

Tai Chi and Fall Reductions in Older Adults: A Randomized Controlled Trial

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Background. The authors' objective was to evaluate the efficacy of a 6-month Tai Chi intervention for decreasing the number of falls and the risk for falling in older persons.

Methods. This randomized controlled trial involved a sample of 256 physically inactive, community-dwelling adults aged 70 to 92 (mean age, 77.48 years; standard deviation, 4.95 years) who were recruited through a patient database in Portland, Oregon. Participants were randomized to participate in a three-times-per-week Tai Chi group or to a stretching control group for 6 months. The primary outcome measure was the number of falls; the secondary outcome measures included functional balance (Berg Balance Scale, Dynamic Gait Index, Functional Reach, and single-leg standing), physical performance (50-foot speed walk, Up&Go), and fear of falling, assessed at baseline, 3 months, 6 months (intervention termination), and at a 6-month postintervention follow-up.

Results. At the end of the 6-month intervention, significantly fewer falls ($n = 38$ vs 73 ; $p = .007$), lower proportions of fallers (28% vs 46%; $p = .01$), and fewer injurious falls (7% vs 18%; $p = .03$) were observed in the Tai Chi group compared with the stretching control group. After adjusting for baseline covariates, the risk for multiple falls in the Tai Chi group was 55% lower than that of the stretching control group (risk ratio, .45; 95% confidence interval, 0.30 to 0.70). Compared with the stretching control participants, the Tai Chi participants showed significant improvements ($p < .001$) in all measures of functional balance, physical performance, and reduced fear of falling. Intervention gains in these measures were maintained at a 6-month postintervention follow-up in the Tai Chi group.

Conclusions. A three-times-per-week, 6-month Tai Chi program is effective in decreasing the number of falls, the risk for falling, and the fear of falling, and it improves functional balance and physical performance in physically inactive persons aged 70 years or older.

FALLS among older persons are a serious public health problem (1–3) leading to widespread loss of independence, increases in the chronic disease mortality rate, and the need for costly long-term care. Approximately 35% to 40% of generally healthy, community-dwelling persons aged 65 or older fall annually (4). More than 50% of falls among elderly persons result in at least some minor injury (5). Approximately 5% to 15% of these falls result in serious injury (2,6,7) requiring hospitalization (4). Falls are also closely associated with musculoskeletal problems, including impaired balance (8,9) and restricted mobility (7). Efforts to reduce the incidence of falls among the elderly and associated health care costs have thus become an important public health mission.

Several preventive intervention strategies have proven effective in preventing falls and decreasing the risk for falling (4,7,10,11), although less is known about their effectiveness in preventing fall-related injuries (11). Exercise has been a key feature in reducing the risks for falls (10–13), and for older persons, Tai Chi has become a popular choice of exercise. As a nontraditional form of exercise, Tai Chi is receiving increasing research attention, mainly because Tai Chi is purported to be beneficial for improving flexibility and balance, through its unique capacity to enhance lower-extremity strength and improve postural stability (14–17).

Tai Chi has also been shown to reduce the risk for falls and fear of falling. In a 15-week randomized trial, Wolf and colleagues (18) reported a fall risk ratio of .53, demonstrating that older adults who participated in Tai Chi had a 47% reduced relative risk for multiple falls, compared with an exercise control group. The results of this study provided the first evidence of the potential for Tai Chi to decrease the number of falls and the risk for falling. In a joint communiqué on the prevention of falls among the elderly, the American Geriatrics Society, the British Geriatrics Society, and the American Academy of Orthopedic Surgeons suggested that Tai Chi "... is a promising type of exercise, although it requires further evaluation before it can be recommended as the preferred balance training" (4). To act on this recommendation, we conducted a randomized controlled trial of the effect of Tai Chi on falls and the risk for falling in older persons who are particularly susceptible to falling. The primary objective of this study was to evaluate the efficacy of a 6-month Tai Chi intervention on falls in a sample of adults aged 70 years and older. Two secondary objectives of the study were to: 1) assess functional ability (balance, physical performance) and fear of falling, and 2) determine, during a 6-month postintervention follow-up, whether intervention gains obtained during the 6-month intervention could be maintained.

