timed Up and Go (TUG) test, the Five Times Sit-to-Stand (FTSTS) test, the Four Square Step Test (FSST), the Ten Meter Walk Test (10MWT), and the Sensory Organization Test (SOT). Gait parameters were measured by inertial measurement units and videotaping for 2-dimentional motion analysis. Surface electromyography was used for measuring muscle activity during gait in the bilateral rectus femoris, biceps femoris, gastrocnemius, and tibialis anterior.
Results: In a pre- and postintervention comparison, significant improvements were observed in the FTSTS, FSST, and TUG scores as well as in the composite, vision, and vestibular scores in the 10MWT and SOT ($P < .005$). The results indicated improvement in balance. As for the gait analysis, no significant differences were observed in spatiotemporal parameters, including speed, cadence, step length, stride length, step duration, stride duration, swing-phase duration, stance-phase duration, and double support duration. Insignificant changes in the percentage maximum voluntary contraction of all the muscles examined were found, while a significant decrease in maximum voluntary contraction was identified in the left biceps femoris.
Conclusions: The Ai Chi program produced a significant improvement in balance in individuals with PD, with insignificant results shown in gait. Ai Chi is an appropriate intervention to improve balance in individuals with PD. (J Aquat Phys Ther 2023;31(1):2–10)
Key words: aquatic exercise, balance, electromyography, gait, Parkinson's disease

Parkinson disease (PD) is a progressive degenerative neurological disorder of the basal ganglia.[1] Because of dopamine deficiency, the brain fails to properly stimulate or inhibit various motor function pathways. Hence, individuals with PD usually encounter difficulty with movements.[2] In addition, individuals with PD demonstrate impaired ability in active muscle control, which can potentially result in poor mobility.[3] Consequently, this can lead to a pathological gait pattern and affect an individual's quality of life.[4] Furthermore, individuals with PD may be affected by other motor symptoms, such as progressive bradykinesia, hypokinesia, tremor, rigidity, and impaired postural control.[5] The decline in the movement function of individuals with PD, along with the associated decrease in quality of life, is commonly observed in the development of PD.[2] Hence, the disease has large effects on balance, physical function, and gait performance. As a result, it is not uncommon to incorporate balance training and gait reeducation into rehabilitation in order to prevent falls and optimize quality of life for individuals with PD.[4]

Extensive evidence has shown how the balance and gait of individuals with PD may be improved by various exercise interventions, including physiotherapy, aerobic training, and resistive training.[4,6] For instance, land-based interventions are able to improve the gait parameters[6-8] and balance[9-12] in individuals with PD. The most commonly adopted land-based interventions include trunk mobility training,[11] postural stability training,[11] treadmill walking,[6] progressive strengthening exercises,[7] active limb mobilization,[8] Tai Chi,[9] and gait reeducation.[10] In recent decades, aquatic therapy, an alternative to land-based interventions, has been advocated as an effective means of improving balance in individuals with

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PD.[11,12] Aquatic therapy uses the physical properties of water to facilitate improvement. For example, the hydrostatic pressure and warmth of water contribute to pain relief and muscle relaxation,[13,14] the turbulence and dragging force of water contribute to a reduction in fall risk,[13] and the viscosity and the cushioning effect of water allow patients with neurological deficits to have a longer buffer time for movement control, which may potentially improve balance. The most common aquatic exercises include stretching exercises, trunk mobility exercises,[12] Ai Chi,[15,16] gait training,[17] water resistive strengthening exercises,[17,18] and circuit dual-task balance training.[17]

Although both land- and water-based interventions have been shown to be effective in improving the static and dynamic balance of individuals with PD, Volpe et al[12] revealed that individuals with PD who participate in aquatic therapy achieve a greater improvement in balance.[12] This may be explained by the aforementioned advantageous physical properties of water. Yet, the optimal design and combination of water-based interventions remain unclear. As a result, a new combination of an evidence-based intervention (Ai Chi), gait training, and balance training was proposed for our study.

