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Tai chi in patients with heart failure with preserved ejection fraction

Gloria Y. Yeh, MD MPH^{1,2}, Malissa J. Wood, MD³, Peter M. Wayne, PhD^{1,4}, Mary T. Quilty, BS^{1,4}, Lynne W. Stevenson, MD⁵, Roger B. Davis, ScD^{1,2}, Russell S. Phillips, MD^{1,2}, and Daniel E. Forman, MD^{5,6}

¹Osher Center for Integrative Medicine, Harvard Medical School

²Division of General Medicine and Primary Care, Department of Medicine, Beth Israel Deaconess Medical Center

³Division of Cardiology; Massachusetts General Hospital

⁴Division of Preventive Medicine; Brigham and Women's Hospital

⁵Cardiovascular Division; Brigham and Women's Hospital

⁶New England Geriatric Research, Education, and Clinical Center, Veterans Administration Boston Healthcare System

Abstract

Background—Although exercise is an important component of heart failure management, optimal regimens, particularly in heart failure with preserved ejection fraction (HFPEF), are uncertain. Tai chi (TC) is a mind-body exercise that may have potential benefits but has not been studied in this population.

Methods—We randomized sixteen patients with HFPEF to either 12 weeks TC or aerobic exercise. Assessments included peak oxygen uptake, 6-minute walk, quality-of-life, echocardiography, mood, and self-efficacy at baseline and 12 weeks. Cardiorespiratory measures during exercise were obtained to characterize training intensities.

Results—Baseline characteristics were as follows: age 66±12 years, E/A ratio 1.3±0.7, E/e' ratio 15.9±4.8. Adherence overall was excellent (89% attendance). Change in peak oxygen uptake was similar between groups after 12-weeks, but 6-minute walk distance increased more after TC (+69±46 m vs. +10±31 m, p=0.02). While both groups improved Minnesota-Living-with-Heart-Failure score and self-efficacy, POMS-depression scores improved more with TC (-1.7±2.8 vs. +1.6±3, p=0.05). Cardiorespiratory assessment during TC showed lower oxygen uptake (4.3 ml/kg/min vs. 9.4 ml/kg/min, p<0.01), respiratory rate and heart rate

Conclusions—TC is feasible and safe in HFPEF. Therapeutic endpoints appear similar with TC relative to aerobic exercise despite a lower aerobic training workload.

Introduction

Heart failure with preserved ejection fraction (HFPEF) is widely prevalent and growing in incidence, particularly since aging increases susceptibility to the disease and the population of elderly is expanding.¹ Definitive therapy for HFPEF, however, remains unclear and there is a critical need to expand and optimize therapeutic insights and options.

Exercise training is an important component of heart failure management, however most studies to date have investigated heart failure with systolic dysfunction. More recently, exercise training in HFPEF has gained attention. One study by Kitzman et al demonstrated that a 16-week aerobic training regimen provided significant benefits in HFPEF.² Peak exercise oxygen consumption and 6-minute walk distance improved significantly as compared to an attention control group. Physical quality of life score also improved ($P=0.03$). These data provide important rationale for exercise. Unfortunately, multiple trials have demonstrated problematic adherence to aerobic exercise over time, particularly with diverse populations and settings.³⁻⁴ Moreover, studies have suggested that peripheral effects play a particularly important role.⁵ Thus, one question that has been raised is whether exercise gains might be adequately and efficiently achieved with alternative training options that may directly address these behavioral and physiological issues.

Tai chi (tai chi chuan or taijiquan) is a gentle, meditative exercise that has its roots in ancient Chinese martial arts. It employs detailed regimens of flowing circular arm movements, balance and weight shifting, breathing techniques, and cognitive tools (such as visualization and focused internal awareness).⁶⁻⁷ Also inherent in tai chi is a component of core strengthening and stretching. This may facilitate a beneficial training effect particularly in those who are deconditioned, older, or have chronic disease. In addition, compared to aerobic training, the relatively lower intensity and meditative qualities of tai chi may help accessibility and promote longer-term exercise adherence over time. Prior studies have reported good long term adherence with tai chi in various chronic disease populations.⁸⁻¹¹

In prior studies, we investigated the potential of tai chi to improve exercise capacity and quality-of-life in patient with systolic heart failure.¹²⁻¹³ In this pilot investigation, we expand our inquiry to explore the potential benefits of tai chi for HFPEF. Our aims were to preliminarily assess changes in functional and physiological outcome measures after 12 weeks of tai chi as compared to low intensity aerobic exercise, explore relative differences in training intensities, and determine feasibility of a larger, more definitive trial.