METHODS

Study Design

The study was a parallel-group, randomized, controlled trial involving 2 intervention arms: Tai Chi and stretching control. Each arm included a 1-hour class, three times per week for 26 consecutive weeks (or 6 months). The trial was primarily designed to investigate the efficacy of Tai Chi, compared with a low-level stretching activity, for decreasing the number of falls and the risk for falling. The intervention phase lasted 6 months and was followed by a 6-month (postintervention) follow-up period in which no exercise classes were provided. Outcome data were collected at baseline, 3 months, and 6 months (intervention termination), and at a 6-month postintervention follow-up, between March 2001 and May 2002. The institutional review boards of the Oregon Research Institute and the Legacy Health System approved the research protocol, and all study participants provided informed consent before they enrolled in the study.

Participants

Participants were recruited from the pool of patients enrolled in the Legacy Health System in Portland, Oregon, between February 2001 and November 2002. Eligibility criteria included being 70 years or older; inactive (defined as not being involved in any moderate or strenuous activity in the previous 3 months); being an independent ambulator; being free of chronic medical problems that would limit participation in low-to-moderate intensity exercise; having a physician's clearance to participate; and having no cognitive impairments (19).

Study Protocol

Elderly patients (aged 70 years or older) who were enrolled in the Legacy Health System received a letter signed by their primary care physician encouraging participation in an exercise trial. Research staff made an initial follow-up telephone contact and screened potential participants to establish their interest and eligibility for the study. Those who met the study criteria and agreed to participate were scheduled for an assessment in which the study was described in further detail and informed consent was obtained. Participants underwent baseline assessments, after which they were randomized to either a Tai Chi or a stretching control condition, using computer-generated random numbers with an allocation ratio of 1:1. Assignment numbers were concealed from all participants, who did not learn of their assignment condition until baseline assessments were completed. Trained assessors conducted all study outcome assessments. These study assessors were not privy to information that would allow them to compare scores with any previous assessments, nor were they involved in randomization or the intervention training. All assessments and surveys (baseline, 3 months, 6 months [intervention termination], and 6 months after intervention) were made at a prescheduled appointment with each participant.

Intervention

Tai Chi.—The Tai Chi classes were taught by experienced Tai Chi instructors who followed the classical Yang style (24 forms) (20), which emphasizes multidirectional weight shifting, awareness of body alignment, and multisegmental

(arms, legs, and trunk) movement coordination. Synchronized breathing (aligned with each Tai Chi movement) was also emphasized and integrated into the Tai Chi movement routine. Sessions included 5 to 10 minutes of warm-up, Tai Chi practice, and 5 to 10 minutes of cool-down. Instruction covered learning new movements and reviewing movements learned in previous sessions. Each practice session included musical accompaniment.

Stretching control.—This program, taught by qualified exercise instructors, consisted predominantly of seated exercises, comprising stretches, controlled breathing, and relaxation. The rationale for designing this condition was to provide participants with a structured, low-intensity exercise program that would contain comparable social interaction and enjoyment, without providing the lower-extremity strength and balance training benefits of Tai Chi. The weekly schedule and class format was identical to that of Tai Chi. Each session consisted of exercises that focused on a variety of seated and standing stretches for the trunk and upper body, accompanied by deep abdominal breathing.

Outcome Measures.—The primary outcome measure of falls was assessed using fall counts, recorded by each participant in a daily "fall calendar." Participants were asked to record any fall event and to indicate whether the fall caused them to seek medical attention. A fall was defined as landing on the floor or the ground, or falling and hitting objects such as stairs or pieces of furniture, by accident. A fall was considered "injurious" if it resulted in fractures, head injuries, sprains, bruises, scrapes, or other serious joint injuries (21,22), or if the participant sought medical care. Falls were monitored for all participants throughout the 6-month intervention and the 6-month postintervention period, or until the date that they withdrew from the study. A research assistant collected fall records, which were coded by another research assistant, who was blinded to intervention assignment and study hypotheses. Data records of injurious falls and medical care received for falls were verified from either hospital or clinic medical records or participant self-reports.

