Cardiorespiratory Effects of Tai Chi Versus Walking: Exploratory Data from the LEAP Trial

Stephen A. Maris, PhD[1,2,3], Yan Ma, MD[4,5], Daniel Litrownik, BA[1,5], Marilyn L. Moy, MD[6], Roger B. Davis, ScD[1], Peter M. Wayne, PhD[5], Gloria Y. Yeh, MD[1,5]

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ABSTRACT

Background: Tai Chi (TC), a mind-body exercise, may be a potential exercise maintenance strategy for patients with chronic obstructive pulmonary disease (COPD) after pulmonary rehabilitation. We sought to characterize the acute cardiorespiratory response during TC versus walking in patients with COPD after a 24-week intervention.

Methods: Cardiorespiratory data were available on 26 adults with COPD (46% female, 54% GOLD stage III–IV) randomized to TC (n = 19) or group walking (n = 7). At 24 weeks, we examined between-groups standard cardiorespiratory measures (heart rate (HR), oxygen consumption (VO_2), expired carbon dioxide (VCO_2), respiratory rate (RR), and ventilation (V_E)) during a multiphase in-class characterization protocol. Continuous HR data during resting and exercise phases were analyzed for time- and frequency-domain HR variability (HRV) indices.

Results: At 24 weeks, during exercise phases, those in TC exhibited a mean HR of 80 ± 15 $b \cdot min^{-1}$, RR of 16.5 ± 4 $breaths \cdot min^{-1}$, and VO_2 of 434.8 ± 146.5 $mL \cdot min^{-1}$; and in walking 95.7 ± 9.2 $b \cdot min^{-1}$, 26.2 ± 8 $breaths \cdot min^{-1}$, and 901.3 ± 261.2 $mL \cdot min^{-1}$, respectively ($P < 0.05$). Overall, TC was less strenuous with lower HR, VO_2, VCO_2, RR, and V_E ($P < 0.05$). At rest, TC demonstrated more favorable respiratory efficiency (V_E/VCO_2; 35.53 ± 5.65 versus 41.07 ± 5.21, $P < 0.05$). During the postexercise recovery phase, time-domain HRV indices decreased after walking (e.g., pNN20: 35.7 ± 24.1 baseline, 10.3 ± 9.5 postwalk; pNN50: 20.9 ± 18.5 baseline, 3.9 ± 3.7 postwalk), while they remained relatively unchanged after TC. Frequency-domain HRV measures suggested greater total power (TP) across all phases of TC versus walking, particularly during meditation ($P < 0.05$ for LnTP).

Conclusion: Preliminary data support that TC may be associated with improved pulmonary efficiency and reduced rapid shallow breathing compared with walking and be a viable exercise maintenance option after pulmonary rehabilitation.

Keywords: chronic obstructive pulmonary disease, lifestyle intervention, cardiorespiratory physiology

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a major health concern and the fourth leading cause of death worldwide (1–4). The disease is characterized by chronic airflow limitation and acute exacerbations that lead to the development of progressive dyspnea and associated physical

[1]Division of General Medicine, Department of Medicine, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA 02115, USA
[2]Department of Exercise Science and Athletic Training, Springfield College, Springfield, MA 01109, USA
[3]Division of Endocrinology, Diabetes, and Hypertension, Brigham and Women's Hospital and Harvard Medical School, Boston, MA 02115, USA
[4]Division of Interdisciplinary Medicine and Biotechnology, Department of Medicine, Beth Israel Deaconess Medical Center, and Harvard Medical School, Boston, MA 02115, USA
[5]Osher Center for Integrative Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, MA 02115, USA
[6]Pulmonary and Critical Care Medicine Section, Department of Medicine, Veterans Administration Boston Healthcare System and Harvard Medical School, Boston, MA 02115, USA

Address for correspondence: Stephen A Maris, PhD, Department of Exercise Science and Athletic Training, Springfield College, 263 Alden Street, Springfield, MA 01109; (401)742-0074; e-mail: smaris@springfieldcollege.edu.

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deconditioning, disability, and physical inactivity (5–7). Together, these contribute to a marked reduction in exercise capacity and progressive limitations in cardiorespiratory function characterized by detriments in ventilation (caused by airway obstruction), gas exchange (loss in alveolar function), more rapid shallow breathing, and a reduction in ventilatory efficiency (higher ratio of ventilation to carbon dioxide expiration, VE/VCO_2) (8–10). Mainstay treatment and management options for COPD to target these changes include pharmacotherapy, preventive care (e.g., smoking cessation), and increased physical activity (6,8,11,12).

