SPECIAL ARTICLE

Selected As the Best Paper in the 1990s: Reducing Frailty and Falls in Older Persons: An Investigation of Tai Chi and Computerized Balance Training

Steven L. Wolf, PhD, FAPTA,[*] Huimnan X. Barnhart, PhD,[†] Nancy G. Kutner, PhD, Elizabeth McNeely, PhD,[‡] Carol Coogler, ScD, PT,[§] Tingsen Xu, PhD,[¶] and the Atlanta FICSIT Group[**]

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OBJECTIVES: To evaluate the effects of two exercise approaches, tai chi (TC) and computerized balance training (BT), on specified primary outcomes (biomedical, functional, and psychosocial indicators of frailty) and secondary outcomes (occurrences of fall).

DESIGN: The Atlanta Frailty and Injuries: Cooperative Studies and Intervention Techniques, a prospective, randomized, controlled clinical trial with three arms (TC, BT, and education (ED)). Intervention length was 15 weeks, with primary outcomes measured before and after intervention and at 4-month follow-up. Falls were monitored continuously throughout the study.

SETTING: Persons aged 70 and older living in the community.

PARTICIPANTS: A total of 200 participants, 162 women and 38 men; mean age was 76.2.

MEASUREMENTS: Biomedical (strength, flexibility, cardiovascular endurance, body composition), functional instrumental activities of daily living (IADL), and psychosocial well-being (Center for Epidemiological Studies for Depression scale, fear of falling questionnaire, self-perception of present and future health, mastery index, perceived quality of sleep, and intrusiveness) variables.

RESULTS: Grip strength declined in all groups, and lower extremity range of motion showed limited but statistically significant changes. Lowered blood pressure before and after a 12-minute walk was seen following TC participation. Fear of falling responses and intrusiveness responses were reduced after the TC intervention compared with the ED group ($P = .046$ and $P = .058$, respectively). After adjusting for fall risk factors, TC was found to reduce the risk of multiple falls by 47.5%.

CONCLUSION: A moderate TC intervention can impact favorably on defined biomedical and psychosocial indices of frailty. This intervention can also have favorable effects upon the occurrence of falls. TC warrants further study as an exercise treatment to improve the health of older people. **J Am Geriatr Soc 51:1794–1803, 2003.**

The Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) studies were designed as a cooperative effort to gather a common set of data about functional, physiological, psychosocial, and environmental variables affecting older people, while serving as an exploration of novel interventions to improve frailty and/or reduce the effects of falls.[1] The Atlanta FICSIT site evaluated two contrasting interventions—tai chi (TC) quan and computerized center of mass feedback for balance training (BT)[2]—among community-dwelling-older individuals.

Frailty, defined as a reduction in physiological reserves[3] and behavioral capacities,[4] can affect individuals throughout the age continuum, but the consequences of frailty are particularly devastating for older persons. Substantial evidence exists that older people can become stronger,[5] improve their balance,[6,7] and/or increase their gait speed.[8] At the same time, falls constitute a major impediment to independence among older individuals. Falls are attributable to multifactorial events[2] that have both intrinsic components, such as changes in single or multiple physiological systems,[9–11] and extrinsic factors, including medication intake and environmental hazards.[12,13] Identifying interventions that can reduce frailty and fall-related

From the [*]Department of Rehabilitation Medicine, School of Nursing, [§]Division of Physical Therapy Education, and [¶]Department of Biochemistry, Emory University School of Medicine; and [†]Department of Biostatistics, Rollins School of Public Health, Emory University, Atlanta, Georgia. [**]See Acknowledgment for members of the Atlanta FICSIT Group.

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Address correspondence reprint request to Steven L. Wolf, PhD, FAPTA, Center for Rehabilitation Medicine, 1441 Clifton Road, NE, Atlanta, GA 30322.

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injuries in older persons is an important public health priority.

Many group activities undertaken for the total physiological benefit of older people fail to stress balance control mechanisms.[14] Such activities are often performed in comparatively static postures that eliminate the need for controlling center of mass alterations over a dynamically changing base of support. Relying primarily upon static balance exercise is incompatible with maintenance of balance in later life.[15] Both TC and center of mass feedback provide muscle or force information that can facilitate movement control.