Secondary outcomes included functional balance, physical performance, and fear of falling. Functional balance measures included the Berg Balance Scale (23), which evaluates a person's ability to perform 14 different tasks of increasing difficulty; the Dynamic Gait Index (24), which evaluates a person's ability to modify gait in response to changing task demands; Functional Reach (25), which assesses the maximal distance a person can reach forward beyond arm's length while maintaining a fixed base of support in a standing position; and single-leg standing tests, which measure right and left leg standing for a maximum of 60 seconds (eyes open and closed for each leg).

Physical performance tests involved the 50-foot speed walk (26) and the Up&Go (27). The 50-foot walk measures the time taken to walk 50 feet. The Up&Go measures the time taken to rise from a chair, walk 10 feet (3 meters), return, and sit down. Fear of falling was assessed by the Survey of Activities and Fear of Falling in the Elderly (SAFFE) (28), which consists of 11 items representing activities of daily living and instrumental activities of daily living associated with fear of

falling, mobility, and social activities. The SAFFE score was calculated by averaging item responses (possible range: 0 = not at all worried to 3 = very worried), with higher scores indicating greater fear of falling.

Statistical Analyses

We analyzed the data using the principle of intention to treat, so that all participants were included according to original group assignment and analyzed regardless of adherence to intervention or dropout status. We compared baseline demographic and functional measures across groups using analysis of variance for continuous variables and the chi-square or Fisher's exact test (when cell sizes were less than five) for categorical variables. We calculated the number of falls, injurious falls, and medical care resulting from a fall during the 6-month intervention for each group and across groups. Where appropriate, we used the chi-square or Fisher's exact test to compare between-group differences in frequency of falls, injurious falls, and medical visits resulting from a fall. Formal evaluation of the impact of the intervention on the primary endpoint was based on: 1) Kaplan–Meier survival methods, which analyze time to the first fall; 2) the Cox proportional hazards model of the hazard ratio for falls accounting for relevant baseline covariates; and 3) the extension of the Cox model (29), which allows for multiple events (i.e., recurrent falls) per participant. In all the proportional hazards models, we included important baseline covariates. Participants who withdrew before the end of the study were censored at the time of withdrawal. We also calculated and reported fall counts and fall rates during the 6-month postintervention follow-up period. We performed repeated measures analysis of variance (Group \times Time) to assess the effect of intervention on the secondary outcome measures of functional ability and fear of falling. To determine whether the gains achieved during the intervention deteriorated during the 6-months postintervention follow-up, we compared all functional balance, physical performance, and fear of falling scores from the follow-up assessments with participants' postintervention scores using a Group by Time analysis of variance. All probability values are two tailed. To correct for the use of multiple comparisons on measures of functional balance, we applied a Bonferroni adjustment correction, and only probability values equal to or less than .007 were considered significant for balance measures. We used Statistical Analysis System (30) and Statistical Package for the Social Sciences (31) software for all analyses.

The goal of this Tai Chi intervention was to reduce falls risk by approximately 50% compared to the stretching control condition (18). Based on a .80 power to detect a significant between-group difference on the primary outcome of falls ($p = .05$), 130 participants were required for each group. This allowed us to detect a difference of .15 between the proportions not falling in the Tai Chi (0.85) and stretching control (0.70) groups, respectively, on completion of the 6-month intervention. The calculation was based on the assumption that the risk of falling within 6 months for a stretching control participant was .30.

RESULTS

An initial pool of 2308 persons from the patient database was screened for initial age eligibility. Of these, we

contacted 669 persons who were 70 years or older for further screening. Four hundred thirteen (62%) of these were not randomized because they did not meet the extra screening criteria (16%), were noncommittal (10%), had no interest (14%) or declined (10%), were in poor health (9%) or deceased (2%) or out of reach (2%), had language barriers (2%) or transportation problems (5%), or gave unidentified reasons for not participating (30%). Two hundred fifty-six (38% of the original pool of 669) eligible persons were finally randomized. Of the 256 randomized participants, 34 (13%) dropped out ($n = 10$ in Tai Chi; $n = 24$ in exercise control) immediately after randomization. These 34 persons never attended a single intervention session for reasons including health-related causes ($n = 14$), a dislike of the group into which they were randomized ($n = 10$), and time conflicts ($n = 10$). Figure 1 shows a summary of study participant flow and retention throughout the 6-month intervention trial.