Facilitating an exercise regimen is the cornerstone of formal conventional pulmonary rehabilitation (PR) programs (12–14), which are shown to improve exercise capacity, shortness of breath, health-related quality of life, and reduce COPD hospitalizations in the short term, (5,15,16). Unfortunately, maintenance of exercise after PR is a problem, as various in-hospital and home-based strategies have been studied with mixed results. Walking is often included in standard post-PR exercise prescriptions (13,16). In this context, we recently reported primary data from the long-term exercise after PR (LEAP) study that Tai Chi (TC), a mind-body exercise, may be a promising and feasible option to maintain functional benefits after PR with impact on exercise capacity and quality-of-life domains compared with usual care that is also supported by others (16–21). In exploratory analyses, the TC group had better adherence than a walking group, and we reported potential trends toward an increase in 6-minute walk distance at 24 weeks with TC that were not seen in the usual care group.

In this current analysis, we aimed to characterize and explore the acute cardiorespiratory physiologic response during TC and walking after 24 weeks of training to provide insight into these 2 exercise modalities as options after PR for patients with COPD. We hypothesized that there may be measurable differences in cardiorespiratory response to TC versus walking that may inform mechanistic understanding of TC's effects and the generation of further explanatory hypotheses regarding potential impact on cardiorespiratory function in COPD.

METHODS

Study Design

The parent study (LEAP) was a 3-arm pilot randomized controlled trial comparing a 24-week group TC class versus group walking class versus usual care (2:1:2) with detailed methods described elsewhere (Figure 1) (16,17). All study procedures were approved by or ceded review to the Committee on Clinical Investigations at Beth Israel Deaconess Medical Center and the VA Boston Healthcare System. Data collection was conducted by study staff, physicians, or technicians who were blinded to treatment assignment.

Participants

Following institutional review board approval and signing of informed consent, participants were screened for inclusion and exclusion criteria. In brief, inclusion criteria included (a) COPD defined as $FEV_1/FVC < 0.70$ or chest computed tomography (CT) evidence of emphysema; (b) age > 40 years; (c) Global Obstructive Lung Disease (GOLD) stages 1, 2, 3, or 4; and (d) completion of standard PR of at least 8 weeks duration within 24 weeks prior to study enrollment. Exclusion criteria included (a) COPD exacerbation requiring steroids, antibiotics, emergency department (ED) visit or hospitalization within the past 2 weeks; (b) hypoxemia on walk test; (c) inability to ambulate due to vascular or other neuromuscular conditions; (d) clinical signs of unstable cardiovascular disease; (e) severe cognitive dysfunction; (f) non-English speaking; (g) current regular practice of TC; (h) current diagnosis of lung cancer or treated for lung cancer within the past 5 years; or (i) unstable/untreated mental health issue (22). Use of supplemental oxygen was an additional exclusion criterion for this analysis.

Intervention Protocol(s)

The TC intervention was designed for older, deconditioned patients with dyspnea and exercise intolerance and based on a protocol used in prior studies of COPD and chronic heart failure (10,16,23–25). The intervention comprises 5 essential TC movements from the traditional Cheng Man-Ch'ing's Yang-style short form that includes the movements of "raising the power," "withdraw and push," "grasp the sparrow's tail," "brush knee twist step," and "cloud hands" (16,17). Each movement is practiced in cyclic repetition and emphasizes mindfulness in movement, relaxation, and breath awareness. Each TC session also included traditional TC warmup exercises (including "swinging and drumming," standing meditation, and seated meditation) and a cooldown that incorporated self-massage (16,23,26). More information on the TC exercise program can be found in our previously published methodology paper (16).

The group walking classes were matched to the TC classes for duration and frequency. Each group walking session began with 5 minutes of lower extremity warmup stretching and flexibility exercises and ended with a brief cooldown. Exercise intensity of the walking class was approximated to a low-moderate intensity TC class through monitoring of heart rate (HR) and the Borg breathlessness scale to reach approximately 60% of maximum HR during walking (16,17).