TC has been used for centuries as a martial arts form in oriental cultures and has also been used in this country as an exercise, performed predominantly by older individuals of Asian heritage, to enhance balance and body awareness. Although reports in Chinese literature[16,17] indicate substantial psychological and physiological benefits from the practice of TC, corroborative data and controlled studies to support such claims have not been reported in Western scientific literature. Nonetheless, observing the sequence of forms undertaken in learning TC readily led to the conclusion that balance was stressed under conditions that continuously invoked body rotational movements under a progressively diminishing base of support. This exercise form appears to dynamically tax balance mechanisms while facilitating concentration of body position within the immediate environment.

Alternatively, by providing feedback about how center of mass changes through the resolution of outputs from force transducers embedded within a standing platform, computerized balance training (BT) can help subjects improve the magnitude of their sway. Resolution of outputs from transducers imbedded in the floor of a movable platform can provide direct knowledge of results of total sway magnitude. This information might be incorporated into the development of new strategies that allow for greater body excursion of changes in bases of support and, in the process, may facilitate lower extremity flexibility (see [18] for a review).

TC and BT appear quite disparate in nature; TC is a low technological, inexpensive group activity, whereas the BT approach is a comparatively expensive, high technological approach performed individually. To gain preliminary insights into these contrasting techniques, the Atlanta FICSIT site carried out exploratory investigations in a randomized clinical trial consisting of three arms (TC, BT, and an education (ED) exercise-control group). We assessed the influence of these approaches on biomedical, functional, and psychosocial indicators of frailty and, secondarily, evaluated their influence on the occurrence of falls. A preliminary overview of this study has been presented.[19] The purpose of this paper is to report the outcomes of this clinical trial.

METHODS

Study Design

This study was a prospective, randomized, controlled clinical trial with three arms (TC, BT, and ED). The intervention length was set at 15 weeks with primary outcomes measured before and after intervention and 4 months later. The outline of the trial and the randomization process are shown in Figure 1. Data collectors were blind to intervention assignment.

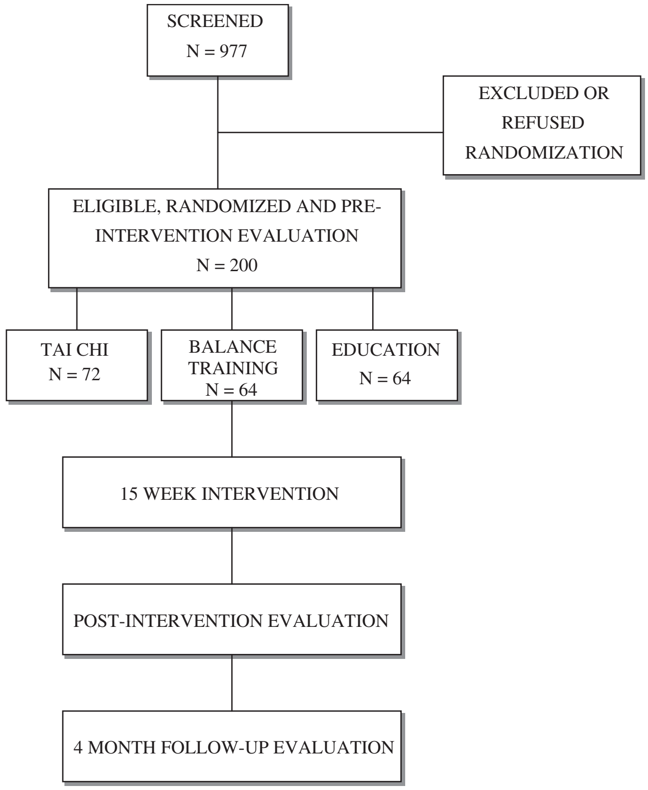

Figure 1. Flow chart depicting the procedure for screening randomization, evaluation, intervention, and follow-up at the Atlanta Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) site.

Subject Recruitment

Participants were recruited by local advertisements and by direct contact with residents in an independent living facility. To be included in the study, subjects had to be 70 years of age or older, live in unsupervised environments, and be ambulatory. Exclusion criteria were the presence of debilitating conditions such as severe cognitive impairments, metastatic cancer, crippling arthritis, Parkinson's disease or major stroke, or profound visual deficits that could compromise balance or ambulation. In addition, subjects had to agree to participate on a weekly basis for the 15-week intervention and at the 4-month follow-up.

