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Tai Chi, arterial compliance, and muscle strength in older adults

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Abstract

Background: Aerobic exercise can alleviate the declines in arterial compliance common in older adults. However, when combined with strength training, aerobic exercise may not reduce arterial compliance. Tai Chi practice has been found to improve muscle strength and cardiopulmonary function in older subjects, but whether or not it improves arterial compliance is not known. The primary aim of this study was to investigate whether Tai Chi practitioners have better arterial compliance and muscle strength.

Design: Twenty-nine older Tai Chi practitioners (73.7 ± 4.5 years) and 36 healthy control subjects (71.4 ± 6.6 years) participated in this cross-sectional study.

Methods: The participants were independent in their daily living activities. They were screened for apparent cardiovascular disease and underwent arterial compliance testing and isokinetic knee muscle strength testing at 30°/s.

Results: Tai Chi practitioners showed significantly better haemodynamic parameters than the controls as indexed by larger and small artery compliance. They also demonstrated greater eccentric muscle strength in both knee extensors and flexors.

Conclusion: The findings of better muscle strength without jeopardizing arterial compliance suggests that Tai Chi could be a suitable exercise for older persons to improve both cardiovascular function and muscle strength.

Keywords
Aging, arterial compliance, muscle strength, Tai Chi

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Introduction

Arterial compliance describes an artery's ability to expand and contract with cardiac pulsations and relaxation.[1] When an artery fails to distend or rebound in response to pressure changes, it is considered to be stiff. Arterial stiffness has been found to be closely associated with cardiovascular diseases such as hypertension,[2,3] heart disease,[4] and stroke.[5] How poor arterial compliance causes cardiovascular diseases has been discussed by Gates and Seals.[6] Changes in the arteries might contribute to the increased blood pressure and pulse pressure, reduced cardiovagal baroreflex sensitivity, increased aortic input impedance, left ventricular hypertrophy and diastolic dysfunction, and atherosclerosis. Arterial compliance can be an important predictor of cardiovascular mortality in the elderly.[7,8] Therefore, good arterial compliance is an important therapeutic target for physical exercise in the prevention of cardiovascular disease.[6]

Cross-sectional studies show that age-related arterial stiffness is absent in physically active women[9] and men.[10] Studies have shown that after 3 months of aerobic training, arterial compliance may improve to the level of endurance-trained subjects.[10,11] Muscle strength training is common nowadays and often employed to counteract aging, but this form of training has led to a decrease in arterial compliance.[12,13] Any change in arterial compliance caused by strength training in middle-aged and older subjects is still elusive. A recent randomized clinical study by Cortez-Cooper

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and colleagues[14] with adults aged 50 and above found that, after 13 weeks of intervention, only subjects in the stretch training group showed improved arterial compliance, while subjects in the strength training and combined strength and aerobic training groups did not. However, strength training is an important prescription for older persons, especially those with osteopenia or balance problems. Consequently, exercise which can improve both arterial compliance and muscle strength would be a preferred mode of training for older persons.

Tai Chi is a Chinese mind–body exercise usually regarded as aerobic.[15] Significant improvement in cardiopulmonary function has been found in Tai Chi practitioners when compared with sedentary control subjects middle-aged and older.[16–18] Tai Chi training can also improve cardiopulmonary function in patients with cardiovascular diseases like chronic heart failure [19,20] and myocardial infarction.[21] In fact, the effect of Tai Chi training in lowering the blood pressure of subjects with hypertension has been extensively reviewed.[22,23] It is known that Tai Chi practice includes a great deal of stretching movements. The latter has been found by Cortez-Cooper and colleagues[14] to increase arterial compliance in older adults. However, the effect of Tai Chi practice on arterial compliance has not been investigated in older subjects. Having shown experienced Tai Chi practitioners to have better leg strength than their healthy counterparts,[24] we wondered if Tai Chi practitioners would have also achieved greater arterial compliance as a result of performing the stretching movements embedded in its many styles. This study was therefore designed to investigate whether experienced Tai Chi practitioners have (1) better arterial compliance and (2) greater knee muscle strength than older controls.

