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Long-term Exercise After Pulmonary Rehabilitation (LEAP): design and rationale of a randomized controlled trial of Tai Chi

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Abstract

Background—Persons with chronic obstructive pulmonary disease (COPD) have reduced exercise capacity and levels of physical activity. Supervised, facility-based pulmonary rehabilitation programs improve exercise capacity and reduce dyspnea, but novel long-term

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Trial Registration

This trial is registered in Clinical Trials.gov, with the ID number of NCT01998724.

Trial status

This study is currently open and in active enrollment.

Competing interests

Peter Wayne is the founder and sole owner of the Tree of Life Tai Chi Center. Peter Wayne's interests were reviewed and are managed by the Brigham and Women's Hospital and Partners HealthCare in accordance with their conflict of interest policy.

Authors' contributions

MM and GY conceived of the study, led its design and coordination, and drafted the manuscript. PW participated in study design and coordination and assisted in drafting the manuscript. DL participated in study coordination and assisted in editing the manuscript. DB and EK participated in the design of the study and assisted in coordination. RD participated in design of the study and development of the statistical analysis plan. All authors have read and approved the final manuscript.

strategies are needed to maintain the benefits gained. Mind-body modalities such as Tai Chi which combine aerobic activity, coordination of breathing, and cognitive techniques that alleviate the physical inactivity, dyspnea, and anxiety and depression that are the hallmarks of COPD are promising strategies.

Methods/Design—We have designed a randomized controlled study to examine whether Tai Chi will maintain exercise capacity in persons with COPD who have recently completed a supervised pulmonary rehabilitation program, compared to standard care. The primary outcome is 6-minute walk test distance at 6 months. Secondary outcomes include health-related quality of life, dyspnea, mood, occurrence of acute exacerbations, engagement in physical activity, exercise self-efficacy, and exercise adherence. Simultaneously, we are conducting a pilot study of group walking. We will enroll 90 persons who will be randomized to one of 3 arms in a 2:2:1 ratio: Tai Chi, standard care, or group-based walking.

Discussion—The **L**ong-term **E**xercise **A**fter **P**ulmonary Rehabilitation (LEAP) study is a novel and clinically relevant trial. We will enroll a well-characterized cohort of persons with COPD and will comprehensively assess physiological and psychosocial outcomes. Results of this study will provide the evidence base for persons with COPD to engage in Tai Chi as a low-cost, long-term modality to sustain physical activity in persons who have completed a standard short-term pulmonary rehabilitation program.

Keywords

Pulmonary rehabilitation; exercise; physical activity; mind-body therapies; chronic obstructive pulmonary disease

Introduction

Burden and clinical course of COPD

Chronic obstructive pulmonary disease (COPD) is projected to become the third leading cause of death in the world by 2020 [1]. In 2000, COPD was the only major disease among the top ten to increase in prevalence [2, 3]. More than 1.5 million emergency room visits, 726,000 hospitalizations, and 119,000 deaths were attributed to COPD, with costs estimated at more than $24 billion yearly [4]. Shortness of breath leads to physical inactivity, deconditioning, and significant functional disability [5]. Anxiety and depression are salient comorbidities [6,7]. The clinical course is characterized by acute exacerbations (AEs), periods of worsening that require treatment with antibiotics and/or systemic corticosteroids [8]. AEs result in worse health-related quality of life (HRQL), more rapid decline in forced expiratory volume in one second (FEV_1), and higher mortality [9, 10]. AEs contribute to 31–68% of the $6.5 billion/year cost of health care for COPD patients in the United States [11].

Importance of exercise and physical activity in COPD

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines recommend regular physical activity (PA) for all patients with stable COPD [5]. PA is an integral component of COPD self-management programs [12]. Exercise capacity, measured by in-clinic tests such as the 6-minute walk test (6MWT), is a significant predictor of mortality in COPD [13,14]. In addition, PA directly measured in the field is significantly reduced, even

at the earliest stages of disease [15–17]. Adjusting for % predicted FEV_1, higher levels of PA are associated with better functional status, fewer AEs and COPD-related hospital admissions, and lower mortality [18–23]. Regular PA may be a modifiable lifestyle behavior that decreases COPD morbidity and mortality. COPD is also associated with a high prevalence of cardiovascular and oncologic comorbidities [24]. PA may also modify risk of these comorbid conditions.

Pulmonary rehabilitation and need for maintenance exercise interventions in COPD

The current standard of care to promote PA can be broadly separated into (1) counseling and (2) exercise referral [25]. Brief advice from a healthcare provider to exercise has a moderate short-term effect [26]. Supervised pulmonary rehabilitation (PR) programs clearly improve exercise capacity, decrease breathlessness, and improve HRQL in COPD [27,28]. PR also reduces inpatient hospital days related to COPD and reduces health care costs [27–29].