All subjects who met inclusion criteria were asked to undergo a comprehensive screening by a nurse practitioner to assure that study criteria were met, confirm living arrangements, determine accessibility to intervention locations, etc. Those individuals screened successfully then underwent a baseline evaluation, which included the acquisition of psychosocial, demographic, physical health, and fall-related variables that comprised the FICSIT common database.[1] A physical examination was then administered to gather past medical history, present complaints, and vital signs. A detailed neurological examination was also provided. Lastly, information was obtained about cardiovascular status strength, coordination, sensation, and proprioception. A total of 977 individuals were screened using inclusion/exclusion criteria. Subjects who satisfied the criteria were asked for consent for randomization. Two hundred of these individuals consented to be randomized. At that time the activities involved with each intervention were explained, and informed consent was obtained.

Interventions

This study included three arms: TC, computerized BT, and an ED exercise-control condition. TC classes were a synthesis of the existing 108 forms into 10 that could be completed during the 15-week session. These forms emphasized all components of movement that typically become limited with aging. Specifically, the progression involved a gradual reduction of the base of standing support until single limb stance was achieved (the most advanced form), increased body and trunk rotation, and reciprocal arm movements.[20] Subjects were encouraged to practice at least 15 minutes twice a day, but home practice was not monitored.

BT involved use of a Balance System (Chattecx Corporation, Chattanooga, TN). This system contains force transducers embedded in each of two movable pylons upon which subjects stand. The output of these transducers is resolved into a moving cursor representing the center of mass. The subject views the cursor on a monitor positioned at eye level and is instructed to move the cursor into specific targets that can be placed anywhere on the screen. This task is successfully achieved by moving the center of mass with no foot displacement. The goal is to progressively increase sway to the limits of postural stability. Added to this paradigm is the capability of moving the floor upon which the pylons are placed at either linear or angular directions at varying velocities. The 15-week training period consisted of positioning progressively more difficult targets that required increased sway first in the absence of, and then with, concomitant floor movement. For each session, subjects were asked to practice these tasks with eyes open and then with eyes closed, thus demanding more dependence upon vestibular and somatosensory systems to maintain balance.

The ED groups were composed of individuals who were instructed not to change their exercise levels throughout the study and follow-up periods and hence as a control for exercise applications. They met weekly for an hour with a gerontological nurse/researcher to discuss topics of interest to older people, such as pharmacological management, sleep disorders, cognitive deficits, coping with bereavement, and other issues of interest to each newly configured group. (See [19] for details regarding these interventions.)

Intervention Assignments

After screening and consent of randomization, subjects were assigned randomly to the TC, BT, or ED interventions in cohorts of 32, with 10 assigned to BT, 10 assigned to ED, and 12 assigned to TC for each of the first four cohorts. The subjects in the last two cohorts were randomized in cohorts of 36, with 12 subjects assigned to each group. The slight change in-group distribution was precipitated by the need to complete total sample size recruitment and participation in the time remaining in the project. After each cohort was successfully screened, individuals were assigned to an intervention using a computer-generated, fixed randomization procedure. TC and ED members met as groups, whereas BT was undertaken individually. All interventions lasted 15 weeks, and each group had its own instructor. There was only one instructor per group. Both ED and BT participants met once a week, and the TC group met twice a week. This procedure was necessary so that TC participants could receive some individual attention regarding proper movements in applying new forms. The total individualized weekly contact time between clinician and subject was comparable. The total individual contact time with an instructor was approximately 45 minutes per week for BT and TC participants. The dynamic nature of TC permitted chances for between-session practice. In fact, subjects were requested to try TC forms twice daily for 15 minutes Monitoring compliance with this request was impractical. BT as a static exercise on a computerized machine was not amenable to home practice exercises that simulated the training situation. By the end of recruitment, 200 subjects were entered into the study and randomized, with 64 subjects assigned to BT, 64 to ED, and 72 to TC.

Adherence and Dropouts

A study staff member was responsible for overseeing each intervention. All participants were asked to contact that person if they anticipated absences from their respective interventions. Subjects who failed to appear were contacted by the nurse coordinator and rescheduled for the next session. Subjects were expected to not miss two consecutive sessions. Those few subjects who did miss consecutive sessions were encouraged to make them up individually unless they could not do so because of prolonged, serious illness or need to care for an ill spouse. Only 13 subjects (6 TC, 4 BT, 3 ED) were unable to maintain their participation for these reasons.

Hypothesis Testing

We identified a series of outcome variables at the outset in order to explore treatment and time differences among the three groups.