Characterization of Acute Cardiorespiratory Physiology

To characterize the acute physiology and describe differences between TC and walking, we collected cardiorespiratory data at a single in-class multiphased exercise session at 24 weeks in a subset of participants in the 2 exercise groups. Both groups participated in 5 exercise phases that each lasted 5 minutes, plus 2-minute resting periods before and after the exercise phases, and a 2-minute postexercise cooldown for a total average protocol testing time of 30 minutes. For TC, the 5 phases included P1 = swinging and drumming (TC

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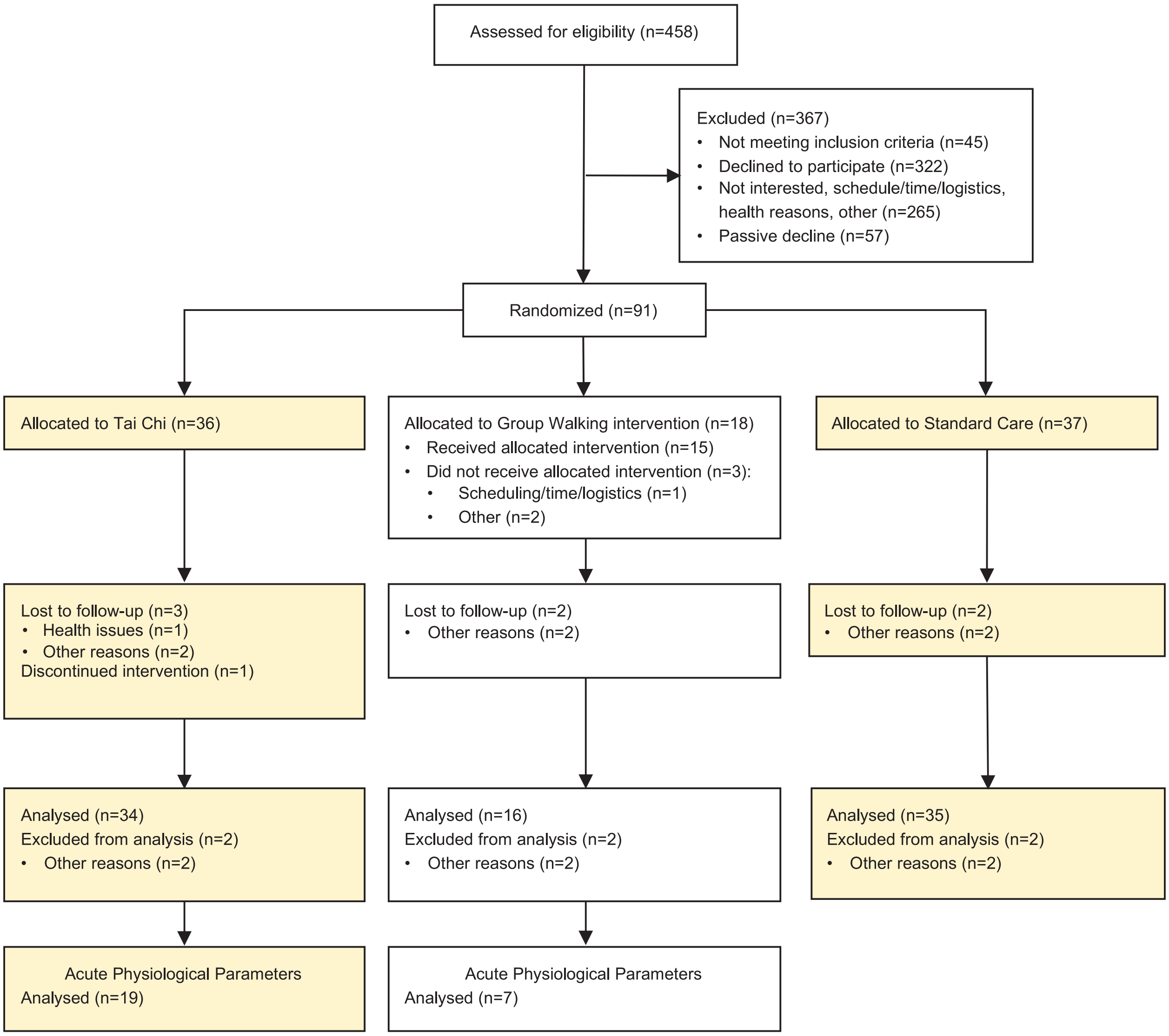

FIGURE 1. CONSORT diagram: Flow of participants throughout the LEAP study.

warmup exercise), P2 = TC standing meditation, P3 = TC seated meditation, P4 = raising the power (TC movement 1), and P5 = withdraw and push (TC movement 2). For the walking group, the 5 phases included P1 = gentle stretching (warmup exercise), and P2–P5 = walking, where participants were told to maintain the same pace and intensity (targeting 60% max HR or 3–5 on Borg Scale of Perceived Exertion) throughout each of the 4 walking sessions.