Ai Chi applies the concepts of Tai Chi with conventional aquatic exercises.[13] With a total of 16 standardized movement katas, Ai Chi involves a series of slow and rhythmic movement patterns performed standing in a pool, with an emphasis on coordination of the lower limbs, upper limbs, and trunk movements synchronized with breathing.[13,19] The benefits of Ai Chi are well documented and can be used to compare with land-based Tai Chi. For instance, static and dynamic standing balance can be trained through constant weight shifting, trunk movement, and pivoting on the stance leg. Similarly, Ai Chi allows individuals to experience a reduction in the base of support with progressive complexity and diversity of movement patterns that can reasonably challenge balance.[19]

Despite studies indicating that aquatic exercises have moderate positive effects in improving static and dynamic balance, there is currently limited evidence exploring the effects of such exercises, and in particular Ai Chi, on lower-limb muscle activation and gait variability among individuals with PD as compared with land-based interventions. In addition, only one study has investigated the effects of aquatic exercise therapy on gait variability using a motion capture system; this study reported no significant differences between the exercise group and the control group.[20] Therefore, the current study investigates the effects of a group-based aquatic exercise program (Ai Chi) on gait and balance variability in individuals with PD. To the best of the authors' knowledge, this is the first study to use surface electromyography (sEMG) and inertial measurement units (IMUs) to measure gait variability in individuals with PD post–Ai Chi intervention. Hence, the objective of this pilot study was to investigate the effect of a structured aquatic exercise program (combination of Ai Chi, gait training, and balance training) on balance and gait variability in individuals with PD.

METHODS

Study Design

This study was a single-group, quasi-experimental cohort study with pretest and posttest comparison.

Participants

Sample size calculations were based on balance and gait parameter effect sizes from previous studies of individuals with PD.[21] An a priori sample size calculation based on gait and balance variables, with a 10% dropout rate, 80% power, and α set at .05, showed that we needed at least 10 participants in the intervention group. Thirteen participants with PD were recruited from the Hong Kong Parkinson's Disease Association through convenience sampling. Participants were screened for the following inclusion criteria: (1) diagnosed with idiopathic stage 1-3 PD (Hoehn and Yahr Scale); (2) aged 18 to 75 years; (3) no fear of water; and (4) able to perform movements in water in standing position. Participants were excluded if they were diagnosed with (*a*) other neurological impairments or cognitive impairments that made them unable to give their own consent for inclusion in the study; (*b*) any infectious diseases; or (*c*) skin conditions that contraindicated participation in aquatic exercises.

Participants who met the inclusion and exclusion criteria were invited to participate on a voluntary basis. An information session was arranged for each participant, and an information sheet was provided. All participants gave written informed consent to participate in the study, which was collected after the information session. The study's protocols were approved by the Departmental Research Committee of the Hong Kong Polytechnic University's Department of Rehabilitation Sciences (reference no.: HSEARS20190611001).

Experimental Setup

Preintervention assessment was scheduled 1 week before the study was initiated. The assessment was performed by a physiotherapist with 10 years of experience, and the tests were performed by the same person on each occasion to improve reliability. The tests consisted of assessments on gait and balance, which were performed over 2 days to minimize fatigue. The gait assessment was conducted in the Gait and Motion Analysis Laboratory, and the balance assessment was performed in the Neuro-rehabilitation Laboratory at the Hong Kong Polytechnic University, where the room temperature was controlled at 25.5 °C. Balance and gait assessments were performed within 3 hours of the participant taking their prescribed medication in order to avoid motor fluctuations. All participants reported that they were in the "on phase," and for each participant, the time since medication was the same at the pretest and posttest assessments.

All the participants then underwent aquatic training twice a week for 6 weeks (12 sessions in total), with each session lasting 60 minutes. One participant was lost to follow-up due to a change in medical status. All participants were required to avoid participation in other exercise or therapeutic interventions during the study period. Postintervention assessment was scheduled 1 week after the intervention was completed, using the same settings as in the preintervention assessment (Figure 1).

Outcome Measures

Gait Measurement. Participants were first asked to perform the Timed Up and Go (TUG) test, followed by the Ten Meter Walk Test (10MWT) at their usual speed,[22] with