Despite the initial improvements, the benefits diminish to pre-intervention levels within 6–12 months of program completion if patients do not continue to exercise [30–34]. Currently, there is no standard of care for patients to maintain an exercise regimen in the post-rehabilitation period. Studies of exercise maintenance programs, combining supervised exercise classes with unsupervised home exercise, support groups, and/or telephone contact with a healthcare professional, have shown mixed results [34–40]. Non-adherence to the maintenance home exercise prescription is one key factor associated with waning benefits [31–33].

Novel strategies to maintain the benefits of PR over the long-term are needed. Long-term interventions would ideally be ones that: (1) are multidisciplinary, (2) patients can perform at home, (3) do not require equipment, and (4) are low cost.

Tai Chi in COPD

With its origins in traditional Chinese medicine and martial arts, Tai Chi (also referred to as tai chi chuan or taijiquan), is a gentle, conditioning exercise that coordinates breathing with physical movements, and meditative attention [41–43]. It employs detailed regimens of flowing movements, with an emphasis on breathing techniques, balance, and weight shifting [41–43]. The majority of studies report Tai Chi exercise intensity at about 3.5 METS (low-moderate intensity aerobic activity) [44,45]. This approximates the intensity of moderate-paced walking (about 3 miles per hour on level ground) [44–49]. Tai Chi is distinguishable from conventional exercises in that it incorporates cognitive components, including heightened somatic awareness, focused mental attention, and imagery [41–43].

The general cardiopulmonary benefits of Tai Chi include improved peak oxygen consumption, exercise endurance, ventilatory capacity, heart rate variability, decreased blood pressure, and adrenergic tone [50–62]. Tai Chi is safe in patients with chronic diseases, including COPD, as well as frail adults [63]. Tai Chi is relatively low-cost, uses no special equipment, and requires minimal space [64]--all characteristics that foster long-term adherence. Many clinical and community-based studies report higher adherence to Tai Chi than the comparison group or other exercise [51,52,58].

In persons with COPD, preliminary data support Tai Chi's feasibility, safety, and efficacy [65–67]. The low impact and adaptable movements and postures make Tai Chi particularly attractive for persons with COPD [68]. Decreases in dyspnea were observed after 3 months of Tai Chi versus usual care [69]. Yeh et al. demonstrated in a pilot RCT in patients with moderate-severe COPD trends toward improvement in 6MWT distance, depression scores, dyspnea, and functional residual capacity after 3 months of Tai Chi versus usual care [70]. Qualitative data based on structured interviews suggest that these patients found the Tai Chi program to be enjoyable, it promoted exercise self-efficacy, and that participants planned to continue Tai Chi after the study ended [70]. These studies have led to the conclusion that Tai Chi could be considered part of a comprehensive interdisciplinary PR program [71].

To the best of our knowledge, there have been no studies examining the role of Tai Chi to maintain benefits gained after completion of a conventional supervised PR program. We hypothesize that Tai Chi may be effective in maintaining exercise and PA in those who have completed a PR program. Tai Chi exercise comprehensively integrates three key elements of supervised PR programs, and has features that can promote long-term adherence (Figure 1).

Key Element 1: Physical Activity and Exercise—Tai Chi exercise combines mild-moderate intensity aerobic activity, core strength training, lower extremity and unsupported upper extremity training (e.g. having the arms work against gravity), each of which has been shown to benefit patients with COPD. Tai Chi places emphasis on unsupported upper extremity exercise which is an effective way to train COPD patients in activities similar to those required for daily living [72].

Key Element 2: Dyspnea Management—Tai Chi includes breathing techniques that target a deepening and slowing of respiration that can potentially decrease dynamic inflation, minimize the dead space ventilation of rapid shallow breathing patterns commonly seen in COPD, increase pulmonary muscle strength and endurance, improve chest wall mechanics, and overall breathing efficiency [73]. Tai Chi breathing is taught and integrated within a broad context of relaxation, self-awareness, imagery and principles of structure and posture, which may make it more accessible to patients and facilitate adoption during activities of daily life.

Key Element 3: Anxiety and Depression Management—Patients with COPD are at high risk of developing symptoms of anxiety and depression [6,7]. Anxiety over dyspnea-producing activities is common and may promote maladaptive sedentary lifestyles [74,75]. Inherent in mind-body exercises such as Tai Chi is training in mindfulness, stress-reduction and other relaxation techniques that may improve mood, perceived stress, and directly address anxiety and depression-related factors. Evidence supports that Tai Chi can reduce anxiety and depression comorbid with chronic conditions, including COPD [75–78].

METHODS

Study design

The primary aim of this study, called **L**ong-term **E**xercise **A**fter **P**ulmonary Rehabilitation (LEAP), is to determine the effect of Tai Chi exercise on 6MWT distance, compared to usual

care in participants with COPD who have completed a conventional, supervised PR program. Simultaneously, we are conducting a pilot study of group walking in order to obtain preliminary estimates of outcomes to inform a future study. To ensure that the pilot is conducted in a sample drawn from the same patient population, we are randomizing patients to all 3 treatments.