To obtain exploratory cardiorespiratory exercise parameters, we used a portable metabolic cart (VIASYS Oxycon, Conshohocken, PA) with a fitted face mask and pulse oximeter that was worn throughout the acute characterization protocol. Measures included oxygen consumption (VO_2), end-tidal carbon dioxide (VCO_2), HR, respiratory rate (RR), ventilation (VE), metabolic equivalents (METs), and ventilatory efficiency (VE/VCO_2). These measurements were assessed throughout the 5 phases of each exercise session (breath-by-breath analyses).

Continuous channel electrocardiogram (ECG) signals suitable for analysis of HR variability (HRV) were also obtained during the acute characterization protocol using an Embletta GOLD device (EMBLA, Broomfield, CO) attached to the chest via a respiratory effort belt (27). Measures of HRV to quantify cardiac autonomic regulation followed recommendations of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology and included both standard time- and frequency-domain measures (27,28). Time-domain indices included HR, the root mean square of successive differences (RMSSD), the proportion of the number of pairs of successive NN (R-R) intervals that differs by more than 20 seconds (pNN20) and 50 seconds (pNN50). Frequency-domain indices included total power (TP), low-frequency (LF, 0.04–0.15 Hz) power, and high-frequency (HF, 0.15–0.4 Hz) power. Given the differences in respiration among the 2 groups, and the well-acknowledged impact of respiration on frequency-domain power distribution (22,28–30), our primary interest was TP, which reflects overall autonomic activity (total variance) (31–33). Together, these measures provide a reasonable estimation of HR dynamics (34–36).

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Statistical Analyses

Cardiorespiratory data and frequency-domain HRV measures were log transformed to account for differences in variance between the exercise groups. We used a repeated-measures analysis of variance (ANOVA) with a Bonferroni adjustment to account for the multiple comparisons to characterize each of the cardiorespiratory variables during the TC and walking exercise. All data are reported in raw measurements for ease of translation; however, the *P* values for cardiorespiratory and frequency-domain HRV measures represent comparisons after log transformation. All analyses were conducted with STATA (Version 15.1) and results are presented as means ± standard error.

RESULTS

From the larger randomized control trial (RCT), including all available cardiorespiratory data in those compliant with classes at 24 weeks (n = 37) and after excluding those on supplemental oxygen that precluded cardiorespiratory measurement, other technical issues (metabolic cart failure and repair), or those unable to wear the face mask (n = 11), data were available in 26 participants (19 in TC, 7 in walking). Table 1 reports baseline demographic and clinical characteristics of the sample. Across all exercise phases, TC was characterized by a lower HR, VO_2, VCO_2, RR, and VE than walking (Figures 2A–F). Tai Chi exercise was characterized by a reduced VO_2 during P2–P4 (374 ± 184 versus 1110 ± 291 mL · min^{-1}, 317 ± 161 versus 1026 ± 278 mL · min^{-1}, and 438 ± 201 versus 836 ± 470 mL · min^{-1}, $P < 0.05$, respectively) and the postexercise recovery period (316 ± 183 versus 750 ± 516 mL · min^{-1}) when compared with walking (Figure 2A, $P < 0.05$), accompanied by a similar reduced VCO_2 during P2–P4 (338 ± 161 versus 1014 ± 307 mL · min^{-1}, 302 ± 161 versus 922 ± 283 mL · min^{-1}, and 386 ± 174 versus 695 ± 439 mL · min^{-1}, respectively) when compared with walking (Figure 2B, $P < 0.05$).

TABLE 1. Baseline demographic and clinical severity data.

	Tai Chi (N = 19)	Walking (N = 7)
	N (%)	N (%)
Sex		
Female	9 (47.4)	3 (42.9)
Male	10 (52.6)	4 (57.1)
Race		
White	14 (73.7)	3 (42.9)
Black	3 (15.8)	1 (14.3)
Hispanic	1 (5.3)	1 (14.3)
Other	1 (5.3)	2 (28.6)
Annual income		
<$35,000	9 (47.4)	3 (42.9)
≥$35,000	10 (52.6)	4 (57.1)
Regular oxygen use (yes)	7 (36.8)	1 (14.3)
Current smoking status		
Currently smoking	2 (11.1)	1 (14.3)
Not smoking	16 (88.9)	6 (85.7)
GOLD Stage		
GOLD Stage I–II	7 (36.8)	5 (71.4)
GOLD Stage III–IV	12 (63.2)	2 (28.6)