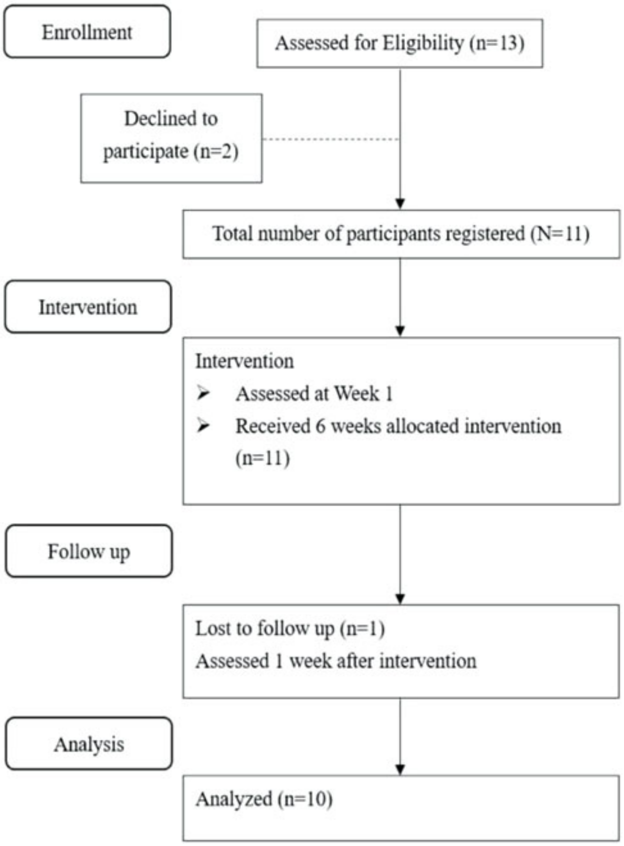

Fig. 1. Study design and flow of participants throughout the study.

IMUs and sEMG electrodes in situ. The IMUs collected acceleration data for motion tracking by referencing each sensor for comparison.[23] sEMG is a measurement of the change in electrical potential across the muscle fiber membrane.[24] The locations of the IMUs and sEMG electrodes are listed in Table 1. The 10MWT was videotaped in both vertical and horizontal planes.

The sEMG activities and IMU signals were recorded using Akto sensors of the Myon system (SX230 surface EMG sensor, Biometrics Ltd, Newport, United Kingdom) and a customized data logger at a 1000-Hz sampling rate. The raw sEMG signals were digitized using a bandpass filter (at 20-300 Hz) and a root-mean-square sliding window (50-millisecond constant) (MatLab 2017a; Mathematical computing software; The MathWorks, Inc, Natick, Massachusetts). The sEMG signals were then exported using LabView8.6 (National Instruments Corporation, Austin, Texas). In the 10MWT, the gait parameters and muscle activities of the first and last 2 m were not processed so that the effects of acceleration and deceleration were eliminated. Only the gait parameters and muscle activation of the mid-6 m of the 10MWT were determined using our customized programs. The amplitudes of the sEMG signals for the corresponding muscles were then calculated and averaged. The maximum voluntary contraction (MVC) data collected were also processed in the same way, with the first 5 seconds of contraction being taken for data processing. The percent maximum voluntary contraction (%MVC) was then generated and compared between pre- and postintervention assessments.

Surface Electromyography. The sEMG signals were analyzed to measure activities of the bilateral rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and gastrocnemius (GME), as these are the 4 key muscles involved in gait to generate movements at the hip, knee, and ankle joints (Figure 2).[25] The electrodes were placed 2.5 cm apart to avoid interference.[26] Participants were asked to perform an MVC for 5 seconds to normalize sEMG under the instruction of an investigator. Table 1 provides details of the locations of the sEMG electrodes and the MVC procedures. The data are represented by mean %MVC.

Spatiotemporal Parameters. Gait speed, cadence, stride duration, step duration, swing duration, and double support duration were calculated by IMU recording. The IMU sensors were placed at the S2 spinous process, 2 cm above the femoral lateral epicondyle (Figure 3A) and 2 cm above the lateral malleolus (Figure 3B). Stride length was deduced from videotapes, analyzed by ImageJ (National Institutes of Health, Java 1.8.0_172; Bethesda, Maryland).

Balance Measurement. Both static and dynamic balance performance was assessed. To simulate the participants' daily activities involving balance, 3 balance assessments were used: Four Square Step Test (FSST), Five Times Sit-to-Stand (FTSTS) test, and Sensory Organization Test (SOT).

Timed Up and Go Test. Participants were required to move from sitting to standing from a chair, walk at their usual walking speed for 3 m, and return to sit on the chair.[27] The process was timed as a functional assessment of gait and mobility. The TUG total score and the interexaminer, test-retest, and intraexaminer reliabilities were classified as excellent (0.95 ≤ intraclass

TABLE 1

Locations of sEMG Electrodes and MVC Testing Procedures

Muscle	Location of the Electrode	MVC Testing Procedure
RF	Midpoint between ASIS and patella	Participants laid in supine position with tested hip flexed 45° and supported. Investigator resisted isometric knee extension for 5 s.
BF	Midpoint between gluteal fold and knee crease, 2 cm lateral from central line	Participants laid in prone position with tested knee flexed 90°. Investigator resisted isometric knee flexion for 5 s.
TA	Belly of TA	Participants laid in supine position with tested ankle in neutral. Investigator resisted isometric dorsiflexion for 5 s.
GME	Belly of GME, 2 cm lateral from the central line	Participants performed heel-off in single-leg standing position and sustained for 5 s.