Methods

Study design

Sixteen patients were recruited from the ambulatory cardiology practice at Beth Israel Deaconess Medical Center in Boston, MA. Inclusion criteria were based on the following: 1) physician diagnosis of HFPEF; 2) New York Heart Association functional class I, II or III; 3) left ventricular ejection fraction $\geq 50\%$ (by echocardiography, radionuclide angiography or contrast angiography) within 2 years of screening. Exclusion criteria included: 1) unstable angina, myocardial infarction or major cardiac surgery in the past 3 months; 2) cardiac arrest in the past 6 months; 3) significant valvular or pericardial disease accounting for signs and symptoms of heart failure; 4) severe chronic obstructive pulmonary disease on bronchodilators or chronic lung disease with cor pulmonale; 5) moderate or severe pulmonary hypertension; 6) atrial fibrillation as the dominant rhythm; 7) severe peripheral vascular disease, claudication or other physical condition that would preclude a walk test; 8) inability to perform bicycle ergometry; 9) technically inadequate echocardiographic windows or valvular conditions precluding assessment of diastolic function, ie. patients with severe mitral annular calcification; 10) cognitive dysfunction (MMSE ≤ 24), 11) non-English speaking; 12) current participation in conventional cardiac rehabilitation or regular practice of tai chi.

Patients were assigned randomly to receive 12 weeks of either tai chi or aerobic exercise. All participants continued to receive their usual care which included pharmacologic therapy and general exercise advice as per the ACC/AHA HF guidelines. Permuted block

randomization with variable block size was used to generate treatment assignments. All patients provided written informed consent. The Beth Israel Deaconess Medical Center's human subjects review board approved the protocol.

Tai chi intervention

The tai chi intervention consisted of one-hour group classes held twice weekly for 12 weeks with an experienced instructor. A standard training regimen was utilized that we have used in prior trials for patients with systolic heart failure (**Table 1**). The protocol included traditional warm-up exercises followed by five simplified tai chi movements. Classes incorporated weight shifting, arm swinging, gentle stretches (of the neck, shoulders, spine, arms, legs), visualization techniques, and traditional breathing. These exercises focus on releasing tension in the physical body, incorporating mindfulness and imagery into movement, increasing awareness of breathing and promoting overall relaxation of body and mind. The core tai chi movements were adapted from Master Cheng Man-Ch'ing's Yang-style short form⁶ and performed repetitively. Chairs were provided for resting, and patients were allowed to progress at their own comfort and pace.

Each subject in the tai chi group was also provided with a 35-minute instructional videotape that reviewed the exercises presented in class and was encouraged to practice at home at least three times per week.

Aerobic exercise control

The conventional aerobic exercise group also met for one hour twice a week under the guidance of an experienced instructor. The aerobic training was modeled on a typical community-based conventional low-impact aerobic exercise class offered at a local community center and designed for a senior population with low to moderate training intensity. Warm-up, peak exercise, and cool-down stages were routine. Exercises included stretching of the torso/waist, neck, upper and lower extremity; step in place and side to side with rhythmic leg and arm movements, and seated strengthening exercises. One or two pound hand weights and resistance bands were optional. Chairs were available for seated cool-down exercises and for support when performing basic stretches and strengthening exercises. As this class replicated what was readily available in the community, patients were allowed to progress at their own comfort and pace.

Each subject in the aerobic exercise group was also provided with a 35-minute instructional videotape that reviewed the exercises and instructions presented in class, and subjects were encouraged to practice at home at least three times a week.

Outcome measures

Comprehensive assessments were completed at baseline and 12 weeks.

Exercise capacity and functional status—Symptom-limited cardiopulmonary exercise testing was completed using an electronically calibrated upright bicycle and continuous electrocardiographic monitoring. A standard 10 watt graded bicycle ramp protocol was utilized.⁴¹ Patients were encouraged to exercise to exhaustion. Gas exchange was assessed using a SensorMedics (Yorba Linda, CA) metabolic cart. Peak oxygen uptake (VO_2) values were averaged from the final 20 seconds of the test. The exercise testing staff was blinded to subjects' exercise group assignments.