Baseline Characteristics

The 2 intervention groups were comparable with regard to demographic descriptors at baseline (Table 1). We found no statistical differences in demographic variables or key functional outcomes between those who attended intervention classes ($n = 222$) and those who did not attend (no-shows; $n = 34$). With regard to fall-related information at baseline, 53 (42%) of those assigned to Tai Chi and 41 (31%) of those in the stretching control group reported one or more falls in the 3 months before study entry ($p = .08$). Twenty-four (19%) in Tai Chi and 22 (17%) in the stretching control group reported injurious falls ($p = .37$), and a further 15 (12%) in Tai Chi and 17 (13%) in the stretching control group reported receiving medical attention resulting from a fall ($p = .39$) before study entry.

Intervention Compliance, Retention, and Adverse Events

We calculated class compliance rates across the 26-week period (78 sessions) for all class-attending participants ($n = 222$). Median compliance was 61 sessions for both groups, ranging from 30 to 77 sessions for Tai Chi participants and from 35 to 78 sessions for the controls. Ninety-two (80%) Tai Chi participants and 87 (81%) stretching control participants attended 50 or more sessions. A total of 47 (21%) participants withdrew ($n = 24$ in Tai Chi, $n = 23$ in the control group) during the intervention period. The overall dropout rate (excluding no-shows) during the 6-month intervention was 21% (Tai Chi, 24 of 115; control, 23 of 107). We found no statistical differences in baseline demographics (e.g., age, sex, health status, medication use, history of falls), fall counts, and functional ability measures between participants who dropped out ($n = 47$) and the remaining participants ($n = 175$). No intervention-related injuries or falls were observed during the course of the study.

Change in Primary Endpoint Measure

Table 2 shows information on falls during the 6-month intervention trial. A total of 188 study participants provided follow-up data on falls. At the end of 6 months of intervention, significantly fewer falls occurred in the Tai Chi group than in the stretching control (38 vs 73, $p = .007$), and a lower proportion of falls occurred in the Tai Chi (28%) than in the control group (46%) ($p = .01$). Figure 2