Abbreviations: ASIS, anterior superior iliac spine; BF, biceps femoris; GME, gastrocnemius; MVC, maximum voluntary contraction; RF, rectus femoris; sEMG, surface electromyography; TA, tibialis anterior.

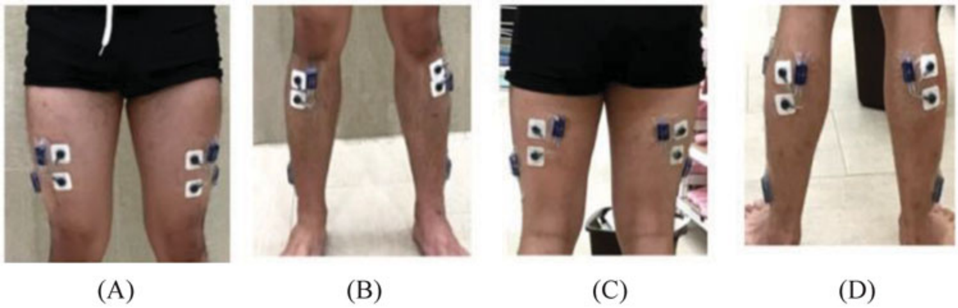

Fig. 2. Electrode placement locations: (A) RF electrode; (B) TA electrode placement; (C) BF electrode; (D) GME electrode placement. RF indicates rectus femoris; TA, tibialis anterior; BF, biceps femoris; GME, gastrocnemius.

correlation coefficient [ICC] ≤ 0.99).[28] The sensitivity and specificity of the TUG test in identifying fallers have been found to be 41% and 73%, respectively.[29]

Four Square Step Test. Participants stepped on 4 squares sequentially in a cross configuration illustrated on the floor. They were asked to start at the bottom left square and step in a clockwise manner and then in a counterclockwise direction, without turning their body. The interrater and test-retest reliability was excellent (r = 0.916-0.999, $ICC_{2,2}$ = 0.96-0.99).[30] The sensitivity of this test is 85%, with a specificity of 88% to 100%, and a positive predictive value of 86% for the identification of subjects with risk factors for falls.[31]

Five Times Sit-to-Stand Test. In this test, the participants were asked to sit against the back of a chair and then move from sitting to standing at their fastest speed 5 times with their arms folded across their chest. The duration of the sequence of movements was counted to quantify quadriceps strength.[32] Interrater and test-retest reliability for the FTSTS test was high (ICC: 0.99 and 0.76, respectively).[33] The sensitivity and specificity of the test are reported to be 75% and 68%, respectively, to quantify functional lower extremity strength.[33]

Sensory Organization Test. Performance of the sensory systems of static balance was measured by the SOT with Bertec's Computerized Dynamic Posturography using a force plate (CDP/IVR; Bertec, Columbus, Ohio). The SOT identifies an individual's ability in using visual, somatosensory, and vestibular information to effectively maintain balance and posture. The SOT, a test of sensory integration for balance control, is recognized as a criterion standard to measure postural sway and identify fall risk in older people.[34]

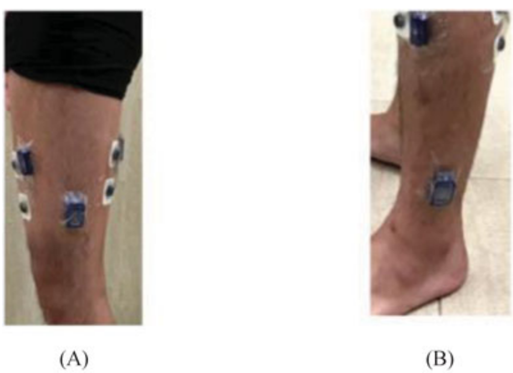

Fig. 3. Location of inertial measurement units (A) 2 cm above femoral lateral epicondyle and (B) 2 cm above the lateral malleolus.

Intervention

The exercise intervention took place at an indoor swimming pool located at the Young Men's Christian Association (YMCA) of Hong Kong. The water depth was 1.2 m, and the water temperature was 28.5 °C to 29.5 °C. The program was supervised and implemented by a qualified physiotherapist with more than 10 years of aquatic physiotherapy experience and expertise in Ai Chi. The ratio of physiotherapists to participants was 1:10. Each session lasted for 60 minutes.