The six-minute walk test (6MW) per the American Thoracic Society protocol and timed up-and-go (TUG) assessments were also completed.¹⁴⁻¹⁶ The 6MW is often cited as providing a more meaningful assessment of functional performance with respect to daily activity. TUG

serves as an integrative assessment of functional and strength capacities and is often used to gauge susceptibility to falls. The staff assessing 6MW and TUG was blinded to the subjects' exercise group assignments.

Physical activity was assessed using the Community Healthy Activities Model Program for Seniors (CHAMPS) Physical Activity Questionnaire for Older Adults,¹⁷ an assessment which captures weekly frequency and total time spent in different activities and allows estimation of caloric expenditure.

Health-related quality-of-life, symptoms, mood, psychosocial functioning—

The Minnesota Living with Heart Failure Questionnaire (MLHF) was used to assess health-related quality-of-life. MLHF consists of 21 validated items covering physical, psychological, and socioeconomic dimensions (e.g. swelling in the ankles, difficulty climbing stairs, fatigue, feeling depressed, spending money for heart failure). The score range is 0 to 105, with a lower number denoting better quality-of-life.¹⁸

The Profile of Mood States (POMS) is a well-validated instrument for assessing emotional states that are transient and expected to respond to clinical intervention.¹⁹ It has been widely used to assess the effects of exercise interventions. We used the POMS-Brief version which consists of 30 single-word items rated on a 5-point scale to indicate recent mood in 6 dimensions: tension/anxiety, depression/dejection, anger/hostility, vigor/activity, fatigue/inertia, and confusion/bewilderment. A decreased total mood disturbance score denotes an improved emotional state (range 0-200). Prior studies of tai chi have reported improvement in mood, decrease in anxiety, and enhancement in vigor as measured by the POMS scale.²⁰

The Self-Efficacy-Barriers to Exercise Scale is a reliable and validated measure which assesses one's confidence to perform exercise 3 times a week for 20 minutes each in the face of different barriers (range 0-100). Items are scored from 0-10 (Not confident to Very confident).²¹

Biomarkers—B-type natriuretic peptide (BNP) was analyzed on whole blood collected in EDTA using a commercially available Biosite Triage BNP Test point-of-service meter (fluorescence immunoassay). Serum BNP >100 pg/ml supports a diagnosis of symptomatic heart failure.

Echocardiography—Serial echocardiographic studies were performed at baseline and at 12 weeks by a blinded assessor using a commercially available echocardiographic machine (GE Vivid 7). Assessments included mitral annular tissue Doppler measures, strain, strain rate, and flow propagation velocity. In particular, E/A (the ratio of mitral peak velocity of early filling to mitral peak velocity of late filling) and E/e' (the ratio of mitral peak velocity of early filling to early diastolic mitral annular velocity) were calculated to estimate degree of diastolic dysfunction. Image analysis was performed off-line using the Echopac digital system. Tapes were read by a single experienced cardiologist who was blinded to subject treatment assignment.

Cardiorespiratory assessments during exercise

At weeks 2 and 10 of training, all subjects underwent cardiorespiratory assessments for 5 minutes during each of three separate training phases. Mean VO_2 , respiratory rate and heart rate were assessed to provide a composite gauge of exercise intensity. In the tai chi group, VO_2 was assessed during warm-up, meditation, and tai chi movement phases. In the aerobics group, VO_2 was assessed during warm-up, cool-down and during the aerobic training phases. Gas exchange was assessed in-class at the community health facility using a MedGraphics ULTIMA CARDIO2 cart, and heart rate measurement was captured using a

Marquette Electronics (Milwaukee, Wisconsin) series 8500 Holter monitor, digitized at 128 Hz, and annotated using a MARS 8000 Holter scanner.

Statistical analysis

All statistical analyses were performed on an intention-to-treat basis. Two-sample Wilcoxon rank-sum tests were used to compare the distribution of change from baseline to 12 weeks between treatment and control groups for exercise and functional parameters, questionnaire scores, echocardiographic indices and BNP. Continuous data are summarized as mean (SD). Cardiorespiratory assessments during exercise are reported using descriptive statistics. Comparisons were also made between groups examining the pooled mean (not separated by phase or timepoint) for heart rate, percent maximal heart rate, respirations, oxygen consumption, and Borg rating using Wilcoxon-rank sum tests.