GOLD = Global Obstructive Lung Disease

Respiratory rate was lower in TC versus walking during P2–P5 (average across exercise sessions: 16.5 ± 4 versus 26.3 ± 8 breaths · min^{-1}) and during the recovery phase (18.5 ± 8 versus 27.6 ± 8 breaths · min^{-1}) following activity (Figure 2C, $P < 0.05$). Tai Chi elicited a lower TV during P2 and P3 (763 ± 339 versus 1346 ± 528 mL · min^{-1}, 824 ± 382 versus 1267 ± 429 mL · min^{-1}, respectively) when compared with walking (Figure 2D, $P < 0.05$) and a lower VE in P2–P4 (11.8 ± 5 versus 35 ± 13 mL · min^{-1}, 10.5 ± 4 versus 31.7 ± 13 mL · min^{-1}, 12.8 ± 4 versus 26.8 ± 15 mL · min^{-1}, $P < 0.05$, respectively) and during postexercise recovery (10.7 ± 5 versus 25.8 ± 18 mL · min^{-1}) when compared with walking (Figure 2E, $P < 0.05$). Here, VE/VCO_2 was lower in TC versus walking during P5 (33.6 ± 6 versus 42.1 ± 9.9, $P < 0.05$) of the exercise session (Figure 2F).

Following the 24-week intervention period and at the start of the acute testing protocol (at rest), those in the TC group exhibited a greater pulmonary efficiency than walking. Pulmonary efficiency was assessed by the VE/VCO_2 ratio (35.5 ± 5.65 versus 41.1 ± 5.21, $P < 0.05$) and was accompanied by a lower respiratory rate (12.7 ± 4.0 versus 17.1 ± 5.2 breaths · min^{-1}, $P < 0.05$) when compared with the walking group.

A reduced mean HR was observed in the TC group versus walking throughout the entire exercise period (Figure 3A, $P < 0.05$). Traditional time-domain HRV measures showed a lower pNN20 in TC during P2 (20.3 ± 15.86 versus 39.8 ± 26.4, $P < 0.05$); however, during the recovery period, TC had an increased pNN20 compared with walking (25.8 ± 17.3 versus 10.3 ± 9.5, Figure 3B, $P < 0.05$). This significant increase in pNN20 was accompanied by an increased pNN50 (10 ± 9.3 versus 3.9 ± 3.72, Figure 3C, $P < 0.05$) and a trend suggesting increased RMSSD (Figure 3D, $P = 0.09$) postexercise. In addition, pNN50 was lower in TC during P2 and P3 meditation phases (7.5 ± 9.7 versus 22.7 ± 19.5, 8.55 ± 8.8 versus 21.2 ± 19.2, both $P < 0.05$) when compared with walking (Figure 3B, $P < 0.05$). Frequency-domain HRV measures suggested greater TP across all phases of TC versus walking, particularly during P2 and P3 (TP of 188,165.3 ± 75,757.6 versus 98,646.8 ± 29,656, TP of 192,035.1 ± 92,015 versus 105,636.3 ± 28,298.2, Figure 3F, both $P < 0.05$ for LnTP). Postexercise, TC also demonstrated trends toward higher HF power (Figure 3E, $P = 0.11$ for LnHF).