Primary Outcome Variables

The primary outcome variables were biomedical, functional, and psychosocial indicators of frailty that were measured before and after the period of intervention participation as well as at the 4-month follow-up. Biomedical measures included strength, flexibility (lower extremity range of motion), cardiovascular endurance, and body composition. Of these measures, all but flexibility was site-specific. Strength was assessed using the Nicholas MMT 0116 muscle tester (Lafayette Instruments). One end of the muscle tester was placed in series with an on-compliant chain affixed to an immovable base, and the other end was secured to the appropriate limb segment. The average force generated from three isometric contractions about the hip, knee, or ankle was recorded for specific movements. Grip strength was evaluated from the average force developed from three contractions using the Jamar Smedley-type hand dynamometer (Therapeutic Equipment Corporation).

Cardiovascular endurance was assessed by recording the time required to complete a 12-minute walk and by recording heart rate and blood pressure immediately before and after this task. Body composition was assessed through skinfold measurement taken at the chest, anterior abdominal wall and thigh. Heart rate, blood pressure, and skinfold thickness were measured before and after participation in the intervention but not at follow-up.

Subject's ability to perform instrumental activities of daily living (IADLs) was assessed by the Lawton and Brody IADL scale.[21] FICSIT sites agreed that each of the 13 IADL items, scored from 3 = independence to 1 = dependence, would be dichotomized, with independence scored "0" and any degree of dependence scored "1." Thus larger total scores imply greater dependence.

Measures of psychosocial well-being from the FICSIT common database[1] included the Center for Epidemiologic Studies—Depression (CES-D) scale[22] and a fear of falling measure.[23] Site-specific well-being measures included respondents' rating of how well they were taking care of their own health (1 = excellent to 5 = poor);[24] respondents' perception of their control over their future health (1 = a great deal to 4 = none);[24] a mastery index (scored 7–28; higher score = more mastery);[25] and perceived ability to do all that one would like to do (1 = strongly agree to 4 = strongly disagree), or intrusiveness.[26]

Primary Hypotheses

The Atlanta FICSIT study hypothesized that both TC and BT would improve these biomedical and psychosocial well-being indicators and that the magnitude of improvement in psychosocial well-being indicators would be greater for the TC intervention. In addition, it was hypothesized that the improvement would persist through a 4-month follow-up.

Secondary Outcome Variable

Time to occurrence of falls was an outcome variable of interest for all FICSIT sites. The FICSIT Falls and Injury Committee established a trial-wide definition of a fall as "unintentionally coming to rest on the ground, floor, or other lower level." The FICSIT definition of an injurious fall was a FICSIT fall that resulted either in (a) fractures; (b) head injuries requiring hospitalization; (c) joint dislocations; (d) sprains defined as injury to a ligament when joint carried through range of motion greater than normal; (e) other nonspecified serious joint injuries; and (f) lacerations required sutures.[1] We also explored specific types of falls that caused a medical problem in one of the following categories: fractures, dislocation, sprains, strains, bruises, lacerations, scrapes, and others. Our modified falls definition is narrower than the FICSIT falls definition but is based on information about medical problems related to the severity and intensity of a fall and discounts minor events such as stumbles. Falls were defined as any of these specific types of falls occurring during participants' enrollment in the Atlanta FICSIT study. Coming to rest at a lower level[1] often implied a stumble in which the subject touched the first shelf of a drawer rather than the drawer top. By the FICSIT definition noted above, this event would be considered a fall because body position was now lower than it was previously. Falls incidents were monitored continuously from the time of randomization. Thus the longest follow-up period was 20 months for subjects in the first study cohort, and the shortest follow-up was 7 months for subjects in the last study cohort. Fall incidents were ascertained by monthly calendar with fall information or by monthly phone calls from project staff. All fall reports that required physician or hospital visits were verified by the nurse coordinator.

Secondary Hypothesis

TC and BT interventions were expected to decrease the time-specific risk for (injurious) falls compared with the risk among subjects in the exercise control condition.

Data Analyses

All 200 subjects were included in the baseline data analyses. Baseline characteristics and preintervention values were compared among TC, BT, and ED groups. The chi-square test or Fischer Exact test was used to determine the significance of differences for categorical variables, and the analysis of variance (ANOVA) *F*-test or Kruskal-Wallis test was used for continuous variables.[27] To test the primary hypotheses, repeated measures analysis of covariance was used for each continuous outcome variable, with adjustments for significant baseline characteristics. If there were significant time and group interactions, multiple pairwise comparisons with a Tukey adjustment were examined to see if the changes from pre to postintervention or from preintervention to follow-up were significantly different from zero within each group. An adjustment was not made for multiple comparisons because this study was designed to explore the possible effects of treatment and time on each outcome variable. For ordinal level primary outcome variables, analyses were based on cumulative logistic models using generalized estimating equations that take correlations into account for repeated measures.[28] These models assume that the cumulative logits (i.e., log of cumulative odds) at each response cutpoint depend linearly on the interaction effect and main effects of treatment and time, as well as baseline covariates. In addition, the model assumes effects are to be the same for each response cutpoint (proportional odds assumption).