Ai Chi Intervention. Ai Chi combines slow and coordinated rhythmic movements involving the upper and lower limbs and the trunk of the body while standing in a pool. Sixteen movement patterns were included in the intervention (Figure 4). Most of the Ai Chi movements were performed at shoulder depth immersion while the participants stood in a mini-squat position (Figure 5). Further combinations of deep breathing, trunk movements, and limb movements were also incorporated into the Ai Chi program. For each session, additional patterns were added such that all 16 Ai Chi movements were completed by the end of the 12 sessions.

Data Analysis

The pre- and postintervention data were analyzed by the software SPSS Statistics 23 (IBM, Armonk, New York). Changes of outcomes between baseline and postintervention assessments

Fig. 4. Photograph simulating an Ai Chi class.

Fig. 5. Performing Ai Chi at a semi-squat position.

in each group were compared. The data were first preanalyzed for normality using the Shapiro-Wilk test. Parametric data (FSST, SOT, TUG, speed, cadence, step duration, stride duration, stance-phase duration, double support, mean %MVC of RF [left], TA [left and right], BF [left], and GMR [left and right]) were compared with paired *t* tests. Nonparametric data (FTSTS, step length, stride length, swing-phase duration, RF [right], BF [right]) were compared with the Wilcoxon signed rank test. The level of significance was set at $P < .05$.

RESULTS

Characteristics of the Participants

The demographic characteristics of the 10 participants (3 males and 7 females) are shown in Table 2. The results for the 10 individuals were analyzed, with all of the participants completing at least 9 of the 12 sessions. The mean age was 65.4 years (SD = 7.2). The mean duration of being diagnosed with PD was 46 months (SD = 23.9). All of the individuals attended at least 9 of the 12 sessions (75% attendance) of the intervention. There were no adverse events reported in this study.

TABLE 2

Descriptive Characteristics of the Participants[a]

Characteristics	Aquatic Group (N = 10)
Sex	
Male	n = 3
Female	n = 7
Age, y	65.4 (7.17)
Weight, kg	57.7 (12.5)
Height, m	157.45 (11.7)
BMI, kg/m^2	22.99 (2.27)
Leg length	
Left leg	76.87 (11.03)
Right leg	76.74 (12.10)
Mean of both legs	76.73 (11.50)
Diagnosis time, mo	46 (23.90)
HY stage	
Stage 1	n = 8
Stage 2	n = 1
Stage 3	n = 1
Living alone	n = 4
Fall history in past month	n = 1
Fall history in past year	n = 5
No. of days of exercise per week	4.70 (1.95)
Hours of walking each day	2.40 (1.51)
Hours of sitting each day	3.90 (2.5)

Abbreviations: BMI, body mass index; HY stage, Hoehn and Yahr stage.
[a]Data are presented as means (SDs).

TABLE 3

Results for the FTSTS Test, FSST, and SOT[a]

	Aquatic Group (N = 10)		
Outcome	Pre	Post	Differences
FTSTS, s	12.82 (4.73)	8.50 (2.72)	− 4.32[b]
FSST, s	10.23 (2.68)	7.18 (0.87)	− 3.05[b]
SOT			
Composite	75.67 (7.20)	83.94 (5.16)	8.27[b]
Vision	72.30 (9.26)	85.70 (6.27)	13.40[b]
Somatosensory	99.00 (3.37)	100.40 (1.78)	1.40
Vestibular	71.60 (13.70)	87.70 (6.93)	16.10[b]
Visual preference	100.20 (6.11)	96.40 (3.66)	− 3.80

Abbreviations: FSST, Four Square Step Test; FTSTS, Five Times Sit-To-Stand; SOT, Sensory Organization Test.
[a]Data are presented as means (SDs).
[b]Statistically significant at $P < .05$.

Balance Performance

The results of the FTSTS test, FSST, and SOT are reported in Table 3. There were significant reductions in the FTSTS ($Z = -2.80$, $P = .005$) and FSST ($t = 4.50$, $P = .001$) scores postintervention. These findings indicate that Ai Chi may improve dynamic balance, as shown by the faster performance of the FTSTS test and FSST. The SOT with computerized dynamic posturography showed significant increases in the composite ($t = -3.33$, $P = .009$), vision ($t = -5.69$, $P < .001$), and vestibular ($t = -3.41$, $P = .008$) scores; however, no significant changes were found in the somatosensation and visual preference scores. These results demonstrated improvements in overall equilibrium performance and improved performance in 2 of the sensory systems (vision and vestibular). Such findings could provide additional evidence that Ai Chi may improve overall static balance for individuals with PD, impacting the vision and vestibular functions in particular.

Gait Performance

The TUG results and the spatiotemporal gait parameters are presented in Table 4. There were significant reductions in the TUG scores ($t = 4.02$, $P = .003$). There were no significant differences in gait parameters detected postintervention. As such, the effects of Ai Chi on balance were more significant than its effects on gait parameters in individuals with PD.

