

**Effects of Tai Chi training on arterial compliance and muscle strength in female
seniors: a randomized clinical trial**

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Abstract

Background Exercise which can improve muscle strength while not compromising arterial compliance is especially needed for older adults. Tai Chi practitioners are known to have better than average arterial compliance and muscle strength. This study was designed to establish a cause and effect relationship between Tai Chi training and both increased arterial compliance and increased muscle strength.

Design In a single blind randomized clinical trial, 31 elderly women were randomly assigned to receive either Tai Chi training or an education programme, three sessions per week for 16 weeks.

Results After training, the subjects in the Tai Chi group showed significant improvements in arterial compliance and eccentric knee extensor strength. The subjects in the control group showed no significant improvement.

Conclusion Practicing Tai Chi can improve the eccentric knee extensor strength and arterial compliance of elderly women. Tai Chi maybe a good exercise choice to improve the cardiovascular health and muscle strength of the elderly.

Keywords: Arterial compliance, elderly, muscle strength, Tai Chi,

Introduction

According to a World Health Organization estimate in 1998, there will be more than 1000 million people aged 60 years and older in 2020 [1]. Cardiovascular disease is one major cause of mortality and morbidity [2], and studies have shown that the risk for developing cardiovascular disease generally rises with age [3]. Arterial stiffness has been found to be closely associated with heart diseases [4], hypertension [5, 6] and stroke [7]. Stiffness changes in the arteries may contribute to increased systolic pressure, reduced cardiovagal baroreflex sensitivity, increased aortic input impedance, left ventricular hypertrophy, diastolic dysfunction and atherosclerosis. An artery's ability to expand and contract with cardiac pulsations and relaxation is termed arterial compliance, and it is regarded as an important predictor of cardiovascular death in the elderly [8, 9].

Effective exercise programmes to maintain or even improve arterial compliance are important for successful aging. Studies have found that physically active subjects have better arterial compliance [10, 11]. Strength or resistance training, however, has been found to have negative effects on arterial compliance [12, 13]. Nevertheless, strength training is an important prescription for older persons, especially those with osteopenia or balance problems. To resolve this difficulty, investigators now are trying to find an exercise programme that can improve muscle strength with no harmful effect on arterial compliance [14, 15].

Tai Chi is a Chinese mind-body exercise usually regarded as aerobic in nature [16]. It is popular in both China and Western countries nowadays. Studies have shown the positive effects of Tai Chi training on various indicators of cardiovascular health with both healthy persons [17, 18] and those with cardiovascular problems [19, 20]. Studies have

also found that Tai Chi practitioners achieve greater leg strength than their healthy counterparts [17, 21]. This may be because much Tai Chi practice is in a semi-squatting position.

A natural question is then whether Tai Chi practice can achieve muscle strengthening without jeopardizing the arterial compliance of older adults? A recent study in our laboratory has shown that older subjects (73.7 ± 4.5 years) who practice Tai Chi regularly have better arterial compliance (40% higher in large artery elasticity index and 29.6% higher in the small artery elasticity index) and greater knee muscle strength than healthy controls [22]. These findings suggest that Tai Chi could be an exercise which could achieve muscle training without jeopardizing arterial compliance, but no cause and effect relationship has yet been established. The present study was therefore designed to investigate whether Tai Chi training can improve both the arterial compliance and leg strength of the elderly using a single blind randomized clinical trial design.

Methodology

Subjects

Thirty-one community-dwelling elderly females were recruited by distributing pamphlets at two elderly community centers in Hong Kong. None of the subjects had previous experience practicing Tai Chi. All of the participants were independent in their activities of daily living. They were required to score at least 21 on the Chinese version of the Mini-mental Status Examination to ensure the validity of the measurement and intervention procedures [23]. Subjects with severe cognitive impairments, symptomatic cardiovascular disease at moderate levels of exertion, poorly controlled hypertension or symptomatic orthostatic hypotension, a diagnosis of a stroke, Parkinson's disease or any

other neurological disorder, peripheral neuropathy of the lower extremities, crippling arthritis, or a recent fracture of either lower limb were excluded.

By drawing lots, sixteen subjects were randomly assigned to learn 12- forms Yang style Tai Chi, while the other 15 served as a control group.

This study was approved by the Ethics Committee of the Hong Kong Polytechnic University. The procedures were fully explained to all subjects, and all gave written informed consent.