Approximately 90 persons will be enrolled, with 36 persons randomized to receive Tai Chi (total 36 classes of 1-hour duration with 2 classes per week for 3 months, then weekly for 3 additional months), 36 persons to usual care (general recommendations for exercise at home), and 18 persons to group walking class (same frequency and duration as Tai Chi) (Figure 2). Primary and secondary outcomes will be assessed at study entry, 3 and 6 months. Exercise capacity, measured by 6MWT distance, is the primary outcome. Secondary outcomes include HRQL, dyspnea, mood, occurrence of AEs, engagement in PA, exercise self-efficacy, and exercise adherence. Although the intervention is completed at 6 months, we will follow the participants for an additional 6 months by telephone to assess for the occurrence of AEs at 9 months and secondary outcomes at 1 year.

Study objectives

The objectives of the current clinical trial are:

1. To determine the impact of a 6-month post-pulmonary rehabilitation Tai Chi program on 6MWT distance in participants with COPD, as compared to usual care.
2. To evaluate the impact of a 6-month post-pulmonary rehabilitation Tai Chi program on HRQL, dyspnea, mood, and occurrence of AEs in participants with COPD, as compared to usual care.
3. To evaluate the impact of a 6-month post-pulmonary rehabilitation Tai Chi program on engagement in PA, exercise self-efficacy, and exercise adherence in participants with COPD, as compared to usual care.

An exploratory aim of this trial is to estimate the effect of a 6-month post-pulmonary rehabilitation group walking program on the primary outcome of 6MWT distance and the secondary outcomes, compared to Tai Chi and usual care.

Study population and recruitment

The study population will be identified from the PR programs at 4 main institutions: Beth Israel Deaconess Medical Center, VA Boston Healthcare System, Brigham and Women's Hospital, and Boston Medical Center, as well as referrals from other sites in Massachusetts. Recruitment will occur over 48 months; participants will be enrolled in cohorts. Study staff will approach patients within the last 6 weeks of PR classes or at their PR discharge visit. Those interested in the study will be scheduled for a screening visit. All participants will receive written instructions on transitioning to post-rehabilitation exercise.

Eligibility criteria

Inclusion criteria are age > 40 years and COPD defined as either FEV_1/forced vital capacity (FEV_1/FVC) <0.70 or chest CT evidence of emphysema. We will include persons with

GOLD stages I, II, III, or IV [5]. Persons would have completed a supervised PR program within 24 weeks prior to study entry, defined as having attended 65% of the program's sessions, with a minimum of 10 sessions and of at least 8 weeks duration. We chose a window of 24 weeks to capture enough patients who had completed PR to make the cohorts a reasonable size and since the literature shows that benefits do not generally return to pre-PR levels until 6–12 months post PR.

Exclusion criteria include COPD AE requiring corticosteroids, antibiotics, emergency room visit or hospitalization within the past 2 weeks; hypoxemia on 6MWT (O_2 sat < 85% on oxygen); inability to ambulate; clinical signs of unstable cardiovascular disease (i.e. chest pain on 6MWT); severe cognitive dysfunction; non-English speaking; current regular practice of Tai Chi; lung cancer treated in the past 5 years; or unstable/untreated mental health issue that precludes informed consent or affects ability to participate in the intervention.

Informed Consent, Randomization, and Allocation Concealment

Ethics approval has been obtained at each institution, and written informed consent will be obtained from each participant by the research assistant at the screening visit. After baseline testing, eligible participants will be randomly assigned to one of 3 groups in a 2:2:1 ratio: Tai Chi, usual care, or group walking. Group assignments will be generated by a permuted blocks method with randomly varying block size to ensure balanced but unpredictable assignments. Assignments will be sealed in numbered, opaque envelopes. The sequence of randomization and blocking factor will differ for each cohort. All outcomes testing will be conducted by study staff, physicians, or technicians who are blinded to treatment assignment.

Interventions

***Tai Chi* (Table 1)—**The Tai Chi intervention is designed specifically for an older, physically limited population with COPD [54,79,80]. The structured intervention emphasizes essential Tai Chi movements that are easily comprehensible and can be performed repetitively in a flowing manner. The five chosen Tai Chi movements—'raising the power', 'withdraw and push', 'grasp the sparrow's tail', 'brush knee twist step', and 'cloud hands' — are based on the traditional Cheng Man-Ch'ing's Yang-style short form [41]. In addition to the five formal movements, the intervention includes a complementary set of traditional Tai Chi warm-up exercises which focus on loosening the physical body, incorporating mindfulness and imagery into movement, promoting overall relaxation, and coordinating breathing awareness. Four traditional interrelated breathing techniques are integrated into the training regimen and coordinated with physical movements [80]. Chairs will be provided for tai chi exercises that are performed in a seated position and resting, as well as for stability as needed when performing other exercises. Each session will conclude with a brief cool-down exercise of self-massage on the face, abdomen, flanks, and mid-back while in a sitting position.

The first class will include discussion of participant expectations and overview of the program. Participants will receive written instructions on specific Tai Chi exercises, an audio

CD, and a DVD to facilitate home practice. They will be encouraged to practice Tai Chi outside of class at least three times a week for at least 30 minutes each time.