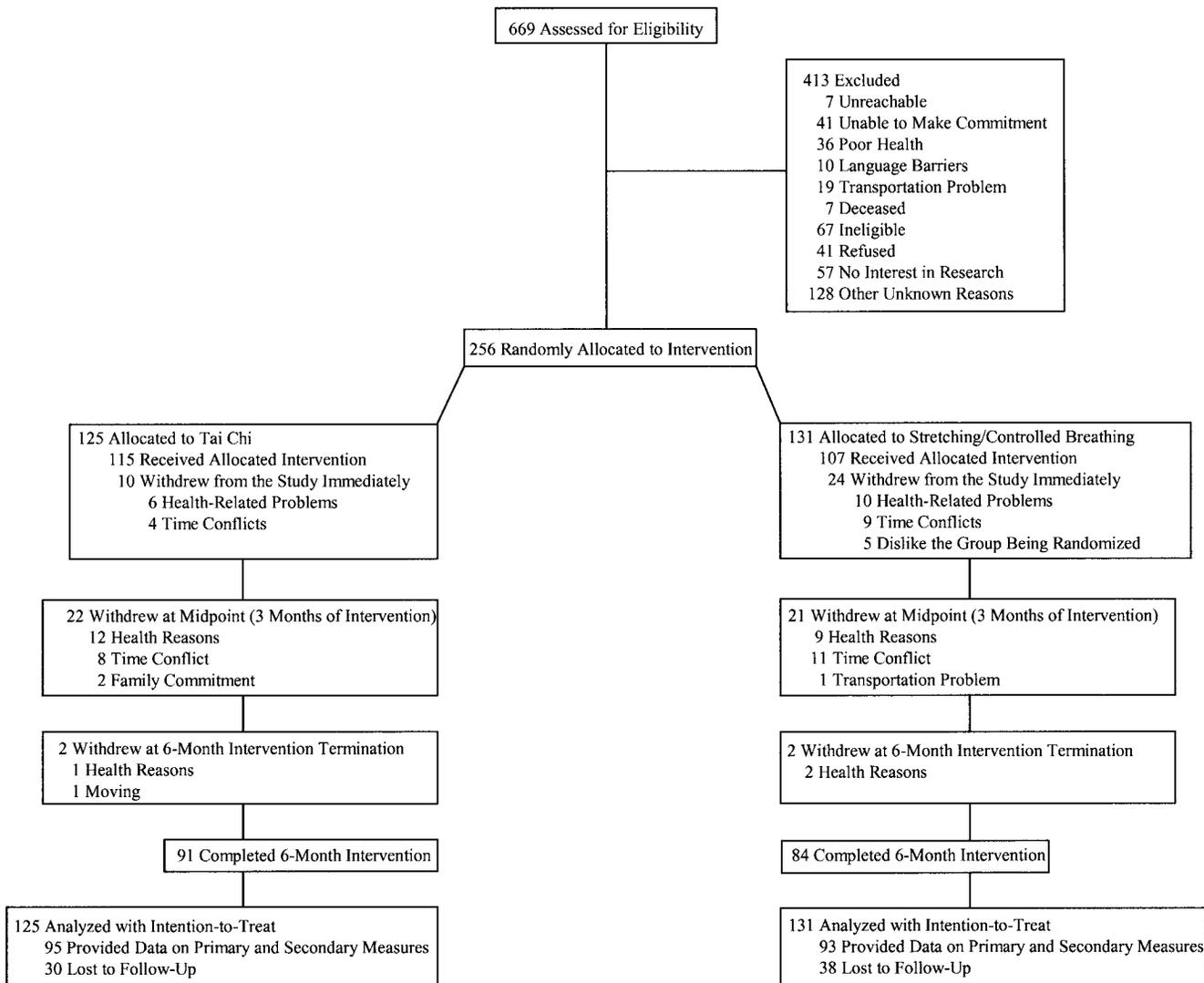


Figure 1. Study participant enrollment and follow-up is profiled. The number of participants for whom data were available is greater than the number of participants who completed the 6-month intervention because some of participants who withdrew provided follow-up data.

shows the percentage of participants who reported one or more falls during each month of intervention. Although some initial reduction occurred after the first month for the Tai Chi group, the most evident reduction began after the first 3 months of training.

We observed 24 injurious falls during the intervention period. Seven Tai Chi participants reported injurious falls compared with 17 controls ($p = .03$). We considered most of these injurious falls ($n = 21$) moderate (i.e., bruises, sprains, scrapes on the hands, elbows, knees, or legs), and only 3 participants reported severe injury (i.e., fractures or broken ribs). Of those who reported injurious falls, Tai Chi participants reported significantly fewer medical care visits resulting from an injurious fall ($n = 5$) compared with controls ($n = 14$) ($p = .03$). We used medical records (68%) and self-reports (32%) to confirm the injury data on falls that required medical care. The relative risk for moderate injurious falls for Tai Chi compared with the control condition was 0.31 (95% confidence interval [CI], 0.12 to

0.84), and the relative risk for severe falls requiring medical attention was .28 (95% CI, 0.09 to 0.86).

We found significant difference between the intervention and stretching control groups in the length of time to the first fall (log-rank = 7.34, $p = .007$). The hazard ratio (unadjusted) for the Tai Chi group compared with the stretching control group was .48 (95% CI, 0.28 to 0.83; $p = .009$). The risk ratio remained significant after adjustment for the baseline covariates of age, sex, health status, medical condition, fall history, and fear of falling (risk ratio = .46, 95% CI, 0.26 to 0.80, $p = .006$). Similarly, using the extension of the Cox model method, the hazard ratio for falls for the Tai Chi group compared with the stretching control group for multiple falls was .45 (95% CI, 0.30 to 0.70, $p < .001$), after adjustment for the baseline covariates, indicating that the Tai Chi group had a significantly reduced risk for multiple falls.