Results

Baseline characteristics

Characteristics of the 16 patients enrolled in the study are described in **Table 2**. Mean age ($\pm$ SD) of the study population was 66($\pm$ 12) years, and the distribution of New York Heart Association functional class (I, II, III) was 3, 9, and 4 patients, respectively. Based on echocardiographic indices, seven patients had mild diastolic dysfunction (abnormal relaxation), six patients had moderate dysfunction (pseudo-normalization), and three patients had severe dysfunction (restrictive filling); seven patients exhibited left ventricular hypertrophy. All patients were clinically euvolemic at baseline. The groups were similar with respect to demographics or co-morbidities except for physical activity and POMS score; members of the tai chi group reported more baseline activity and relatively worse moods. There were no differences in baseline exercise performance or quality-of-life scores.

Feasibility, adherence, and safety

We demonstrated feasibility of tai chi as an intervention for HFPEF. Patients were willing to be randomized. Mean class attendance rate was 89% for tai chi and 88% for aerobic exercise training. Data are unavailable with respect to specific frequency and duration of home practice. However, 7 out of 8 in the tai chi group and 4 out of 8 in the aerobics group self-reported compliance with home practice three times a week. No adverse events or hospitalizations occurred during class sessions or the study period. At a follow-up phone call conducted three months after the intervention ended, 6 out of 8 in the tai chi group reported continued practice of tai chi; two of these individuals reported starting aerobic training in addition to tai chi. Four out of 8 in the aerobics group reported continued aerobic training.

Change in clinical outcomes after 12 weeks

Tables 3, 4 and 5 present outcome measures at baseline and 12 weeks. Compared to those randomized to conventional aerobic exercise, subjects in tai chi showed no significant differences in peak VO_2 but relatively greater improvements in 6MW.

While both groups improved quality-of-life, there was no differential change between groups detected based upon MLHF score. However, the tai chi group showed improvements in the POMS-total mood disturbance and depression subscale.

There were increases in physical activity outside of classes as measured by the CHAMPS questionnaire in both groups, but no statistically significant difference between the groups. There were no significant changes in BNP in relation to exercise training. Echocardiographic indices of diastolic filling showed that E/e' improved after exercise in the aerobics group more so than tai chi, while left atrial size decreased in the tai chi group.

Characterization of tai chi and aerobic training intensity

Table 6 shows the mean values of cardiorespiratory data collected during three phases of both tai chi and aerobic exercise sessions. Mean heart rate and VO_2 were lower in tai chi. Respiratory rates were also slower in tai chi, particularly in the phase of training corresponding to meditation which deliberately incorporates slow, deep breathing.

Discussion

While HFPEF is common and associated with high morbidity and mortality, definitive treatment remains unclear. Exercise options that promote adherence are needed. Overall, this pilot study provides preliminary information regarding feasibility and potential safety of tai chi. Despite its relatively lower aerobic training intensity, tai chi may provide benefits that are similar to a typical conventional, community-based low-impact aerobics regimen in this population.

Within the context of this small study, we found that 6MW distance improved more significantly than with aerobic training. Likewise, depression scores decreased to a greater extent with tai chi. While preliminary, these findings are provocative. One possible physiological rationale is that as a training stimulus, tai chi places relatively more emphasis on skeletal muscle strengthening, stretching, and neuroregulatory enhancements that can translate into significant functional gains and which might be achieved rather efficiently using tai chi rather than conventional aerobic exercise techniques. While strength was not measured here, there are trials in the elderly that suggest that tai chi can enhance peripheral muscle strength (legs and hand grip), peripheral blood flow, and neuromuscular coordination (gross postural control and fine motor skills).^{9,11,37,39-40}

Whereas Kitzman, et al. showed benefit of 16 weeks of aerobic training for patients with HFPEF, related analyses attributed peripheral differences in skeletal muscle to be a primary determinant of these training benefits.⁵ Aerobic training is associated with important peripheral advantages, particularly in regard to increased endothelial health and improved vasodilatory and perfusion capacities. However, strength and neuroautonomic physiologic effects also play important roles. These may be adequately achieved by other non-conventional exercise training modes. Consistently, guidelines for systolic heart failure call for strength training as part of a composite exercise regimen.²²⁻²⁴ In addition, intrinsic respiratory limitations have been recognized as an important component of HF pathophysiology with bearing on exercise intolerance, well-being, and prognosis. Inspiratory muscle training may provide key benefits, including improved inspiratory muscle and peripheral strength, functional capacity, ventilatory efficiency, perception of dyspnea and quality of life.²⁵⁻²⁶ Tai chi constitutes a unique blend of these exercise training attributes that may potentially address aerobic, strength, and even respiratory aspects of HFPEF. Importantly, studies of tai chi in varied populations have suggested good adherence and significant patient well-being.¹¹