Usual Care—As part of usual care, upon completion of the supervised, facility-based PR program, all participants will meet with PR staff to formulate an exercise plan to follow at home. Recommendations may include walking in the community, using exercise equipment at a local gym, or continuing to use the exercise equipment at the facility-based PR program.

Recommendations will also typically include strength training for a total of 20 minutes a day, 3–4 days a week. Participants are allowed to participate in the maintenance programs of their usual PR program.

Group Walking—The walking classes will be identical to the Tai Chi classes in terms of duration (one hour), number (36 classes) and frequency (twice weekly for the first 3 months, then once a week for the remaining 3 months), and approximate amount of PA (low-moderate aerobic exercise with gentle stretching). Classes will begin with 5 minutes of gentle flexibility and lower extremity stretching exercises prior to walking at participants' own pace around an indoor track. Since participants have already learned how to monitor their heart rate and assess their breathlessness using the Borg scale during conventional supervised PR, they will use the same parameters to target the intensity of exercise to reach approximately 60% of their maximum heart rate and to keep breathlessness within the 3–5 range on the Borg scale [81]. The first class will include discussion of participant expectations and overview of the program. Like the Tai Chi group, participants will be instructed to walk or perform stretches at least 3 times per week outside of group classes for at least 30 minutes each time.

Primary outcome measure

Exercise capacity—The 6MWT is a standardized assessment of exercise capacity that measures the maximum distance covered in six minutes [82]. The test will be conducted at all sites using scripted instructions. The Borg scale will assess breathlessness and leg fatigue immediately before and after the 6MWT [81]. Participants will use supplemental oxygen if already prescribed oxygen during activity. If hypoxemia (O_2 sat <85%) is observed, the participant will be referred to their primary provider for further evaluation. The minimal clinically important change in 6MWT distance is 30–54 meters in stable COPD [83,84].

Secondary outcome measures

HRQL—The disease-specific Chronic Respiratory Disease Questionnaire (CRQ) has been validated in COPD [85]. The CRQ covers four domains--dyspnea, fatigue, emotional function and mastery. Items are scaled on a 7-point modified Likert Scale, with higher scores indicating better HRQL [85]. A 0.5 point change in CRQ score is clinically meaningful [86].

Dyspnea—We will use the University of California, San Diego Shortness of Breath Questionnaire (UCSD SOB) to assess overall dyspnea. The UCSD SOB Questionnaire has 24 items assessing detailed information about general dyspnea during usual physical activities and has a recall period of one week. The UCSD SOB Questionnaire is a validated

instrument that assesses the degree to which participants feel short of breath while performing activities of daily living. Respondents rate symptoms on a 6-point scale from "not at all" to "maximally or unable to do because of breathlessness" [87]. The minimal clinically important difference has been determined to be 5 units [88].

Acute exacerbations—AEs are a major contributor to the functional deterioration seen after completion of PR [27,32]. Participants will be interviewed in person or by telephone every 3 months using a structured questionnaire to query symptoms, use of corticosteroids and/or antibiotics, and hospitalizations. Participant reports will be verified with medical records. We will use an *a priori* definition of AE that is event-based, "a complex of respiratory symptoms (increased or new onset) of at least two of the following: cough, sputum, wheezing, dyspnea, or chest tightness lasting 3 or more days, requiring a course of treatment (5 or more days) with antibiotics or systemic steroids" [89].

Mood—The Center of Epidemiology Studies-Depression Scale (CES-D) is a validated measure of psychological impairment, primarily depressive symptoms, that has been used extensively in epidemiology studies [90]. Participants report how often they experienced various symptoms during the past week using a 4-point ordinal scale. A score of <15 indicates no depression. The CES-D has high internal consistency (r=0.90) and a test-retest reliability of 0.51 [90,91].

Physical Activity—Activities of daily living (ADLs) will be assessed with the Manchester Respiratory ADLs Questionnaire, a validated instrument which measures functional ability and ADLs specific to restrictions from dyspnea in participants with COPD [92]. It was modified from the Nottingham Extended ADLs Scale [93] and covers four domains: mobility, kitchen, domestic tasks, and leisure activities.

To measure participants' self-report of PA, we will use the Community Health Activities Model Program for Seniors (CHAMPS) Physical Activity Questionnaire for Older Adults [94]. CHAMPS is a 41-item instrument validated in the elderly, which covers PA from several domains, including leisure, household, and occupational activity. Weekly frequency and total time spent allows estimation of caloric expenditure. In addition, we will use a PA checklist specifically to measure day-to-day activity in participants with COPD [95]. A higher number of activities performed is associated with better indices of COPD health, including higher FEV_1 and lower BODE (body mass, airflow obstruction, dyspnea, exercise capacity) index. To directly measure PA, we will use the Omron HJ-720ITC, a waist-mounted pedometer with on-instrument digital data presentation, which accurately measures step counts in the majority of persons with COPD [96,97]. Participants will wear the Omron during waking hours for a 14-day monitoring period, excluding periods of bathing or other water activities. The Omron provides feedback with on instrument display of step counts which may be motivating. Importantly, the Omron will be used in the same way for persons in all 3 arms of this study. There is no reason to think that a pedometer is more motivating for one group, such as Tai Chi, compared to any of the other 2 groups.