Interventions

The subjects in the Tai Chi group underwent 16 weeks of training in 12- forms Yang- style Tai Chi under an experienced instructor, with three sessions per week. Each session involved a 15-minute warm-up, one hour of Tai Chi practice and 15 minutes of cooling-down. The 12- forms Yang- style was selected because it is the style most widely practiced by older practitioners [24]. The subjects in the control group attended a series of music, English and handicrafts classes for 16 weeks. The contact time was similar, but most of the time was spent sitting.

Measurements

To ensure similar experimental conditions, participants were tested during the same time period (9-12 noon) and the room temperature was kept constant at 24°C. The subjects' heights and weights were recorded and body mass index index was calculated accordingly. Each subject's medical history was recorded and hypertension was classified as having been diagnosed by a physician and on daily medication for controlling blood pressure.

Each subject was asked to complete a modified Minnesota Leisure Time Physical Activity questionnaire [25]. The questionnaire categorized these older subjects' daily activities (household chores, hobbies and sports) into 3 different physical levels according to metabolic index units (METs): light (<4 METs), moderate (4-5.5 METs), and heavy (> 5.5 METs) in order to rate their energy expenditure. This approach has been used to compare physical activity levels among older subjects in previous studies [21, 26].

Arterial compliance

The arterial compliance indexes were measured using an HDI PulseWave CR-2000 research cardiovascular profiling system (Hypertension Diagnostics Inc., Eagan, MN, USA). The reliability of this instrument and the validity of its readings have been verified in previous studies [27, 28]. It uses a modified Windkessel model to quantify electrical analog model which contains a capacitive compliance element (larger artery elasticity), and a reflective or oscillatory compliance element (small artery elasticity) (Figure 1) [29].

The subject rested for several minutes lying down, and then blood pressure was measured in the left upper arm using a blood pressure cuff. The right hand and arm were stabilized by a rigid plastic stabilizer to avoid any skin and arm movements during measurement, and then a piezoelectric acoustic sensor was placed over the strongest pulse point of the radial artery of the right arm. Blood pressure (BP) was measured using a linear dynamic deflation method. Once the waveform shown on the screen was stable, the radial artery BP waveform data was recorded over a 30-second period for the arterial compliance analysis. Three trials were performed to yield mean values for the large artery

elasticity index (C1) and the small artery elasticity index (C2). A 1-minute rest was given between trials. .

Knee joint muscle strength

Concentric and eccentric knee muscle strength of the dominant leg was also measured in this study because a large part of most Tai Chi routines is performed in a semi-squatting position. The subject's dominant leg was considered to be the leg that subject said they would use to kick a ball. The measurement was done using a Cybex Norm dynamometer (Cybex International Inc., Ronkonkoma, NY) at an angular velocity of 30°/s. The slow testing speed was adopted to achieve “velocity specificity” [21] with respect to the slow movements of Tai Chi. During the measurement, the subject sat with a stabilizing strap over the trunk and the hips held at 70° of flexion. The lateral femoral epicondyle of the subject's dominant leg was in line with the rotation axis of the dynamometer. The starting position was 90° of knee flexion, ending at 0°. A 10- minute warm-up (stretching of the knee muscle groups) was supervised by a physical therapist before testing. Familiarization trials involving three submaximal concentric and eccentric repetitions were completed before the formal testing. Each subject was then asked to give five maximal contractions of the knee extensors and flexors in both concentric and eccentric modes. All twenty trials were recorded for offline analysis. The “peak torque-to-body weight” ratio of the concentric and eccentric measurements was calculated using the average of the three highest peak torques and normalized using the subject's body weight [30].

Statistical analysis

All the analyses were performed using Statistical Package for the Social Sciences (SPSS) software version 17.0 (SPSS Inc., USA). The continuous data were expressed as mean±standard deviation. Age, weight, height and BMI were compared between the Tai Chi subjects and controls using independent *t*-tests. A chi-square test was used to compare the groups' physical activity levels. Repeated measures analysis of variance (group × time) with intention-to-treat was used to compare the two groups' results in the arterial compliance test, and the concentric and eccentric muscle strength tests. The “last observation carried forward” was used to handle the data of the subjects who dropped out during intervention [31]. If statistically significant interaction differences were found, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for the statistical comparisons.