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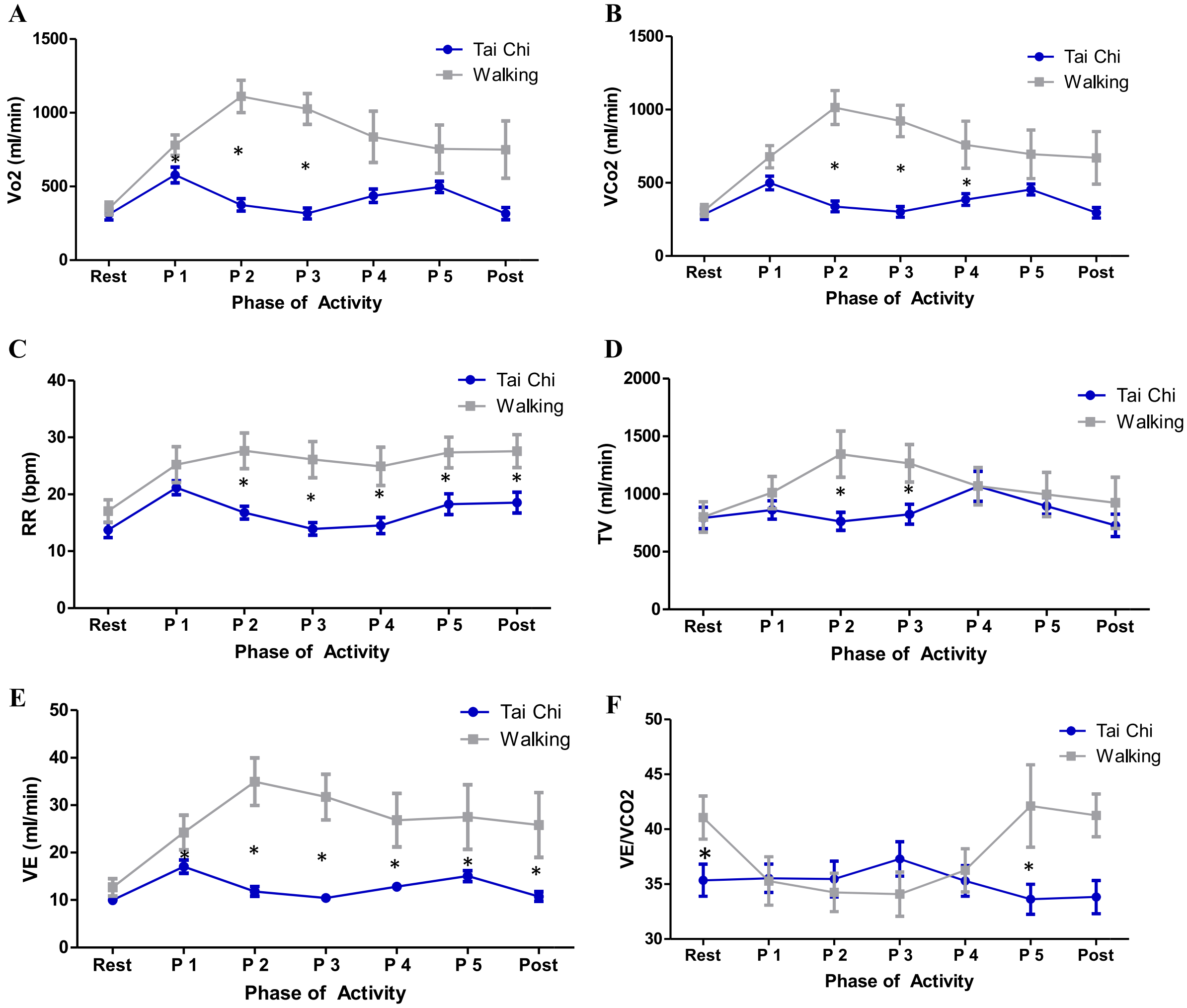

FIGURE 2. Characterization of the phases of Tai Chi (TC) versus walking in standard cardiorespiratory exercise parameters following the 24-week Intervention in (A) oxygen consumption (VO_2), (B) carbon dioxide expired (VCO_2), (C) respiratory rate (RR), (D) tidal volume (TV), (E) minute ventilation (V_E), and (F) ventilation/carbon dioxide expired (VE/VCO_2). *$P < 0.05$, P1 = swinging and drumming, P2 = TC standing meditation, P3 = seated breathing meditation, P4 = raising the power, and P5 = withdraw and push. Data are raw means ± SEM. P values represent comparisons after log transformation. All analyses include a Bonferroni adjustment to account for multiple comparisons.

DISCUSSION

Based on measured oxygen consumption during the exercise phases, the TC group was characterized as low-intensity aerobic exercise (~1.3–1.7 METs), and the walking group was low-moderate intensity (~3.4–4.5 METs). Similarly, mean HRs and RRs illustrate that the TC group was less intense than walking. Prior literature has reported TC intervention range of 1.5–4.0 METs (37,38) which can have significant clinical implications in exercise programming. For example, activities that range between 1.5 and 4.0 METS are appropriate exercise intensities to begin a program in populations that exhibit characteristics of chronic disability, such as COPD (37,38).

In this analysis, we found that, at 24 weeks, participants in TC, at rest prior to the exercise testing phases, had a more favorable VE/VCO_2 ratio and reduced RR when compared with those in the walking group. Since it is not well understood whether the metabolic pathways required of walking versus TC are comparable, comparisons of gas exchange and ventilatory responses between the 2 activities should be interpreted with caution. However, one potential hypothesis is that 24 weeks of TC training may result in improved pulmonary efficiency and reduced rapid shallow breathing (39,40). Whether these improvements may lead to improvements in clinical outcomes in those with COPD requires future investigation. While exercise studies in COPD have typically not shown changes in resting lung function, some types of exercise have reduced exercise-induced dynamic hyperinflation (41,42). Future work may further examine indices of lung function both at rest and with TC exercise.