Exercise Self-Efficacy—The COPD self-efficacy scale (CSES) identifies situations during which participants lack confidence in their ability to manage breathing difficulties

[98]. The situations include times of negative affect ("When I feel down or depressed"), intense emotions, physical exertion, at-risk behaviors ("When I overeat"), or adverse environments. The CSES has high internal consistency (r=0.95) and test-retest reliability (r=0.77) [98]. The Exercise Self-Efficacy scale by Resnick similarly assesses one's confidence in being able to exercise in the face of certain physical, emotional or situational barriers [98–100].

Exercise Adherence—Throughout the 6-month intervention period, we will track participant attendance at the Tai Chi and group walking classes. Non-adherers will be defined *a priori* as participants with attendance of less than 70% of classes. The 70% adherence rate is specifically for class attendance since this can be accurately assessed. There are 36 total classes for each intervention group, so participants must attend at least 26 in order to be considered adherent. In all three groups, we will also monitor adherence to home exercise through weekly self-report logs that will capture practice frequency and duration of home exercise sessions. We will perform exploratory analyses with self-reported engagement in home practice.

Other data collection

Pulmonary function tests—We do not expect spirometry to change in response to the intervention. We will perform spirometry at baseline, 3, and 6 months to document clinical stability. Spirometry will be performed following American Thoracic Society standards for quality and reproducibility [101].

Qualitative interview and analysis—All participants will complete a thirty-minute, semi-structured qualitative interview at 6 months to explore areas not captured in our standardized questionnaires. Specifically, we will elicit participants' candid assessments of various aspects of the intervention groups. These open-ended questions may yield additional insights into facilitators and barriers to exercise, and components of a successful long-term program. Each interview session will be audiotaped, and transcribed verbatim. The transcripts will be reviewed in conjunction with the taped interview to ensure accuracy before data are analyzed. Interviews will be coded using an inductive approach informed by grounded theory methods [102]. Using qualitative analysis, we will identify passages that represent common themes or content categories relating to positive, negative, or neutral aspects of participant experiences with Tai Chi, group walking, or usual care. Data will be analyzed and presented descriptively according to themes [102,103].

Adverse events—Participants will complete an adverse event questionnaire every 3 months. At each in-person visit, participants will be queried about new or worsening medical conditions, change in medications, or urgent care visits, emergency room visits, or hospitalizations. During the intervention, participants will complete logs asking about adverse events, which will be collected every 4 weeks. Intervention instructors will notify study staff immediately of any adverse events that are indicated in the logs that may relate to the intervention, such as musculoskeletal events or adverse events that occurred during class or home practice. If a potential adverse event is reported, study staff contact the participant for further details to determine if a reportable adverse event has occurred and if so,

document the type, whether expected or not, assess relatedness to the study, and severity. Serious adverse events are defined as life-threatening, require hospitalization, result in persistent or significant disability/incapacity or death. Serious adverse events are reported to the Institutional Review Board, our sponsor, and our Data and Safety Monitoring Board as appropriate.

Statistical Analysis

Power analysis and sample size—We have powered the study based on the primary outcome of 6MWT distance. Based on estimates of standard deviations from our pilot data of 12-weeks of Tai Chi versus usual care in patients with COPD [70], we will randomize 36 participants in Tai Chi and 36 participants in usual care, in order to have approximately 90% power to detect a difference of approximately 50 meters in the 6MWT distance between the Tai Chi and usual care groups. A change in the 6MWT distance of 30–54 meters is clinically significant in persons with COPD [83,84,104]. These calculations are conservative, allowing for a 5% loss of statistical efficiency of the nonparametric test compared to a t-test, and 15% loss to follow-up. We determined that a sample of 18 participants would be adequate for the goal of the pilot study of group walking.

Analysis plan—Prior to analyzing the outcomes, we will examine baseline demographic, physiological and psychosocial variables by randomized group. Although we do not expect any statistically significant differences with proper randomization, any imbalances will be adjusted for in the analyses. We will primarily examine changes in outcomes between baseline and 6 months in those assigned to Tai Chi versus usual care. This analysis will be performed on an intention-to-treat basis to minimize biases that can occur when participants not receiving assigned treatments are excluded from the analyses. As a sensitivity analysis, however, we will also examine change in outcomes on a per-protocol basis, where non-adherers (attendance at less than 70% of classes) will be excluded. All statistical analyses will use 2-sided tests. We will test at the 0.05 level of significance.