For the secondary hypothesis, the Andersen and Gill extension of the Cox proportional hazards model was used to analyze the time to one or more (injurious) falls. Like the Cox model, the Andersen and Gill method models the proportional hazards in terms of covariates. However, the Andersen and Gill model allows the subject to remain at risk for subsequent events after the subject has just experienced an event.[29] All analyses were performed using the statistical analysis system (SAS) software,[30] except the Andersen and Gill model, which used S-Plus.[31] In the Andersen and Gill model, time zero is the date of randomization, and the subjects lost to follow-up for fall incidents were censored at the time of lost follow-up. *P* levels equal to or less than .05 were considered statistically significant.

Sample size was calculated originally with the assumption that there would be more than one TC instructor, but only one TC instructor was available when the project started. Because of this change, we recalculated the power based on our collected data for this adjustment. We chose the grip strength variable for the power calculation because it is an important biomedical measure among our primary variables. For 200 subjects in three groups (64, 64, and 72), a power of 80% can detect a 1.05-kg difference in error rate. An estimated standard error of 1.77 was used in the above calculation of power.

RESULTS

Baseline Characteristics

Randomization resulted in a distribution of patient baseline characteristics that was comparable across intervention groups. Of the approximately 60 baseline characteristics and measures that were investigated, only four differed significantly between groups. Table 1 provides data for selected baseline characteristics by group assignment (n = 200) and includes those characteristics for which significant differences were observed. Most of the participants were white and female, and the mean age of participants in each group was similar. A higher percentage of TC participants than of BT or ED participants were working. About twice as many TC and BT subjects were undertaking some form of volunteer work compared with members in the ED group. Baseline biomedical data showed that body mass index (BMI) was higher for BT than for either TC or ED groups. Subjects' history of chronic conditions showed that a higher percentage of TC and BT participants than of ED participants had cataracts. With respect to baseline falls data, participants in all three groups displayed similar profiles for numbers of falls in the year before study enrollment and in responses to the fear of falling questionnaire at baseline assessment.

Compliance

Postintervention evaluations were not completed for 16% of the subjects, and a total of 20% did not return for the 4-month follow-up evaluations. Failure to complete these evaluations usually resulted from subjects' declining health (detection of cancer, arthritis flare-ups, cardiac complications, transient ischemic attacks) or travel plans that interfered with regular attendance. However, some of these subjects did agree to be followed for fall occurrences. For the total study population, only 13% did not provide information about fall incidents. Intervention groups did not differ significantly in rates of completing postintervention evaluations, follow-up evaluations, or fall reports.

Repeated Measures Analysis

The following results for continuous outcome variables are based on a 3 (treatment) × 3 (time) repeated measures

Table 1. Baseline Characteristics by Group

Characteristic[†]	TC n = 72	BT n = 64	ED n = 64	P[§]
Mean age ± SD[‡]	76.9 ± 4.8	76.3 ± 5.1	75.4 ± 4.1	.20
Gender %				.50
Male	19	23	16	
Female	81	77	84	
Currently working for pay %	18	6	6	.033
Volunteering %	51	28	52	.0081
Mean body mass index ± SD	22.5 ± 4.0	26.7 ± 3.8	25.5 ± 4.2	.045
Cataracts %	56	52	30	.0058
Fell last year %	42	31	34	.43
Fear of falling %				.55
Not at all	40	30	47	
Somewhat	38	50	36	
Fairly	12	12	11	
Very	10	8	6	
Mean fall efficacy score ± SD	14.0 ± 3.9	14.2 ± 4.0	13.3 ± 2.7	.73
Education, n (%)				.65
Elementary/high school	15 (20.8)	18 (28.1)	13 (20.3)	
College	41 (56.9)	29 (45.3)	33 (51.6)	
Graduate school	16 (22.2)	17 (26.6)	18 (28.1)	
Trouble falling asleep				.068
Most of the time	6 (8.3)	6 (9.4)	2 (3.1)	
Sometimes	14 (19.4)	22 (34.4)	28 (43.8)	
Rarely	33 (45.8)	25 (39.1)	24 (37.5)	
Never	19 (26.4)	11 (17.2)	10 (15.6)	

[†] More than 55 additional characteristics were not significantly different at baseline.
[‡] Standard deviations.
[§] Determined by *t* test or chi-square test.
TC = Tai chi; BT = Balance training; ED = Education.

analysis of covariance, with adjustment for significant or near-significant baseline variables (volunteer status, working for pay, presence of cataracts, mean BMI, and trouble falling asleep). There were no significant differences between the three treatment groups in preintervention primary outcome measures. An analysis using clusters of variables from a factor analysis yielded similar results and is therefore omitted.