Results

The average attendance of the interest classes was 78%, and 85% for the Tai Chi training sessions. One person dropped out of the Tai Chi group due to family issue, and 3 dropped out of the control group—one because she fractured her arm during daily activity and two due to family issues (Figure 2). The participants' characteristics are presented in Table 1. Before training, there were no inter-group differences in average height, weight, body mass index, cognitive status or physical activity level. The average age of the two groups did, however, show a significant difference, so age was treated as a covariate in the statistical analyses. All the subjects reported no change of their medications during the intervention period.

Arterial compliance

Average large and small artery compliance increased significantly at 26.2 %

($p=0.039$) and 17.9% ($p=0.011$) respectively after Tai Chi intervention. The control group recorded decreases in both large and small artery compliance, but they were not statistically significant (Table 2).

Lower limb knee muscle strength

The concentric and eccentric knee extensors and flexors in the Tai Chi group showed percentage strength changes of from 4.6% to 21.3%, but only the changes in eccentric knee extensor strength were statistically significant ($p=0.01$). For the control group subjects the percentage changes were from 1.2% to 10.5% and none were significant (see Table 3).

Discussion

Tai Chi training and arterial compliance

After 16 weeks of Tai Chi training, these elderly women achieved significant improvements in both large and small artery compliance (26.2% and 17.9%, respectively). The 12- forms Yang style Tai Chi used in the intervention is considered to be aerobic in nature [24] and the results are in line with those of previous studies on aerobic exercise. Tanaka and colleagues [11] investigated the effects of aerobic exercise on arterial compliance in middle aged men. After 3 months of training, their arterial compliance improved from 20% to 35%. In another study on postmenopausal women, Moreau and colleagues [32] showed that improvements could reach 33-43% after 3 months of aerobic training. Fujimoto and colleagues [33] studied subjects aged 70 and older and showed that after 1 year of progressive aerobic training the participants' total arterial compliance improved around 27%, leaving it similar to that of trained athletes of the same age.

Our group has reported a cross-sectional study using a group of experienced Tai Chi practitioners ($n = 29$, mean age 73.9 years, mean Tai Chi experience 6.7 years). By comparing with their average larger arterial compliance index (14.7 ± 4.4 ml/mmHg $\times 10$) and small arterial compliance (3.5 ± 1.5 ml/mmHg $\times 100$) [22], there were significant differences in both parameters ($p = 0.001$ and 0.044 , respectively) with our Tai Chi subjects before intervention, but no significant difference after the 16-week of Tai Chi intervention ($p = 0.809$ and 0.338 , respectively).

It is of course well known that aerobic exercise improves arterial compliance, but the underlying mechanism remains poorly understood. Enhanced endothelial dilatation has been shown in both animal [34, 35] and human studies [36]. On the other hand, Cortez-Cooper and colleagues [37] found that participants in a stretching group showed significant improvements (23%) in arterial compliance. Those improvements could have been related to the improved functioning of the endothelium of the arterial wall. The longitudinal stretching of the muscles with which the arteries are attached could increase endothelial cell replication, leading to improved arterial compliance [38]. Tai Chi practice involves significant stretching movements, and sustained stretching of muscles all over the body could improve the arterial compliance through such a mechanism.

Tai Chi training and muscle strength

The 16 weeks of Tai Chi training significantly improved the average eccentric strength of the participants' knee extensors (21.3%; Table 3). This was in line with the finding by Audette's group [39] that knee eccentric strength was improved after Tai Chi intervention. As Tai Chi practice is in large part performed in a semi-squatting position, it is not unexpected that eccentric control of the knee extensors would be trained. At the

beginning of the training, the trunk must be properly aligned with the limb movements; otherwise an improper semi-squat position will cause an increase in the cardio-thoracic pressure with possible adverse effects on cardiac health.

Arterial compliance and muscle strength

Strength training has been shown to decrease arterial compliance [12, 13]. Several possible mechanisms have been proposed. One suggestion is that the acute elevation in blood pressure in the cardiothoracic region during strength training could cause a chronic increase in the smooth muscle content of the arterial walls to exploit the load-bearing properties of collagen and elastin. Another suggestion is that increased sympathetic nervous system activity in resistance training could provoke greater sympathetic adrenergic vasoconstrictor tone in the arterial walls, leading to reduced arterial compliance [12, 13].