Aim 1: To determine the impact of a 6-month post-pulmonary rehabilitation Tai Chi exercise program on 6MWT distance in participants with COPD, as compared to usual care: Changes in 6MWT distance at 6 months will be analyzed using a Wilcoxon rank sum test to compare the two treatment groups. Additional exploratory analyses will provide insight into the trajectory of 6MWT distances over time. We will fit longitudinal models, with 6MWT distance (measured at baseline, 3, and 6 months) as the dependent variable using generalized estimating equations (GEE) to account for the longitudinal correlation structure. Baseline 6MWT distance and treatment group assignment will be incorporated into every model as independent variables. We will include treatment group and time point (both as categorical variables) and their interaction, as well as the participant's baseline value of the outcome as independent variables. Other covariates will be included to explore their association with the outcome and may include potential confounders such as baseline characteristics not well balanced across treatment groups, medication changes, new comorbidities, and COPD AEs. We will examine time since completion of supervised PR and number of weeks of PR the participants completed prior to study entry.

Aim 2: To evaluate the impact of a 6-month post-pulmonary rehabilitation Tai Chi program on HRQL, dyspnea, mood, and occurrence of AEs in participants with COPD, as compared to usual care: The basic analytic approach for secondary outcomes will parallel the approach for the primary outcome, comparing change in outcomes from baseline to 6 months between the two groups, and exploratory longitudinal analyses at 3,6, and 12 months using GEE. In addition, we will use separate linear regression models using clinical outcomes (6MWT distance, HRQL, and dyspnea) as dependent variables and scores on secondary psychosocial and functional assessments as potential mediators to examine whether clinical outcome is associated with mood, perceived stress, ADLs, or social support. These exploratory models will be developed to provide insight into potential mediators and mechanisms of effect.

Aim 3: To evaluate the impact of a 6-month post-pulmonary rehabilitation Tai Chi program on exercise self-efficacy, PA, and exercise adherence in participants with COPD, as compared to usual care: We will compare participant self-report of PA (CHAMPS and PA checklist), directly measured daily step counts, and scores on exercise self-efficacy questionnaires using the same analytic strategy as for the primary outcome (i.e., comparison of change from baseline to 6 months). We will compare results at 3,6, and 12 months between groups using a longitudinal analysis and fit regression models using GEE methods to account for within-correlations. The models will include terms for assigned group, study week, and the interaction of these effects and will be adjusted for baseline PA level. Home exercise and class exercise (when applicable) may be combined for an overall exercise index at 6 months. Similar methods will be used to analyze data from self-reported exercise logs from 6 to 12 months. We will fit individual regression models to explore whether exercise self-efficacy, intervention adherence, daily step counts, or overall PA is associated with change in 6MWT distance, HRQL, or dyspnea. We will also examine other potentially modifiable predictors of exercise and examine the relationship between intervention adherence and overall PA and candidate variables of supplemental oxygen use, marital status, body-mass index, mood, corticosteroid use, alcohol consumption, and comorbidities (coronary disease, arthritis, heart failure, depression, or diabetes) while adjusting for disease severity with lung function and dyspnea.

Exploratory Aim: To estimate the efficacy of a 6-month post-pulmonary rehabilitation group walking program in participants with COPD, as compared to a Tai Chi program and usual cares: Changes in the primary outcome of 6MWT distance as well as all secondary outcomes will be analyzed using a nonparametric Kruskal-Wallis test, comparing the change from baseline to 6 months among the three treatment groups of Tai Chi, usual care, and walking group. If treatment group is found to be statistically significant, pairwise comparisons of groups will be performed using Wilcoxon rank-sum tests, appropriately adjusted for multiple comparisons in the *post hoc* tests.

DISCUSSION

The Long-term Exercise After Pulmonary Rehabilitation (LEAP) study is a novel and clinically relevant RCT to study the efficacy of Tai Chi to maintain benefits after completion of a conventional PR program. Among other unique attributes, Tai Chi inherently integrates

3 important component of PR--namely, aerobic exercise, dyspnea management, and stress/anxiety management. We will enroll a well-characterized cohort of persons with COPD and will comprehensively assess physiological and psychosocial outcomes. Strengths of this study include the RCT design and enrollment of an ethnically diverse Western population. Results of this study will provide evidence regarding the benefit of Tai Chi as an intervention for maintaining the benefits gained after completion of supervised PR. They will also inform the feasibility of persons with COPD engaging in a mind-body exercise over the long-term. If the results are positive, Tai Chi could be a low-cost, long-term modality to sustain PA in persons with COPD who have completed a conventional, short-term PR program. A broad repertoire of modalities are needed to promote PA in persons with COPD, a lifestyle behavior that can positively impact the disease course.