Methods

Subjects

In this cross-sectional study, a total of 65 community-dwelling subjects participated. They were all independent in the activities of daily living. Twenty-nine Tai Chi practitioners (9 males and 20 females, mean age 73.7 ± 4.5 years) were recruited from local Tai Chi clubs. All of them had practised Tai Chi for a minimum of 1.5 hour per week for at least 3 years (average Tai Chi experience 6.7 ± 4.6 years). Another 36 control subjects (6 males and 30 females, mean age 71.4 ± 6.6 years) with no previous Tai Chi experience were recruited from several elderly centres. They involved either in morning walk, leisure hiking, or household work. Subjects were excluded for diagnosed neurological disorder, severe lung disease, any coronary artery disease, a history of myocardial infarction or other heart failure, significant atrial or ventricular arrhythmia, cerebral artery disease, or any peripheral vascular disease. Subjects with diagnosed hypertension or diabetes were accepted but recorded separately for further analysis. This study was approved by the Ethics Committee of The Hong Kong Polytechnic University. The procedures were fully explained to all subjects, and a written informed consent was obtained from them.

Measurements

All subjects were asked to abstain from taking caffeine and alcohol the night before assessment. However, their daily exercise routine was advised to be maintained. To ensure a similar experimental environment, participants were tested during the same time period, and the room temperature was kept constant at 24°C. Subjects' height and weights were recorded and body mass index (BMI) index was calculated accordingly.

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 three 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.[24,26]

Arterial compliance. An HDI PulseWave CR-2000 research cardiovascular profiling system (Hypertension Diagnostics, Eagan, MN, USA) was used to measure the subjects' arterial compliance. This has been shown to be a reliable and valid instrument for measuring arterial compliance.[27,28] It uses a modified Windkessel model to calculate an electrical analogue model which contains a capacitive compliance element (larger artery elasticity index), a reflective or oscillatory compliance element (small artery elasticity index), and inductance and resistance (systemic vascular resistance).[29] A blood pressure (BP) cuff was placed around each participant's left upper arm to measure the BP of left brachial artery and a piezoelectric acoustic sensor was placed over the strongest pulse point of the radial artery in the right arm. The right hand and arm were stabilized by a rigid plastic stabilizer to avoid any skin and arm movements during measurement. BP was measured using a linear dynamic deflation method. Once the waveform shown on the screen was stable, the radial artery BP waveform data over a 30-sec period were recorded for compliance analysis. The analysis involves equations which can be found in the work of Cohn and colleagues.[29] Since heart rate and BP are involved in the calculation of arterial

compliance, these parameters would be treated as covariate in data analysis if significant difference was found between the two groups. Three trials were performed to yield mean values for the large artery and small artery elasticity indices. A 1-min rest was given between trials. The measurements included systemic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), pulse rate, large artery elasticity index (C1), small artery elasticity index (C2), as well as systemic vascular resistance (SVR), and total vascular impedance (TVI).

Knee joint muscle strength. Both concentric and eccentric knee muscle strengths were measured, because a large part of a Tai Chi routine is performed in a semi-squatting position. The concentric and eccentric knee extensors and flexors of each subject's dominant leg were measured 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'[24] mimicking the slow movements of Tai Chi. Subject's dominant leg was considered to be the one that subject used to kick a ball. Muscle testing was performed in a sitting position with a stabilizing strap over the trunk and with 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 of the knee was 90° of flexion, ending at full knee extension. Before testing, subjects were asked to perform a 10-min warm up which included stretching of the knee muscle groups supervised by a physical therapist. Familiarization trials were given with three submaximal repetitions for both concentric and eccentric trials before 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 five trials were recorded for offline analysis. The peak torque-to-bodyweight ratio of the concentric and eccentric measurements was calculated as average of the three highest peak torques from the five trials and normalized with respect to the subject's bodyweight.[30]

Statistical analysis

All the analyses were performed using Statistical Package for the Social Sciences software version 17.0 (SPSS, 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-squared test was used to compare the groups' gender distributions, physical activity levels, and number of subjects with hypertension and diabetes mellitus. Multivariate analysis of variance (MANOVA) was used to compare the two groups' results in the arterial compliance test and the concentric and eccentric muscle strength tests. If statistically significant differences were found in the multivariate tests, univariate tests were conducted for each of the measures. A significance level (α) of 0.05 was chosen for statistical comparisons.