Although Tai Chi training is not regarded as a muscle strengthening regimen, studies have found that the positive effects of Tai Chi on leg strength arise mainly because practitioners maintain a semi-squatting position during much of the practice [16, 17, 21, 39]. Tai Chi also requires a calm mind and deep, slow breathing. This should tend to decrease blood pressure and tilt autonomic regulation toward parasympathetic modulation and away from sympathetic modulation [40]. Slowness and evenness of movement are also emphasized [41]. Our group has shown [42] that during Tai Chi practice, parasympathetic activity dominates (as compared with arm ergometer cycling). We also showed that prefrontal activity, especially on the left side, was elevated, and this is associated with the mindful relaxation required during Tai Chi practice. This too promotes dominant parasympathetic control [42]. Taken together, these findings may

explain why Tai Chi practice can improve the eccentric knee extensor strength while not jeopardizing arterial compliance.

Limitations

This study recruited only elderly women, so the results may not be applicable to males. Only the pre and post assessments were performed, so no long term effects could be established. Due to the limited number of subjects studied, the significant results on muscle strength parameters probably were confined to one muscle group only.

Conclusions

Tai Chi training can improve the arterial compliance and knee muscle strength of elderly women. Tai Chi may be a good exercise choice for older adults, both for vascular health and for muscle strengthening.

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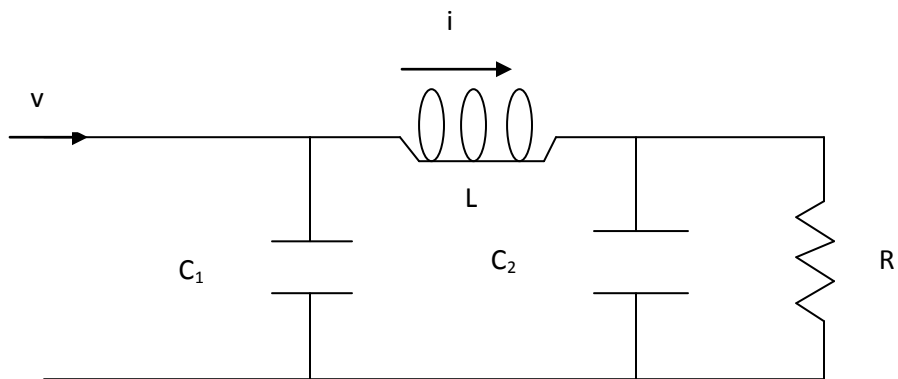


Figure 1: arterial compliance measurement: v indicates voltage; i , current; L , inductance; R , resistance; C_1 , large arterial compliance; and C_2 , small arterial compliance.