The results for the mean %MVC of RF, TA, BF, and GME are reported in Table 5 There was a significant reduction in the mean %MVC of the left hamstring ($t = 3.06$, $P = .01$). In general, all of the studied muscle groups showed a reduction in muscle activity, although the right GME exhibited an insignificant increase. The trends of the mean %MVC of the muscles are shown in Figure 6. The results revealed that Ai Chi could have effects on muscle activity during gait, despite most of the studied muscle groups showing insignificant changes.

TABLE 4
Results for the TUG Test and Gait Parameters[a]

	Aquatic Group (N = 10)		
Outcome	Pre	Post	Differences
TUG, s	9.97 (1.58)	7.79 (1.54)	– 2.18[b]
Gait parameters			
Speed, m/s	1.19 (0.25)	1.19 (0.29)	0.00
Cadence, steps per min	120.85 (12.75)	124.96 (13.10)	0.39
Step length, m	0.62 (0.13)	0.61 (0.15)	4.11
Stride length, m	1.24 (0.26)	1.22 (0.30)	– 0.01
Step duration, s	0.54 (0.12)	0.52 (0.07)	– 0.02
Stride duration, s	1.07 (0.25)	1.04 (0.13)	– 0.02
Swing phase, s	0.37 (0.05)	0.35 (0.05)	– 0.03
Stance phase, s	0.70 (0.21)	0.69 (0.13)	– 0.02
Double support, s	0.33 (0.17)	0.34 (0.14)	– 0.01

Abbreviation: TUG, Timed-Up and Go.
[a]Data are presented as means (SDs).
[b]Statistically significant at $P < .05$.

TABLE 5
Results for the Mean %MVC of RF, TA, BF, and GME of Gait[a]

	Aquatic Group (N = 10)		
Outcome	Pre	Post	Differences
Mean %MVC			
RF (left)	19.73 (0.13)	14.59 (0.06)	−5.13%
RF (right)	16.23 (0.11)	10.03 (0.02)	−6.19%
TA (left)	28.42 (0.17)	27.26 (0.12)	−1.16%
TA (right)	23.67 (0.14)	22.48 (0.05)	−1.19%
BF (left)	35.15 (0.17)	22.70 (0.10)	−12.45%[b]
BF (right)	34.22 (0.11)	29.16 (0.17)	−5.06%
GME (left)	35.29 (0.11)	29.75 (0.06)	−5.54%
GME (right)	28.50 (0.10)	32.03 (0.12)	+3.53%

Abbreviations: BF, biceps femoris; GME, gastrocnemius; %MVC, percent maximum voluntary contraction; RF, rectus femoris; TA, tibialis anterior.
[a]Data are presented as means (SDs).
[b]Statistically significant at $P < .05$.

DISCUSSION

Effect of Ai Chi on Balance

This study investigated the effect of Ai Chi on balance and gait in individuals with PD. The FTSTS, FSTS, and SOT results indicated a positive effect, showing a significant improvement in both static and dynamic balance. An improvement in static balance was indicated by a significant increase in all of the SOT scores, albeit with large SDs, which may reflect a large amount of variation in the group being studied. The improvement in somatosensory function was statistically insignificant, which may be due to a high preintervention score (99/100). An improvement in dynamic balance was shown by a significant decrease in the time taken to complete the FSST and FTSTS test. The smaller SDs posttest for the FTSTS test and FSST may help show decreased variability in performance after the intervention.

Evidence of Ai Chi improving balance and mobility is well supported by previous studies.[15,16,35] When Ai Chi has been compared with conventional land-based physiotherapy, studies have reported that Ai Chi could improve balance and physical function to a higher degree.[15,35] The results of our study echo those of studies that have shown improvements in the balance and gait of individuals with PD after a structured aquatic therapy program, including Ai Chi, as measured by the SOT, TUG test, FTSTS test, and FSST. The aquatic therapy program adopted in those studies[15,16,35] consisted of 20 to 25 sessions of Ai Chi practice, while our study consisted of 12 sessions only. Our study showed that a shorter period of intervention (12 sessions) could also achieve significant benefits in balance.