Table 1. Demographic data

	Control subjects ($n = 36$)	Tai Chi subjects ($n = 29$)	*p*-value
Age (years)	71.4 ± 6.6	73.7 ± 4.5	0.108
Gender			
Male	6	9	0.172
Female	30	20	
Height (cm)	153.1 ± 6.4	154.5 ± 8.1	0.418
Weight (kg)	57.8 ± 8.4	55.0 ± 9.6	0.206
BMI (kg/m^2)	24.6 ± 3.1	23.0 ± 3.5	0.044*
Physical activity level			
Light (<4 METs)	22	13	0.269
Moderate (4–5.5 METs)	14	13	
Heavy (>5.5 METs)	0	3	
No. of subjects with hypertension	22	11	0.063
No. of subjects with diabetes mellitus	4	2	0.56

Values are mean ± standard deviation or *n*. *Denotes a difference significant at the $p < 0.05$ level using an independent t-test. BMI, body mass index; METs, metabolic index units.

Results

Subjects with hypertension and diabetes mellitus reported that they kept their medications when the measurements were taken. The control subjects and experienced Tai Chi practitioners did not differ significantly in their average age, height, weight, or physical activity level, but control subjects had a significantly higher average BMI than the Tai Chi subjects ($p = 0.044$; Table 1).

Table 2 presents the arterial compliance data. Since the average BMI of the two groups was significantly different, BMI was used as a covariate in the statistical analysis of the arterial compliance results. The Tai Chi subjects were significantly better than the control subjects in all the haemodynamic parameters (overall MANOVA, $p < 0.001$) except the pulse rate ($p = 0.420$). Previous studies have shown that higher blood pressure may cause stiffness on the arterial wall.[31] A correlation analysis was also performed in

Table 2. Haemodynamic observations

	Control subjects ($n=36$)	Tai Chi Subjects ($n=29$)	p-value
SBP (mmHg)	126.9 ± 14.7	116.4 ± 11.3	0.004**
DBP (mmHg)	69.8 ± 9.2	64.1 ± 7.5	0.019*
Pulse pressure (mmHg)	57.1 ± 9.5	52.5 ± 6.9	0.028*
Pulse rate (bpm)	64.2 ± 9.3	62.6 ± 8.0	0.420
Larger artery compliance index (C1) (ml/mmHg×10)	10.5 ± 2.8	14.7 ± 4.4	<0.001***
Small artery compliance index (C2) (ml/mmHg × 100)	2.7 ± 1.2	3.5 ± 1.5	0.002**
SVR (dync·sec·cm^{-5})	1974.6 ± 346.8	1792.9 ± 332.7	0.006**
TVI (dync·sec·cm^{-5})	203.5 ± 55.5	153.8 ± 36.9	<0.001***

Values are mean ± standard deviation. *Denotes a difference significant at the $p < 0.05$ level; **$p < 0.01$; ***$p < 0.001$, using a univariate test. DBP, diastolic blood pressure; SBP, systolic blood pressure; SVR, systemic vascular resistance; TVI, total vascular impedance.

Table 3. Concentric and eccentric knee muscle strength

Peak torque-to-body weight ratio (N·m/kg)	Control subjects ($n=36$)	Tai Chi subjects ($n=29$)	p-value
Concentric			
Extensors	0.96 ± 0.33	1.17 ± 0.42	0.026*
Flexors	0.37 ± 0.17	0.45 ± 0.21	0.085
Eccentric			
Extensors	1.31 ± 0.49	1.68 ± 0.62	0.01*
Flexors	0.71 ± 0.31	0.89 ± 0.35	0.03*

Values are mean ± standard deviation. *Denotes a difference significant at the $p < 0.05$ level using a univariate test.