Change in Secondary Endpoint Measures

Table 3 presents summary results on the secondary outcome measures during the 6-month intervention trial.

Table 1. Baseline Characteristics of Study Participants by Randomized Group*

	Tai Chi (N = 125)	Control (N = 131)	p value
Demographic			
Female sex, no. (%)	87 (70)	92 (70)	.50
Age, y	76.94 ± 4.69	77.99 ± 5.14	.09
White, no. (%)	112 (90)	120 (91)	.38
High school education or higher, no. (%)	118 (94)	118 (90)	.20
Household income below \$35,000, no. (%)	80 (64)	93 (70)	.24
Living alone, no. (%)	60 (48)	62 (47)	.39
Occasional use of walking aid, no. (%)	26 (21)	24 (18)	.33
Health status [†]	3.27 ± 0.73	3.21 ± 0.81	.54
Afraid of falling, no. (%) [‡]	109 (87)	109 (83)	.27
Medical visit			
No. of visits to health care providers(s) in the past 3 months (%)	105 (85)	105 (80)	.18
No. of overnight hospital stays over the past 3 months (%)	13 (10)	6 (5)	.13
Treated by an alternative or complementary medicine health care provider in the past 3 months, no. (%)	10 (8)	16 (12)	.23
Medical condition			
Arthritis, no. (%)	60 (48)	77 (59)	.08
Heart disease, no. (%)	40 (32)	42 (32)	.50
High blood pressure, no. (%)	77 (62)	74 (57)	.29
Chronic lung disease, no. (%)	15 (12)	13 (10)	.35
Diabetes, no. (%)	11 (9)	15 (12)	.29
Osteoporosis, no. (%)	25 (20)	27 (21)	.39
Depression, no. (%)	15 (12)	16 (12)	.50
Chronic back pain, no. (%)	32 (26)	37 (28)	.37
Cancer, no. (%)	31 (25)	21 (16)	.08
Trouble with vision, no. (%)	56 (45)	57 (44)	.39
Trouble with hearing, no. (%)	46 (39)	44 (34)	.28

Notes: * Plus-minus values are means ±SD (standard deviation).

† This is measured on a 5-point Likert scale with 1 = Poor and 5 = Excellent; higher scores indicate better health.

‡ This is measured on a single dichotomous item (Are you afraid of falling?), with 1 = Afraid, 0 = Not afraid.

Analyses of repeated measures showed a significant intervention benefit attributable to Tai Chi for all four functional balance measures: Berg Balance Scale ($p < .001$), Dynamic Gait Index ($p < .001$), Functional Reach ($p < .001$), and the single-leg standing tests ($p < .001$). We observed no within-group change for the stretching control condition. We also observed effects attributable to Tai Chi for the two physical performance measures, with the Tai Chi group showing significantly improved scores for the 50-foot speed walk ($p < .001$) and Up&Go tests ($p < .001$), compared with the stretching control condition. On the SAFFE fear-of-falling measure, participants in the Tai Chi group reported a lower fear-of-falling mean score than did those in the stretching control condition ($p < .001$).

Maintenance of Intervention Gains

For the 6-month postintervention follow-up, data on falls were available for 188 participants ($n = 95$ in Tai Chi, 93 in

Table 2. Falls Information During 6-Month Intervention, According to Treatment Group*

	Tai Chi (N = 95)	Control (N = 93)
Falls		
Any falls, no. (%)	27 (28)	43 (46)
Participants reporting one fall, no. (%)	20 (21)	22 (24)
Participants reporting two falls, no. (%)	5 (5)	15 (16)
Participants reporting three or more falls, no. (%)	2 (2)	6 (6)
Total falls reported	38	73
Patients with injurious falls, no. (%)	7 (7)	17 (18)
Falls resulting in medical care, no. (%)	5 (5)	14 (15)

Note: * Based on all available participants who provided fall data during the 6-month intervention period.

exercise control). During this follow-up period, 15 participants in the Tai Chi group reported a total of 18 falls and 43 participants in the control group reported 49 falls. The number of participants who reported falls in the Tai Chi group was significantly lower than that in the control group ($p < .001$). The incidence rate (calculated as the number of falls per participant-time of follow-up) for Tai Chi was 3.16 falls per 100 participant-months of observation, compared with 8.96 falls per 100 participant-months of observation for the control group ($p < .001$).