Effect of Ai Chi on Gait. An improvement in gait performance was also shown by the significant reduction in the time

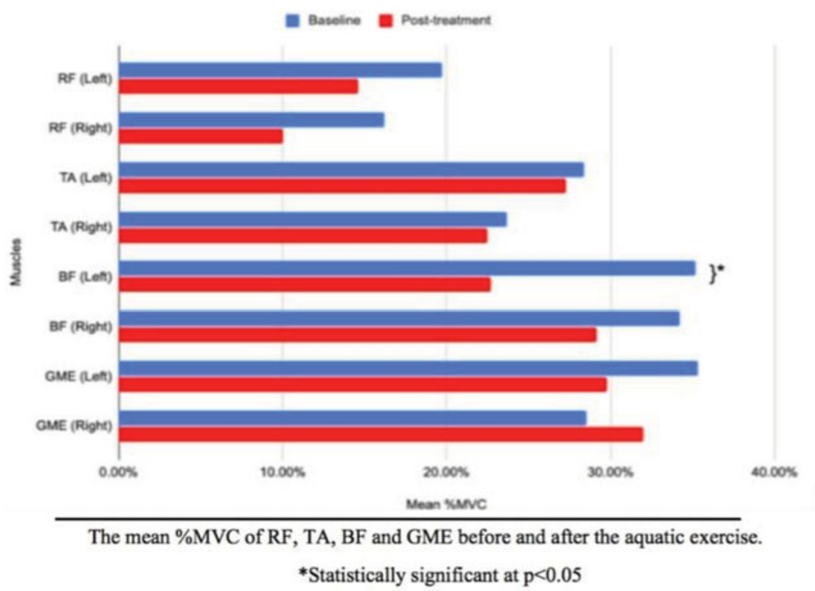

Fig. 6. Mean %MVC pre– and post–aquatic intervention. %MVC indicates percent maximum voluntary contraction; RF, rectus femoris; TA, tibialis anterior; BF, biceps femoris; GME, gastrocnemius.

taken to complete the TUG test. It should be noted that while there was a change in TUG score, the participants' gait speed remained unchanged; this can be interpreted as an improvement in turning and sit-to-stand efficiency specifically resulting from an Ai Chi program. A previous study on gait performance after an underwater gait training exercise program reported similar, but minimal, improvements in gait variability in both aquatic and land-based exercise groups[17]; in that study, spatiotemporal gait variables, such as step length and step time, were measured by a motion capture system. The results of that prior study correspond with those of our study, showing no significant improvement in gait parameters measured after a 6-week aquatic exercise intervention (2 sessions per week, 45 minutes per session). The lack of significant findings on gait parameters may be related to task specificity.[17] Given the variability in the dosage of gait training, the results in regard to gait parameters have been inconsistent. An optimal dosing has yet to be determined. However, many studies have revealed the benefit of gait training when implemented for 20 to 60 minutes, 3 to 5 days per week, for 4 to 12 weeks, which is consistent with our Ai Chi training dosages.[20] It is important to note that various gait training dosages may need to be adopted to optimize gait parameters.

The sEMG electrodes recorded an insignificant change among the targeted muscle groups; however, a decreasing trend of muscle activation was observed. There are 2 possible reasons that might explain this reduction. First, the co-contraction of muscles was reduced because of impaired muscle activity in individuals with PD. There is a tendency for individuals with PD to develop an abnormal muscle activation that is an earlier, longer, and larger antagonist leg muscle activity, while the paired agonist muscles are activated concurrently.[36] Co-contraction could lead to joint stiffness, which may result in balance deficits. A reduction in co-contraction could be one of the rehabilitation goals to optimize balance.[37] A significant improvement in balance was observed post–Ai Chi intervention, which could suggest a reduction in co-contraction as the underlying mechanism in improving balance. Despite the improvement, the dosages of exercise prescription were insufficient to make a significant difference in terms of mean %MVC. Reducing co-contraction is a process of neuromuscular remodulation and thus longer sessions may provide better therapeutic adaptations than shorter sessions.[11] A second possible reason for the decreasing trend of muscle activation was that less power was generated by the muscles. The spatiotemporal changes, although insignificant, showed a decreasing trend in gait parameters. Cadence increased, while stride length, stride duration, stance-phase duration, swing-phase duration, and double support duration decreased, resulting in a shuffling gait. Therefore, less muscle activation was required with smaller steps.

Possible Mechanisms by Which Aquatic Exercise Improves Balance Ability of Individuals With PD

The properties of water and the characteristics of Ai Chi play an important role in improving balance in individuals with PD as shown in our results.

Hydrostatic Pressure. In our study, under head-out-of-water immersion, hydrostatic pressure can cause a shift of blood volume in humans from the lower limbs and abdomen to the thorax.[38] This shift of blood increases central venous pressure, left ventricular end-diastolic volume, stroke volume, and cardiac output and decreases systemic vascular resistance at rest and during submaximal exercise.[39] This increases the rate of blood circulation and hence the delivery of oxygen, with enhanced removal of toxins in muscle metabolism. As a result, individuals report less muscle fatigue when exercising in water.