the present study and there were significant negative correlations found between the systolic blood pressure and large arterial compliance (C1) (Pearson product-moment coefficient of correlation, r, -0.329; $p = 0.007$) and small arterial compliance (C2) (r -0.569; $p < 0.001$). The higher proportion of subjects having hypertension in the control group (61% vs. 38% in the Tai Chi group) and the significant higher systolic blood pressure of control subjects ($p = 0.004$) might confound the findings on C1 and C2. Therefore, further statistical analysis using MANCOVA on the arterial compliances between the two groups with the systolic blood pressure as covariate was performed. The MANCOVA showed an overall significant difference ($p < 0.001$) with Tai Chi practitioners still achieved significant higher C1 ($p < 0.001$) and C2 ($p = 0.037$) when compared to the control subjects.

Though MANOVA showed no statistically significant overall difference in concentric muscle strength between groups, univariate testing revealed that the Tai Chi practitioners had higher average concentric knee extensor strength ($p = 0.026$; Table 3). Eccentric knee muscle strength showed a significant overall difference between the controls and the Tai Chi group in multivariate analysis ($p < 0.05$). Univariate analyses demonstrated that the Tai Chi subjects had greater average eccentric muscle strength in both their knee extensors ($p = 0.01$) and flexors ($p = 0.03$; Table 3).

Discussion

Arterial compliance and Tai Chi training

Our findings show that older subjects who practise Tai Chi regularly had better arterial compliance than the controls similar in age and gender. This is in line with the findings of Tanaka and colleagues,[9] who found that physically active postmenopausal women had better arterial compliance than sedentary controls. In their subsequent study[10] on middle aged (around 50 years) and older men (around 65 years), endurance-trained groups showed arterial compliance 20% to 35% better than the inactive group, when the common carotid artery was tested using ultrasound and a β-index. Better arterial compliance (by 33–43%) has also been observed in postmenopausal women who participated in endurance training.[11]

In this study, the larger artery compliance index (C1) and small artery compliance index (C2) were 40–44% higher in the Tai Chi practitioners than the controls. In previous studies, the controls recruited have usually been sedentary subjects. In this study, there was no significant difference in physical activity levels between the Tai Chi and control subjects (Table 1), so the observed difference in arterial compliance might not be due to their physical activity levels. Longitudinal studies have found that 3 months of aerobic exercise training, a self-implemented walking programme, can decrease the age-related decline in arterial compliance in middle aged and older men[10] and postmenopausal healthy women[11] to a level similar to that of endurance-trained men or premenopausal women. In a recent study, investigators also found that sedentary older subjects (age around 70 years) who underwent 1 year of progressive jogging training could improve their total arterial compliance to the level of master athletes.[32] It seems that in seniors it takes longer (1 year in older subjects vs. 3 months in middle age) to achieve the vascular health benefits of endurance exercise training. The results of this study

show that older persons who have been practising Tai Chi for on average 6 years had better arterial compliance than the healthy controls. These findings were also in line with those of previous studies on aerobic exercise training.

Previous studies have shown that Tai Chi practice could reduce blood pressure in subjects with or without hypertension.[22,23] In the present study, both systolic and diastolic blood pressures of Tai Chi practitioners were lower than the control subjects (8.3% and 8.2%, respectively). The blood-pressure-lowering effect of Tai Chi practice may have an effect on the arterial compliance since the systolic blood pressure and arterial compliance has been found to be significantly correlated in the present and previous studies.[33,34] Therefore, Tai Chi could be an attractive form of exercise for older adults. However, a prospective randomized clinical study is needed before a valid conclusion could be drawn.