Examining the different TC phases may provide further insights into important elements of the exercise. For example, phases 2 and 3 of the TC session (standing and seated meditation, respectively) emphasized mindful awareness and imagery techniques that demonstrated a marked decrease in VO_2, VCO_2, and HR. These reductions were accompanied

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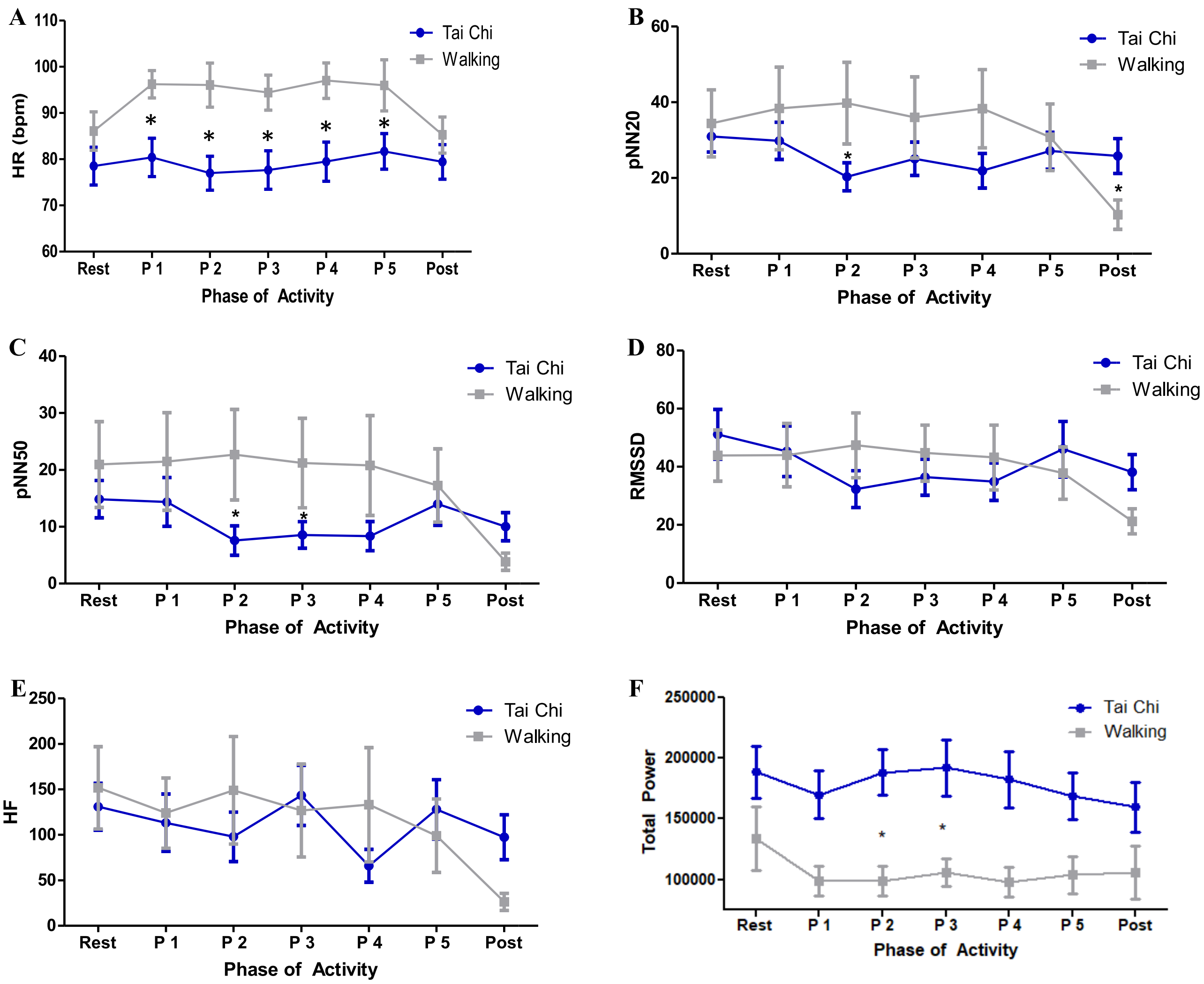