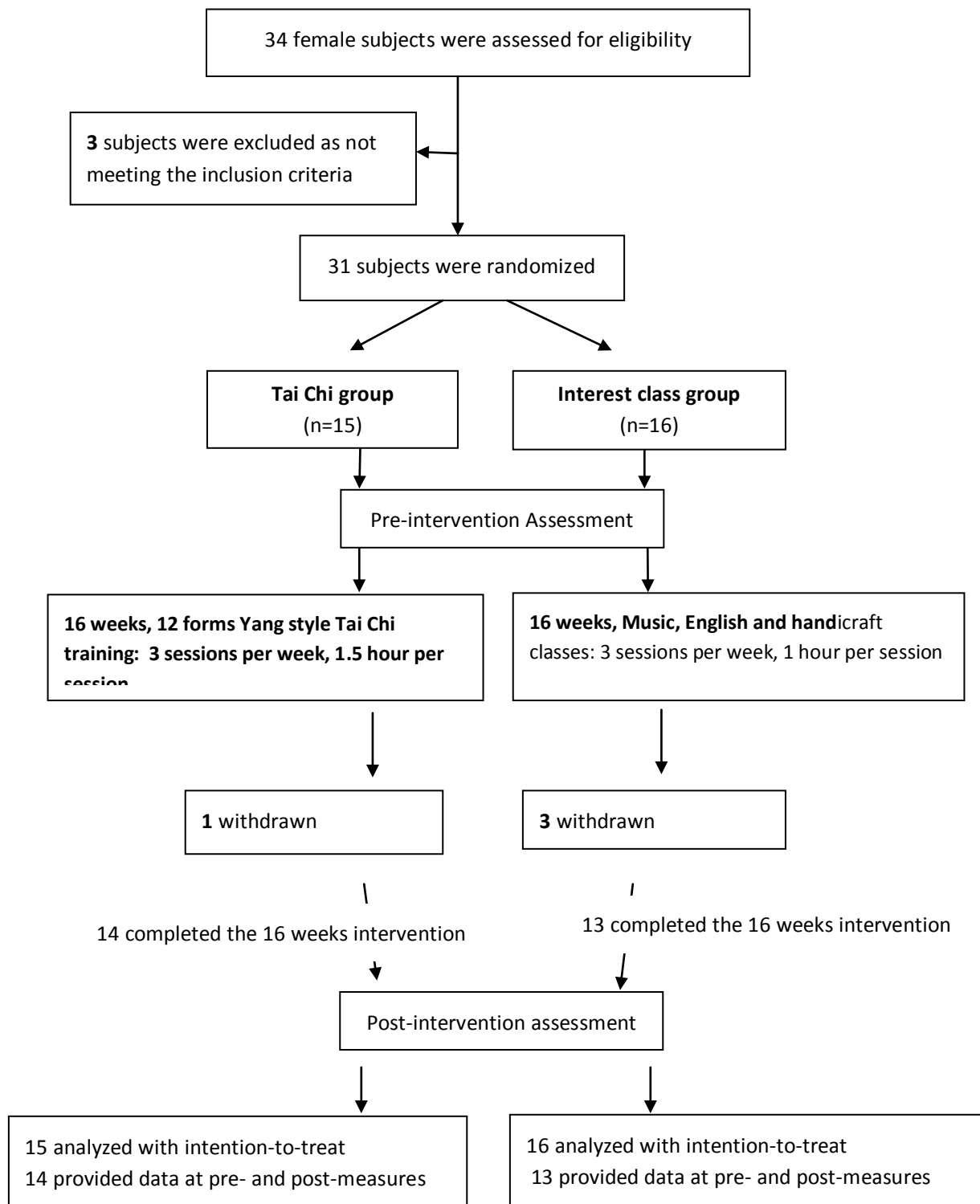


Figure 2. Flow diagram of subjects being recruited to the study

Table 1. Demographic characteristics of the participants

	Interest class group (n=16)	Tai Chi group (n=15)	p
Age	68.9±5.8	73.9±6.6	0.034*
Height (cm)	151.2±5.1	152.3±5.4	0.549
Weight (kg)	56.8±8.8	57.1±8.4	0.927
Body mass index (kg/m ²)	24.8±3.3	24.6±3.1	0.850
MMSE score	27.3±1.9	26.1±3.1	0.189
Number with hypertension	7/16	11/15	0.095
Physical activity level			0.644
before intervention	12	9	
Light (≤4.0METs)	4	6	
Moderate (≤5.5METs)	0	0	
Heavy (>5.5METs)			

* denotes a difference significant at the $p < 0.05$ level of confidence.

MMSE denotes the Chinese version of the Mini Mental Status examination

Table 2. Arterial compliance before and after intervention

	Control group		Tai Chi group	
	Pre	Post	Pre	Post
Large artery compliance index (C1) (ml/mmHg×10)	10.1±2.7	9.6±3.8	10.3±2.7	13.0±3.8*
Small artery compliance index (C2) (ml/mmHg×100)	2.6±1.3	2.3±1.1	2.8±1.3	3.3±1.1*

* denotes a pre to post difference significant at the $p < 0.05$ level.

Table 3. Knee strength before and after intervention

Peak torque-to-body weight ratio (N·m/kg)		Control group			Tai Chi group		
		Pre	Post	% change	Pre	Post	% change
Concentric	Extensors	0.86±0.21	0.87±0.23	1.2%	0.87±0.35	0.91±0.42	4.6%
	Flexors	0.38±0.11	0.39±0.16	2.6%	0.34±0.22	0.37±0.21	8.8%
Eccentric	Extensors	1.14±0.36	1.26±0.41	10.5%	1.22±0.44	1.48±0.56	21.3%*
	Flexors	0.61±0.24	0.66±0.24	8.2%	0.71±0.32	0.79±0.29	11.3%

* indicates a pre to post difference significant at the 5% level of confidence.