A related aspect of this study is that training intensity of tai chi appeared considerably lower than aerobic training while benefits were similar. Reduced oxygen consumption during tai chi training is likely related to the lower heart rate, since VO_2 is based, in part, on heart rate responses. However, reduced breathing rate during tai chi suggests fundamentally different training effects compared to aerobic exercise.

Implications bear not only on the physiological gains facilitated by training, but the behavioral advantages of a lower cardiorespiratory training burden. Prior literature shows that exercise adherence and efficacy is more likely to be achieved with a regimen that can provide effective low intensity options, particularly as exercise is initiated, but that can also

progress in intensity as tolerated or facilitate intermittent intervals of higher intensity.²⁷⁻³⁰ In this respect, tai chi, which is inherently less strenuous, but easily modified to tailor intensity, may directly address tolerability and accessibility, and thus, facilitate exercise adoption and maintenance long-term.

Safety implications may also be relevant. The slower heart rate and cardiovascular workload of tai chi as compared to aerobic exercise constitutes a more modest cardiovascular risk. The likelihood of significant adverse arrhythmia, ischemia, and/or other cardiovascular instability is proportionally reduced. Apparent safety with tai chi practice has been reported in prior trials in high-risk cardiovascular subjects,³¹⁻³³ as well as other populations, including the transitionally frail,³⁴ those with arthritis,³⁵⁻³⁶ and balance-impaired subjects with vestibular disease.³⁷ Tai chi has also been proposed to be particularly suitable in older age, and thus among patients particularly predisposed to HFPEF. Optimal HFPEF exercise therapy must therefore address the fundamental pathophysiology of the disease itself, as well as the context of frailty and age-related limitations that are inherently associated with the disease.

Key limitations of the study are the small sample size and single recruitment site potentially affecting overall generalizability. This study, however, was designed to be a pilot, assess feasibility and gather preliminary estimates for a future trial. Nonetheless, because of the small sample, the likelihood of spurious findings may increase. In particular, we found that E/e' improved after aerobics, suggesting that aerobic training facilitated improved lusitropic function. While prior studies suggest that training benefits in both heart failure with preserved ejection fraction and with left ventricular dysfunction are mediated primarily by peripheral physiological adaptations rather than intrinsic cardiac effects,²³ a recent trial by Edelmann did report improvements in diastolic function.³⁸ It is also noted that the aerobic exercise group did not significantly improve peak VO₂ after 12 weeks, despite our cardiorespiratory data suggesting that adequate training should have been achieved. Limitations in aerobic training efficacy in heart failure have been described, and it is possible that these are amplified in older adults, specifically with HFPEF with a typical community-based intervention.

Despite the prevalence of HFPEF, clinical studies in this population have been notoriously challenging as many confounding issues (e.g., chronic pulmonary disease, and normal age-related ventricular diastolic filling changes) complicate identification of an ideal study population. Albeit a small sample, our study included clinical, echocardiographic and serological parameters to assess patients with HFPEF. To our knowledge, this is the first study to demonstrate the applicability of tai chi to a HFPEF population and to characterize training intensity as compared to aerobic exercise in this population. In summary, our data suggest that tai chi may achieve exercise training benefits with improved 6MW that are similar to a typical community-based low-impact aerobic exercise in patients with HFPEF. Benefits were seen with tai chi at a lower training intensity that may potentially facilitate safety and longer-term exercise adherence. As heart failure is a pervasive and rapidly growing medical problem, our data provide intriguing rationale for further study of tai chi exercise in this cardiac population.