Arterial compliance and muscle strength

The experienced Tai Chi participants had better arterial compliance and knee muscle strength than the healthy controls. Previous cross-sectional studies of strength training of young athletes have found that their arterial compliance was lower than that of sedentary young controls.[12,35] In a longitudinal study, Miyachi and colleagues recruited young subjects with mean age of 22 years and conducted 4 months of resistance training (80% to their one-repetition maximum) and 4 months of detraining. Although there was an improvement in the strength of all their main muscle groups, there was a significant decrease in arterial compliance after 4 months of training. Compliance returned to the baseline value only after 4 months of detraining.[13] So strength training might be harmful to vascular health in young subjects. With older subjects, Cortez-Cooper and colleagues[14] found that in adults with mean age of 52 years, 13 weeks of strength training (70% to their one-repetition maximum) caused slight decrease in carotid artery compliance although not reaching a statistically significant difference. Only stretch training led to improvements in arterial compliance. The difference between findings of Miyachi and Cortez-Cooper in the decrease of the arterial compliance may be explained by different age, resistance intensity, and duration of training. These results suggest that although strength training improved muscle strength, they showed a tendency to reduce arterial compliance. In the study by Cortez-Cooper and colleagues,[14] the combined strength and aerobic training produced no harmful effect on the carotid arterial compliance of the participants. Another cross-sectional study done by Cook and colleagues[36] also found that in the middle aged rowers, the central arterial compliance was higher than their control counterpart while their handgrip strength was also higher than the controls. The investigators suggested the endurance-training components of rowing counteracts the stiffening arterial compliance effects of its strength training.[36]

Miyachi and colleagues have discussed the interaction mechanisms strength training and arterial compliance.[12,13] They suggest 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 arterial wall and the load-bearing properties of collagen and elastin. Increased sympathetic nervous system activity in resistance training could also provoke greater sympathetic adrenergic vasoconstrictor tone in the arterial walls, leading to reduced arterial compliance. These proposed mechanisms were derived from observation of the structural changes in the arterial wall during strength training using an animal model. High blood pressure was found in dogs along with thickening of the arterial walls[37] resulting in a decrease in arterial compliance.

Unlike strength or endurance training, Tai Chi requires mental concentration and calm meditation during movement.[38] Previous studies have shown that its practitioners demonstrate higher parasympathetic nervous system activity before, during and immediately after Tai Chi practice.[39–42] Physiological shifting of the autonomic system to the parasympathetic system may prevent arterial constriction despite the strength training involved in keeping the bodyweight in a semi-squatting position for prolonged time periods during practice.[23] Tai Chi practice also includes lots of stretching movements, which a group led by Cortez-Cooper[14] has shown to increase arterial compliance and decrease pulse pressure. This may explain why the Tai Chi practitioners in this study showed better lower limb muscle strength and better arterial compliance. Recently, investigators have been trying to find an exercise paradigm that could combine both aerobic and strength training components so that strengthening will not cause a detrimental effect on arterial compliance.[36,43] From the present findings, Tai Chi may be a good training mode for older adults to improve both their vascular health and muscle strength.

Tai Chi subjects had higher eccentric knee muscle strength than the healthy controls (Table 3). This was similar to our previous finding which employed a low isokinetic testing speed. However, their concentric knee flexor muscle strength was not significantly better. This may be because the Tai Chi subjects recruited in this study were older (73.7 ± 4.5 years vs. 69.3 ± 5.0 years) and had less Tai Chi practice experience (6.7 ± 4.6 years vs. 8.5 ± 6.7 years) than those in our previous study where better concentric knee flexor muscle strength was observed.[24]

With the use of a cross-sectional study design, no cause-effect relationship could be established in the present study. We have adopted a modified physical activity questionnaire for the comparison between the two groups which was simpler to administer for our elderly participants. However, such modified questionnaire has not been validated. In addition, though the average physical activity level of the two groups was not significantly different, more of the Tai Chi subjects engaged in 'heavy' physical activity. The results should be interpreted with caution. Moreover, factors like smoking habit, depression, and attitude towards health may confound the arterial compliance as those who attend Tai Chi exercise are prone to live a healthier life style. To further investigate whether Tai Chi training improves arterial compliance as well as muscle strength, a randomized clinical study has been conducted. Our findings have shown that 16 weeks of Tai Chi practice has improved the eccentric knee extensor strength and arterial compliance of elderly women.[44]

Conclusion

Older subjects who practise Tai Chi regularly have better arterial compliance and greater knee muscle strength than healthy controls. Tai Chi is an exercise that appears to benefit both muscle strength and arterial compliance for older adults.

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Conflict of interest

No commercial party having a direct financial interest in the research findings reported here has conferred or will confer a benefit on the authors or on any organization with which the authors are associated.

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