Table 2 shows the significant changes over time that were observed in biomedical and psychosocial variables when the three intervention groups were compared. A significant group by time interaction was found in left hand grip strength ($P = .025$). Tukey pairwise comparisons indicated that left grip strength was more likely to decline over time in the BT and ED groups than in the TC group. Cardiovascular variables measured before and after a 12-minute walk around the perimeter of a large room also showed differences for the three intervention groups. Cardiovascular status measurements were collected before and after each intervention. Systolic blood pressure measured after a 12-minute walk showed a group by time interaction ($P = .053$), with the TC group having a greater reduction in systolic blood pressure (Tukey pairwise comparison). A group by time interaction was also observed for distance ambulated over 12 minutes. Interestingly, the BT and ED groups increased their walking distance (0.01 mile), whereas the TC group reduced the distance traveled by 0.02 mile (Tukey pairwise comparison, $P = .040$).

The generalized estimating equation was used to examine changes in ordinal psychosocial well-being variables, adjusting for baseline variables that differed significantly across groups, as well as trouble falling asleep, which showed a borderline significant difference across groups. Change in pre to postintervention scores on the fear of falling measure was significantly different for TC compared with the ED group participants ($P = .046$). A slight trend toward significant change was also found for the pre to postscores on the intrusiveness measure for TC compared with the ED group participants ($P = .058$). These changes indicated reduced fear of falling and increased sense of being able to do all that they would like to do for the TC participants, as compared with subjects randomized to the exercise control group.

No significant changes were observed across intervention groups in the remaining biomedical, functional status, and psychosocial variables measured before and after subjects' participation.

Falls and Injurious Falls

Using the FICSIT definition of falls, there were 209 falls, whereas applying the Atlanta site definition, 110 falls were noted. The distribution of these falls and the average surveillance time for falls are depicted in Table 3. The Andersen and Gill extension of the Cox proportional hazards model was applied to fall data for all 200 subjects. The unadjusted risk ratio (RR) for the TC group was significant ($P = .009$) using the FICSIT fall definition, but it was not significant using the Atlanta site-specific fall definition (Table 4). To obtain adjusted treatment effects, potential baseline risk factors for falls, including variables from the FICSIT common data base,[1] were first examined for association with one or more falls. These factors included age, gender, currently working for pay, volunteer status, Mini-Mental State Examination score, CES-D score, Trails A score, IADL total score, BMI, trouble falling asleep, waking up during the night, feeling rested in the morning, cataract history, fell in previous year, fear of falling, and fall efficacy score. The identified significant risk factors were fall occurrence in past year, fear of falling, and trouble falling asleep. The results with covariates, shown in Table 5, are comparable whether employing the FICSIT or Atlanta definition for a fall. Using the Atlanta site definition, the data suggest that the rate of falls was substantially reduced by 47.5% (RR = 0.525, $P = .01$) if subjects participated in the 15-week TC program, but was elevated if subjects had experienced falls within the past year before entering this study (RR = 2.016, $P = .0003$) or had a relatively higher score on the fear of falling questionnaire (RR = 1.417, $P = .0002$). The data also indicate that trouble falling asleep was associated negatively with one or more falls (RR = 0.611, $P = .00003$). Similar analyses were performed for time to one or more falls. There were no significant treatment differences before and after adjusting for covariates (Tables 4 and 5). Fell last year and fear of falling were associated with injurious falls, but not with trouble falling asleep (Table 5).

DISCUSSION

This study indicated several statistically significant outcomes associated with a comparatively brief TC intervention. Subjects who participated in the TC intervention had less loss in left hand grip strength, reduced ambulation speed, and lowered systolic blood pressure after a 12-minute walk. Fear of falling and intrusiveness improved in the TC group compared with the ED group. Finally, TC participants had a substantial reduction in the rate of falls' occurrences.