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Table 1

Description of the tai chi intervention

Week	Activities	Approx. Duration (min)
1	Introductory Session: Overview of Program	
	1. Tai Chi principles, philosophies	15
	2. Demonstration of Tai Chi form	10
	3. Expectations of participants	10
	4. Description of class format	5
	5. Participation in warm-up exercises	30
2-5	Warm-up Exercises (Repeated during all sessions)	
	1. Standing:	
	a) "Drumming the body"	6
	b) "Swinging to connect kidney and lungs"	3
	c) "Washing the body with qi"	3
	d) Standing meditation and breathing	3
	2. Sitting:	
	a) Neck/Shoulder stretches	6
	b) Arm/Leg stretches	3
	c) Sitting meditation and breathing	6
	Total Warm-up time	30
	Tai Chi Movements	
	1. "Raising the Power"	5-10
	2. "Withdraw and Push"	5 per side
	(Warm-up and Movements 1-2)	
	3. "Grasp Sparrows Tail"	5 per side
	4. "Brush Knee Twist Step"	5 per side
10-12	(Warm-up and Movements 1-4)	
	5. "Wave Hands Like Clouds"	5-10

Table 2

Baseline characteristics of the study sample

	Tai Chi (n=8)	Aerobic Exercise (n=8)
Demographic Factors:		
Age (years±SD)	68±11	63±11
Sex: Men	4(50)	4(50)
Race:		
Black	0(0)	3(37)
White	8(100)	5(62)
Clinical Classification:		
Body Weight (kg)	87±32	94±35
Body Mass Index (kg/m ²)	32±10	34±14
Systolic BP (mmHg)	135±10	134±19
Diastolic BP (mmHg)	74±10	68±11
Heart Rate (bpm)	64±10	68±11
NYHA Class I	1 (12)	2 (25)
Class II	4 (50)	5 (63)
Class III	3 (38)	1 (12)
Weekly caloric expenditure of reported activities (kcal/wk) **	2.4±1.9	1.3±2.3
Physical Capacity:		
Peak VO ₂ (ml/kg/min)	14.5±7	13.1±5
Peak RER	1.15±0.08	1.15±0.14
Exercise time (min)	7.2±6.3	6.6±2.8
6MW (m)	335.4±174	349.7±216
Medications:		
ACE inhibitor/ARB	6 (75)	4 (50)
Digoxin	0 (0)	0 (0)
Diuretics	6 (75)	6 (75)
Beta-blockers	6 (75)	5 (62)
Calcium antagonists	2 (25)	5 (62)
Nitrates	1 (12)	1 (12)
Self-Reported Co-Morbidities:		
Coronary artery disease	3(37)	3 (37)
Arrhythmia	2 (25)	3 (37)
Hypertension	5 (62)	7 (87)
Diabetes	2 (25)	1(12)
High cholesterol	4 (50)	4 (50)
Asthma	1 (12)	3 (37)
Anxiety	4 (50)	1(12)
Depression	3 (37)	3 (37)
Arthritis	2 (25)	3 (37)
Cancer	3 (37)	1(12)

	Tai Chi (n=8)	Aerobic Exercise (n=8)
Renal disease	3 (37)	3 (37)

Data are presented as mean±SD, or N (%)

**

As measured by the CHAMPS questionnaire

Table 3

Exercise and functional performance

	Tai Chi		Aerobic Exercise		P value [*]
	Baseline	12-Week	Baseline	12-Week	
Peak exercise (bike)					
Peak VO ₂ (ml/kg/min)	14.5±7	15.2±6	13.1±5	13.0±4	0.73
Exercise duration (min)	7.2±6	8.3±6	6.6±2	7.2±3	0.81
Heart rate (bpm)	122±29	116±25	119±22	118±24	0.95
Systolic BP (mm Hg)	174±15	172±30	198±30	171±28	0.18
Diastolic BP (mm Hg)	81±6	79±11	85±13	75±16	0.22
Respiratory exchange ratio	1.15±0.08	1.14±0.04	1.15±0.14	1.14±0.10	0.67
6-Minute Walk (m)	335.4±174	404.2±190	349.7±216	360.1 ±205	0.02
Time up and go (sec)	15.9±14	12.7±9	17.8±15	12.8±8	1

Data are presented as mean±SD

^{*} comparing the change scores between groups

Table 4

Quality of life, mood, self-efficacy

	Tai Chi		Aerobic Exercise		P value *
	Baseline	12 - Week	Baseline	12-Week	
Minnesota Living with Heart Failure Questionnaire total [†]	32.8±18	28.7±16	42.0±30	28.6±25	0.09
Profile of Mood States: Total Mood Disturbance [†]	20.0±21	7.8±8	5.2±15	5.2±15	0.13
Profile of Mood States: Depression [†]	4.0±2	2.3±2	1.3±2	3.0±3	0.05
Exercise Self-Efficacy	59.6±30	66.6±29	50.3±24	53±28	0.18