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Abbreviations

AE	acute exacerbation
ADLs	activities of daily living
BODE	body mass: airflow obstruction: dyspnea: exercise capacity
CES-D	Center of Epidemiology Studies-depression scale
CHAMPS	Community Health Activities Model Program for Seniors physical activity questionnaire for older adults
COPD	chronic obstructive pulmonary disease
CRQ	chronic respiratory disease questionnaire
CSES	chronic obstructive pulmonary disease self-efficacy scale
FEV_1	forced expiratory volume in one second
FVC	forced vital capacity
GEE	generalized estimating equation
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HRQL	health-related quality-of-life
PA	physical activity
PR	pulmonary rehabilitation
RCT	randomized controlled trial
6MWT	6-minute walk test

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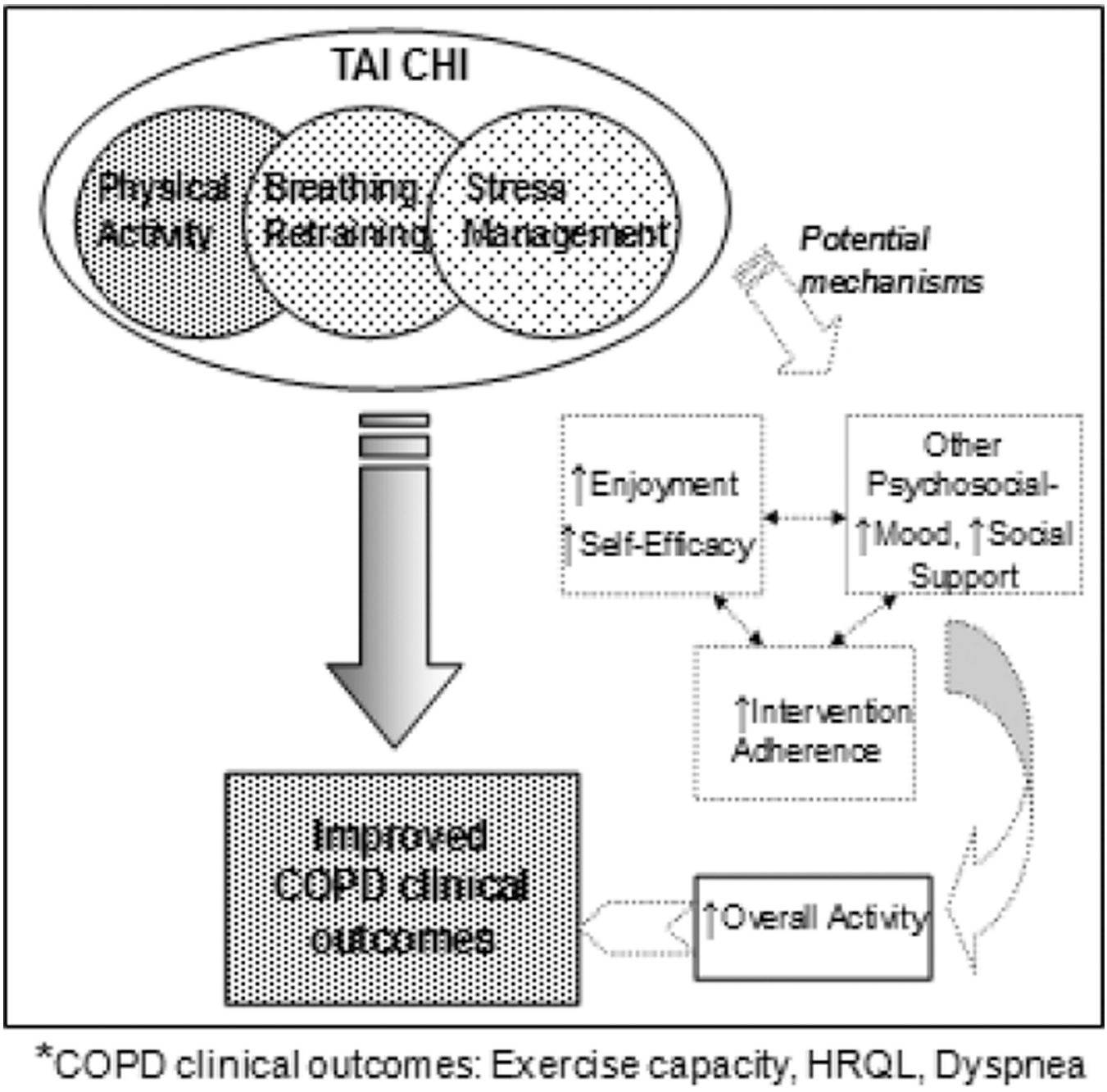