As discussed above, several measures were examined in order to evaluate effects on primary outcome variables that might be related to TC and BT. Statistically significant changes were observed for only a few of these measures (complete data sets available from primary author upon request). However, this study showed a significant reduction in falls events, a secondary outcome, following subjects' participation in the TC intervention, along with reduced fear of falling expressed by these subjects. These data exemplify the beneficial effects of this balance intervention, for which aggregate cross-site data from the FICSIT studies have provided support in a meta-analytic investigation.[32]

Less loss of grip strength in the TC group was an unexpected observation. However, our subjects did not engage in activities designed to strengthen the upper extremities during the intervention, and the clinical relevance of this change (0.7 versus 0.8) is not apparent. The training for TC and BT participants included forward leaning, which stretched their heel cords, and raising their knees upward, thereby contracting hip flexor muscles in the process. The fact that no differences were found between groups in the change of hip flexion and ankle plantar flexion

Table 2. Significant Group and Time Differences for Strength, Cardiovascular and Psychosocial Well-being Outcome Variables

	TC				BT				ED				
Variables[†]	n	Pre	Post	Follow	n	Pre	Post	Follow	n	Pre	Post	Follow	*P*
Strength, mean ± SD													
Grip strength left	58	23.2 ± 8.2	22.5 ± 8.5	22.8 ± 8.1	50	24.8 ± 8.1	23.8 ± 8.0	23.1 ± 8.0	54	23.8 ± 6.5	22.0 ± 6.2	22.2 ± 6.6	.0249*
Cardiovascular, mean ± SD													
Systolic blood pressure post walk (mmHg)	81	172.1 ± 27.7	158.9 ± 27.4		53	170.5 ± 33.0	165.5 ± 25.8		53	164.0 ± 26.8	162.3 ± 27.3		.0525*
Distance (miles)	56	0.57 ± 0.09	0.55 ± 0.10		50	0.56 ± 0.09	0.57 ± 0.08		52	0.57 ± 0.08	0.58 ± 0.11		.0397*
Psychosocial well-being													
Fear of falling (%)													.046**
Not at all afraid	60	43	53	47	51	29	27	33	54	44	35	41	
Somewhat afraid		33	39	37		51	47	43		37	44	35	
Fairly afraid		13	2	8		14	14	12		11	13	15	
Very afraid		10	7	8		6	12	12		7	7	10	
Intrusiveness (%)													.058**
Strongly agree	60	22	33	28	51	27	31	33	54	28	35	32	
Agree somewhat		57	50	57		55	49	49		57	43	52	
Disagree somewhat		15	12	10		16	18	17		11	17	15	
Strongly disagree		7	5	5		2	2	2		4	6	2	

[†] Differences in baseline values not significant across groups (SD ± standard deviation).
* *P* values for group × time interaction.
** *P* value of tai chi vs education for pre-post changes.
TC = Tai chi; BT = Balance training; ED = Education.

Table 3. Distribution of Falls, by Intervention Group

FICSIT Group	Number of Falls			Average Follow-Up Time (days)
	FICSIT Definition	Atlanta Site Definition	Difference	
Tai chi	56	29	27	171
Balance training	76	44	32	164
Education	77	37	40	164
Total	209	110		

† Subjects who had more than one fall are counted more than once.
FICSIT = Frailty and Injuries: Cooperative Studies of Intervention Techniques.

may be attributable to a 5 (degree) goniometric reading error.[33] Compared with the practice of TC in China, our intervention intensity was quite modest,[34] and this may explain why we did not observe changes in strength and flexibility similar to changes reported when TC is practiced routinely.

The change in systolic blood pressure after a 12-minute walk was larger for TC participants than for BT or ED subjects (Table 2). In the literature discussing cardiovascular changes in older TC practitioners, only one study[35] reported that Chinese TC practitioners older than age 60 reduced their resting systolic blood pressure to 134 mmHg compared with a sedentary group (resting systolic blood pressure, 154 mmHg). These values are lower than seen in our treatment groups and may be the result of different age range and exercise intensity, which were not reported previously.[35] TC subjects slowed their walking speed, as measured by reduction in the distance they traversed over 12 minutes. BT and ED subjects, however, actually showed a small increase in distance ambulated (52 feet). TC emphasizes slow, rhythmic movements and awareness of the environment,[17] behaviors that are consistent with subjects' shorter ambulation distance (walking 104 feet less than at baseline) and lowered cardiovascular responses. Whether changes in distance ambulated might have been caused by awareness of pain or movement limitations associated with TC practice or attributable to enhanced awareness of the environment cannot be determined. Further investigations are needed.