FIGURE 3. Characterization of the phases of Tai Chi (TC) versus walking in indices of heart rate variability following the 24-week intervention in (A) mean heart rate, (B) pNN20, (C) pNN50, (D) RMSSD, (E) HF, and (F) TP. *$P < 0.05$, P1 = swinging and drumming, P2 = TC standing meditation, P3 = seated breathing meditation, P4 = raising the power, and P5 = withdraw and push. Data are raw means ± SEM. P values represent comparisons after log transformation only for frequency domain measures. All analyses include a Bonferroni adjustment to account for multiple comparisons.

by decreased HRV values for pNN20 and pNN50. Several studies have reported the positive correlation between mean heartbeat intervals and various time-domain indices of HRV in cardiopulmonary diseased populations (43–45). Thus, the observed lower values in time-domain measures are likely to be associated with lower HR in the TC meditation phases.

We observed that postexercise HRV indices decreased after walking, with the time- and frequency-domain measures indicating possibly decreased vagal or activated sympathetic tone. These observations agree with prior studies that describe sympathetic activation remaining high despite the rapid reactivation of cardiac parasympathetic drive following termination of exercise (46–49). On the contrary, in the novel findings presented here, those HRV measures remained relatively unchanged during TC sessions and in the acute recovery phase after TC, suggesting that TC may be different for sympathetic nervous system activation and recovery.

From the frequency domain, we observed higher TP in the TC group than the walking group with significant differences during the more meditative sessions P2 and P3. Total power of HRV reflects the level of autonomic nervous system activity (both parasympathetic and sympathetic) or the overall autonomic regulation (50,51). Decreased TP is observed with age, with disease, and in individuals under chronic stress. Lower TP is associated with negative physical and psychological distress (52,53). Meanwhile, regular physical activity allows maintenance of a higher TP, and elite athletes have much higher TP/SDNN than nonathletes (52,53). We acknowledge that multiple factors may contribute to the observed differences in individual HRV indices, including respiration, changes in HR during the different phases, and level of physical and psychological distress. However, collectively, these results support that TC may regulate/modulate the autonomic nervous system with less strenuous physical exercise which may be particularly

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appropriate for patients with low exercise tolerance (e.g., COPD, HF). Future research may further delineate effects of the TC exercises used in this study along a spectrum of more static and more dynamic mind-body exercises and allow better tailoring of TC interventions to certain populations.

Studies have suggested that TC is relatively safe in chronic disease populations with few reported serious adverse events (23). Others have reported that low-intensity exercise is associated with a reduced fall risk during the activity and can positively impact fall risk long-term (12,21). Some literature has hypothesized that higher intensity exercise may adversely affect adherence to exercise interventions in deconditioned populations with chronic disease and that more accessible alternatives should be investigated (21). The lower intensity of TC suggests that this exercise program may be a feasible option in COPD populations with minimal risk (18). Studies have reported good adherence with TC (16,17). We previously reported better adherence (83% versus 65%) in TC versus group walking in this study (17).

Limitations of this study include our relatively small sample size and the cross-sectional nature of the data. These data could be confounded by longitudinal variables such as physical activity levels and program adherence. For example, as noted above, we reported better exercise class attendance in the TC versus walking groups in the parent sample (17). Thus, results of this analysis are mainly descriptive and hypothesis generating. Furthermore, given the difference in group sizes, we did not compare the raw measurements between groups but used logarithmic transformation to minimize variance. Another limitation is that we could not account for differences in initial PR programs before the study; however, there were no significant differences at baseline in clinical severity between our study groups based on the PR program attended (16,17). Lastly, given practical limitations of study conduct, we excluded certain populations (e.g., those who were non-English speaking and those with cognitive impairment) who could otherwise benefit from exercise interventions.

We acknowledge the importance of breathing control (e.g., paced breathing or slow breathing) in the accurate interpretation of HRV data (41–43). Given the population and the nature of the 2 interventions, controlled breathing was not a component of the current study. Therefore, while we have presented between-groups comparisons, to avoid overinterpretation, we primarily focus our discussion on the trends within each intervention group.

In summary, our preliminary results support that TC, as a lower-intensity meditative exercise that cultivates breath awareness, may be associated with a favorable ventilatory efficiency and reduced rapid shallow breathing. These might be considered mechanistic processes that can inform improvements in cardiorespiratory function and health-related quality of life in this population. Tai Chi may also beneficially modulate the autonomic nervous system. Overall, TC exercise might be considered a movement-based, mind-body intervention tool in COPD populations, but further investigation is warranted.

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