Figure 1.
Conceptual Model of Potential Positive Effects of Tai Chi in COPD

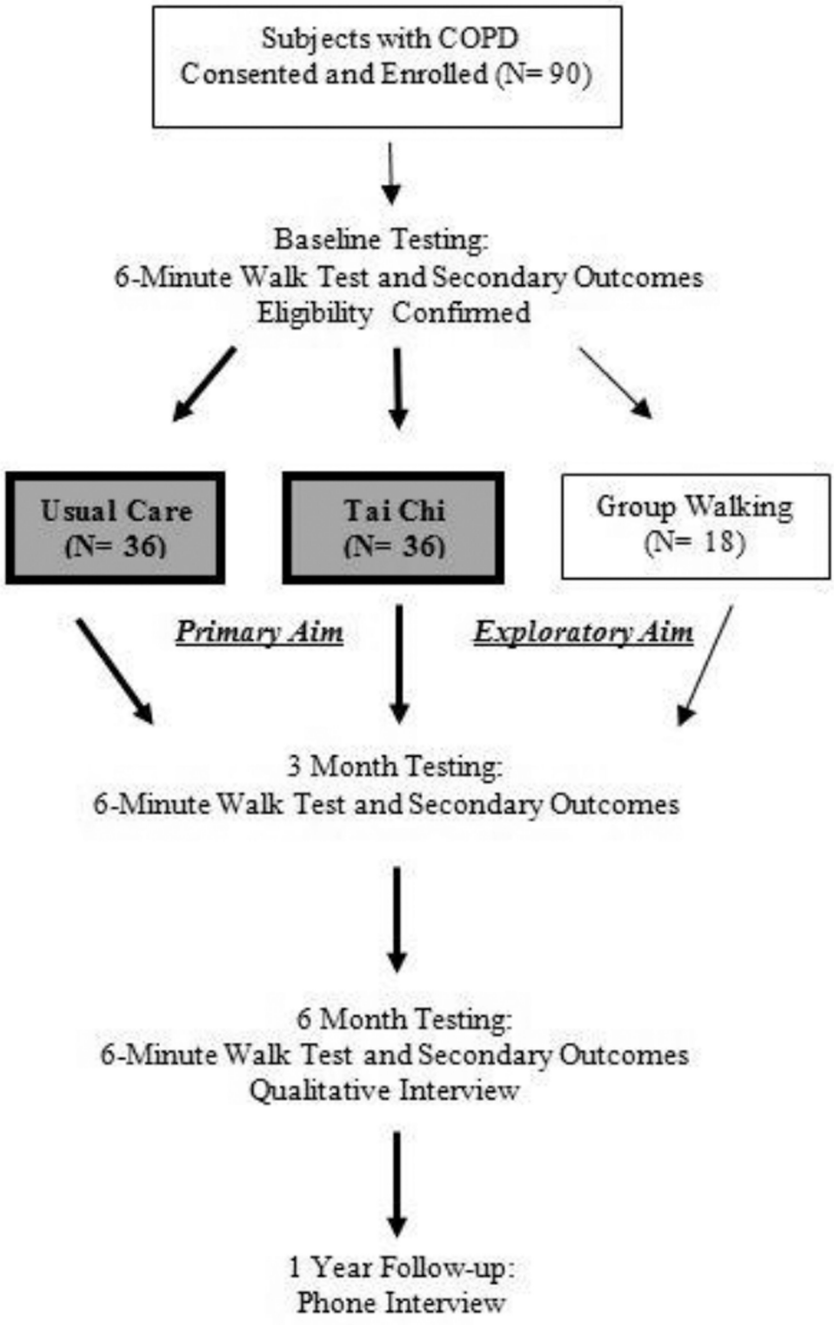

Figure 2.
Study Design

Table 1

Description of Tai Chi classes

Week	Activities	Approximate Duration (min)
1–2	Check-in	2
	Tai Chi Warm-up Exercises--Standing	38
	Tai Chi Pouring and Swinging	
	Drumming the Body	
	Standing meditation	
	Hip Circles	
	Tai Chi Warm-up Exercises—Seated	
	Washing with Qi from the Heaven	
	Renewing the Body with the Breathe	
	Mindful stretching	
	Lower Extremities	
	Upper Extremities	
	Spinal Cord Breathing	
	Head and Neck Rotations	
	Introduction to Tai Chi Movement #1:	15
	Raising the Power	
	Tai Chi Cool-Down Exercises	5
	Self-massage and meridian tapping	
	Washing with chi from heavens	
3–8	Check-in	2
	Tai Chi Warm-up Exercises	18
	Breathing Exercises	10
	Renewing Body with Breath	
	Mindful Breathing	
	Tan Tien Breathing	
	Review and Practice Tai Chi Movement #1:	5
	Learn and Practice Tai Chi Movements #2 and #3	20
	Push and Withdraw	
	Wave Hands Like Clouds	
	Tai Chi Cool-Down Exercises	5
9–12	Check-in	2
	Tai Chi Warm-up Exercises	13
	Breathing Exercises	10
	Renewing Body with Breath	
	Mindful Breathing	
	Tan Tien Breathing	

Week	Activities	Approximate Duration (min)
	Ocean Breathing	
	Review and Practice Tai Chi Movement #1-#3	10
	Learn and Practice Tai Chi Movements #4 and #5	20
	Grasp the Sparrow's Tail	
	Cross Hands	
	Tai Chi Cool-Down Exercises	5
13–24	Check-in	2
	Tai Chi Warm-up Exercises	13
	Breathing Exercises	15
	Renewing Body with Breath	
	Mindful Breathing	
	Tan Tien Breathing	
	Ocean Breathing	
	Practice Tai Chi Movement #1–#3	15
	Practice Tai Chi Movements #4 and #5	10
	Tai Chi Cool-Down Exercises	5