Viscosity. The resistance of movement underwater is caused by the drag force between the water molecules themselves and between the water molecules and the object moving through the water. Therefore, resistance is proportional to movement velocity. Viscosity challenges the proximal stability and strength of the distal extremities. Moreover, turbulence flow, generated by high-velocity movement via water, could disturb stability for individuals with PD.[40] Proprioception, balance responses, and core stability may be challenged when trained underwater. In addition, the resistance of water from the drag force could act as a support for individuals with PD following loss of balance and falls during training. This could reduce the injury rate and the fear of falls in individuals with PD.[35] With the use of water dumbbells and noodles, individuals with PD can perform a variety of movements, which further challenge balance and muscle control. Hence, our Ai Chi program can be progressed with an increase in speed to level up the drag force.

Buoyancy. Buoyancy off-loads the body weight of an individual. The body weight borne by the lower extremities is directly associated with the depth of immersion.[38] By adjusting the immersion level, stress to the weight-bearing joints and muscles is reduced to an optimal level that is suitable for training.[17] Buoyancy may create a torque when the center of buoyancy is not in situ with the center of gravity. If the movement is in the same direction as the torque, it could assist the movements of individuals with PD. It allows a higher degree of movements for our Ai Chi program.

Temperature. The warm temperature of pool water may cause vasodilation, increase peripheral blood supply, and increase the delivery of oxygen while enhancing the removal of toxins in muscle metabolism. Thus, our program can potentially cause a momentary reduction of muscle tone, generate muscle relaxation, reduce rigidity, and consequently maximize training effects.[40]

Characteristics of Ai Chi. Stiffness and rigidity are common symptoms of PD. It is common for individuals with PD to present with a stooped posture.[41] Stooped posture, described as rounded shoulders, decreased low back curve, or a forward lean of the head or whole body, decreases the magnitude and speed of the center of pressure displacements, thereby leading to a decreased stability margin.[6] Stooped posture may be addressed in Ai Chi through stretching the shortened muscles and engaging the weak muscles. Ai Chi, which involves thoracic extension, pectoralis muscles stretching, and retraction of the scapula, could address prolonged stooped posture in individuals with PD. With better postural alignment, less effort is required to maintain balance, and muscles achieve optimal length, leading to better coordination of muscles and hence improved balance ability.[6]

Also, Ai Chi includes a series of weight-shifting and trunk and limb movements performed in an unstable aquatic environment. This could induce the recruitment of muscles that contribute to static and dynamic standing balance. Our Ai Chi training could therefore improve balance ability.

Possible Mechanisms by Which Aquatic Exercise Affects the Gait Pattern of Individuals With PD

This study showed no improvement in gait spatiotemporal parameters. This could be explained by the different environments of water and land. Although exercises performed underwater, such as stride hop and forward reaching with single-leg standing, challenge the balance and gait ability of individuals with PD, their effects are mainly aided by the physical properties of water. However, water properties such as viscosity and drag are absent on land. There is no evidence to conclude that the training effect of walking underwater reflects gait performance on land.

Study Limitations

There are a few limitations of this study. First, there was no comparison group and there was no randomization in this study, which increase the threat to the internal validity of the study. Second, the sample size was small and therefore medium and small changes were not detected, which affect the generalizability of the results. Third, most of the individuals were female and classified as Hoehn and Yahr stage 1; therefore, a conclusion could not be drawn on the effect of Ai Chi on individuals in the later stages of PD. Fourth, although the participants showed improvement in terms of balance measures, they comprised a group of highly active individuals, which may be an important consideration in assessing the applicability of the results. Fifth, the intervention was conducted at the "on stage" of medication use; it is suggested that future studies investigate the effect of an aquatic Ai Chi program on individuals with PD at the "off" medication stage. Finally, the lack of patient self-reports may limit the translation of the study's results into meaningful change for individuals with PD in terms of quality of life, balance confidence, or other aspects of health.

CONCLUSION

This study revealed that a 6-week Ai Chi exercise program could significantly improve the balance of individuals with PD. The change in gait performance after Ai Chi was insignificant. There is a need for further investigation of the effectiveness of Ai Chi for individuals with PD, with particular consideration of the later stages of PD, the intervention dosages, and the effects at the off-medication stage. Overall, the study shows that a 6-week Ai Chi program is sufficient to show an improvement in balance and should be recommended for individuals with PD.

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