One study[36] demonstrated that regular TC practice could significantly improve participants' balance control in three of five clinical tests, compared with a matched group of nine nonparticipants. TC has also been shown to have no adverse effects on active range of motion[38] or weight bearing joint integrity of rheumatoid arthritis.[39] The present study provides the first insight into TC effects on balance control through monitoring falls. When survival analyses were performed with adjustments for baseline covariates, TC was associated with less risk for one or more falls in the presence of identified risk factors (Table 5). At the same time, BT did not reduce the rate of falls in this study. This finding is surprising because center of mass feedback is known to improve balance control under specifically defined circumstances.[14]

Three risk factors—having fallen within the past year, fear of falling, and ease of falling asleep at night—had a statistically significant relationship to the occurrence of one or more falls. Data from several reports[11,12,38] suggest that past falls are predictive of future fall events which, in turn, must be considered within the context of multiple contributing factors.[5,10,40] Subjects who had trouble falling asleep experienced a longer onset to one or more fall events. Certain behaviors, such as sleep apnea,[41] may result in poor quality of sleep and reduced alertness during waking hours. Use of medications, such as psychotropics,[42] antihypertensives, or antidepressants[43,44] may be conducive to feeling as though a sleep state is readily attained, but, in reality, poor quality of sleep is achieved. A resulting inattentiveness

Table 4. Unadjusted Estimates from the Anderson-Gill Extension of the Cox Proportional Hazards Model

Variables	Risk Ratio	95% Confidence Interval	*P*
Time to one or more falls			
FICSIT fall definition			
Tai chi indicator (0 or 1)	0.632	(0.45–0.89)	.009
Balance training indicator (0 or 1)	1.026	(0.74–1.41)	.872
Atlanta site specific fall definition			
Tai chi indicator	0.671	(0.41–1.09)	.107
Balance training indicator	1.215	(0.78–1.88)	.383
Time to one or more injurious falls			
Tai chi indicator	0.947	(0.39–2.33)	.907
Balance training indicator	1.362	(0.57–3.23)	.483

FICSIT = Frailty and Injuries: Cooperative Studies of Intervention Techniques.

Table 5. Adjusted Estimates from the Anderson-Gill Extension of the Cox Proportional Hazards Model

Variables	Risk Ratio	95% CI	*P*
Time to one or more falls			
FICSIT fall definition			
Tai chi indicator (0 or 1)	0.511	(0.361–0.725)	.017
Balance training indicator (0 or 1)	0.976	(0.710–1.341)	.879
Fell last year	1.756	(1.336–2.308)	.0006
Fear of falling	1.160	(1.009–1.335)	.0004
Trouble falling asleep	0.606	(0.0511–0.717)	.00006
Atlanta site specific fall definition			
Tai chi indicator (0 or 1)	0.525	(0.321–0.860)	.010
Balance training indicator (0 or 1)	1.136	(0.733–1.760)	.589
Fell last year	2.016	(1.378–2.950)	.0003
Fear of falling	1.417	(1.180–1.700)	.0002
Trouble falling asleep	0.611	(0.483–1.770)	.00003
Time to one or more injurious falls			
Tai chi indicator (0 or 1)	0.812	(0.327–2.020)	.655
Balance training indicator (0 or 1)	1.174	(0.490–2.810)	.719
Fell last year	3.104	(1.476–6,530)	.003
Fear of falling	1.466	(1.039–2.040)	.029
Trouble falling asleep	0.915	(0.598–1.399)	.680

CI = confidence interval; FICSIT = Frailty and Injuries: Cooperative Studies of Intervention Techniques.

during waking hours may lead to fall-related events. However, an association was not found between medication(s) usage, medical history, BMI, and sleep scores for the entire sample or for intervention groups, nor was there evidence that subjects misunderstood sleep questions. The potential relationship between trouble falling asleep and sustaining a fall warrants further investigation.

Many TC participants provided anecdotal testimony on aborted falls' events, independently reporting awareness of both the environment and appropriate body maneuvers in the presence of unexpected perturbations. Moreover, almost half of all TC subjects chose to continue meeting as an informal group to practice TC after conclusion of the follow-up assessment. Future studies should investigate outcomes associated with TC training as a function of different instructional techniques, different TC leaders, a target diagnostic group such as individuals with rheumatoid arthritis, and an increased intervention intensity. These data suggest that TC can influence older individuals' functioning and well-being significantly and provide some appreciation for why this exercise form has been practiced by older Chinese for more than 3 centuries.

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