Data are presented as mean±SD

[†] lower score denotes improvement

* comparing the change scores between groups

Table 5

Echocardiography and BNP

	Tai Chi		Aerobic Exercise		P value [*]
	Baseline	12-Week	Baseline	12-Week	
Left ventricular ejection fraction (%)	62±9	62±9	65±8	64±7	0.48
Left atrial dimension (mm)	3.8±0.4	3.7±0.3	3.7±0.3	3.8±0.3	0.04
Left atrial volume (mL)	77±22	78±19	70±7	68±24	0.94
E/A ratio [†]	1.2±0.6	1.1±0.4	1.3±0.8	1.1±0.7	0.12
E/e' ratio ^{††}	14±4	13±5	17±4	14±4	0.01
B-type natriuretic peptide (ng/ml)	98±85	98±116	72±85	107±99	0.11

Data are presented as mean±SD

^{*} comparing the change scores between groups

[†] ratio of mitral peak velocity of early filling (E) to mitral peak velocity of late filling (A)

^{††} ratio of mitral peak velocity of early filling (E) to early diastolic mitral annular velocity (E')

Table 6

Cardiorespiratory measurements during tai chi and aerobic exercise training^{*}

Tai Chi	Heart Rate (bpm $\pm$ SD)		%Heart Rate _{max} (% $\pm$ SD)		Respiratory Rate (breaths per min $\pm$ SD)		Peak Oxygen Uptake (ml/kg/min $\pm$ SD)		Rate of Perceived Exertion ^{***} (Borg)	
	t ₁ ^{**}	t ₂ ^{**}	t ₁	t ₂	t ₁	t ₂	t ₁	t ₂	t ₁	t ₂
Warm up	72.8 $\pm$ 11	74.4 $\pm$ 12	62 $\pm$ 18	66 $\pm$ 14	25.2 $\pm$ 6	26.8 $\pm$ 8	6.4 $\pm$ 1.8	6.0 $\pm$ 1.3	2.6 $\pm$ 2	1.5 $\pm$ 1
Meditation	62.3 $\pm$ 6	62.1 $\pm$ 5	53 $\pm$ 13	56 $\pm$ 14	13.9 $\pm$ 6	13.1 $\pm$ 5	3.0 $\pm$ 1.0	2.8 $\pm$ 0.6	0.9 $\pm$ 1	0 $\pm$ 0
Movements	71.7 $\pm$ 8	70 $\pm$ 9	61 $\pm$ 16	62 $\pm$ 14	17.8 $\pm$ 7	16.5 $\pm$ 9	5.0 $\pm$ 0.9	4.2 $\pm$ 1.0	1.4 $\pm$ 2	1.6 $\pm$ 2
Aerobic Exercise										
Warm up	88.9 $\pm$ 16	96.2 $\pm$ 14	76 $\pm$ 14	83 $\pm$ 17	24.9 $\pm$ 8	32.1 $\pm$ 10	8.1 $\pm$ 3.8	9.4 $\pm$ 2.9	2.3 $\pm$ 1	2.1 $\pm$ 1
Aerobics	95.5 $\pm$ 14	104 $\pm$ 15	82 $\pm$ 11	90 $\pm$ 17	31.5 $\pm$ 7	35.0 $\pm$ 8	10.8 $\pm$ 3.9	12.0 $\pm$ 4.3	4.1 $\pm$ 2	3.5 $\pm$ 2
Cool Down	89.1 $\pm$ 12	91.3 $\pm$ 11	76 $\pm$ 12	79 $\pm$ 16	25.4 $\pm$ 6	25.3 $\pm$ 6	7.1 $\pm$ 2.9	7.0 $\pm$ 2.2	3.1 $\pm$ 1	2.1 $\pm$ 1

^{*} p-value <0.01 for comparison between groups of each variable mean (heart rate, % maximal heart rate, respiratory rate, V02, RPE). Mean values (combining each phase) not shown

^{**} t1= week 2, t2=week 10

^{***} Measuring overall perceived exertion (scale 0-10)