The right-hand side of Table 3 shows intervention group comparisons between the 6-month intervention termination scores and the 6-month postintervention follow-up scores on functional ability (balance, physical performance) and fear-of-falling outcome measures. When we used the Bonferroni adjusted significance level ($.05 / 7 = .007$), we found no significant Group × Time interaction or Time effects on the seven balance measures, indicating that the balance scores for the 2 groups, observed at the end of the 6-month intervention, were maintained at follow-up. We observed significant Group × Time effects for two measures of physical performance (the 50-foot speed walk, the Up & Go) and fear of falling (SAFFE). The direction of the interaction

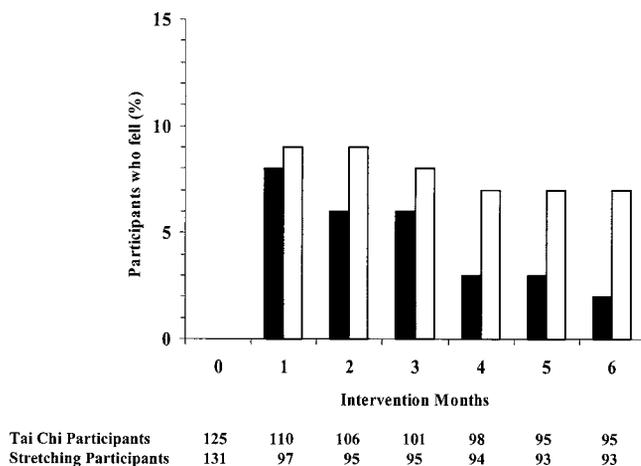


Figure 2. The percentage of participants who fell during the intervention months (month 1 through month 6) is shown. The numbers at the bottom of the figure represent the numbers of participants remaining in the trial at the end of each month. Filled columns, Tai Chi participants; open columns, stretching participants.

Table 3. Summary of Results: Baseline, Midpoint, Endpoint, and Follow-Up Scores by Intervention Conditions*

Variable	Baseline		Midpoint (3-Month)		Intervention Termination (6-Month)		Postintervention Follow-Up (12-Month)		p Value†	
	Tai Chi (N = 125)	Control (N = 131)	Tai Chi (N = 125)	Control (N = 131)	Tai Chi (N = 125)	Control (N = 131)	Tai Chi (N = 125)	Control (N = 131)		
	Mean ± SD		Mean ± SD		Mean ± SD		Mean ± SD			
Berg Balance Scale (range, 0–56)	45.67 ± 3.92	46.18 ± 4.53	48.65 ± 4.02	47.09 ± 4.56	49.28 ± 4.15	47.15 ± 4.22	48.69 ± 4.23	45.86 ± 5.09	<.001	.04
Dynamic Gait Index (range, 0–24)	19.40 ± 2.48	19.76 ± 2.89	20.94 ± 2.65	20.21 ± 3.04	21.43 ± 2.62	20.12 ± 3.07	21.10 ± 2.68	19.47 ± 3.24	<.001	.05
Functional Reach, in.	9.45 ± 2.41	8.90 ± 2.83	10.03 ± 2.29	8.80 ± 2.63	10.73 ± 2.48	8.69 ± 2.71	10.62 ± 2.49	8.38 ± 2.55	<.001	.01
Right Leg-Stand (eye-open, s.)	6.76 ± 8.90	7.25 ± 8.44	9.34 ± 10.71	6.81 ± 9.54	13.18 ± 11.20	7.07 ± 10.21	13.03 ± 11.19	6.05 ± 8.36	<.001	.23
Left Leg-Stand (eye-open, s.)	6.96 ± 9.27	6.67 ± 8.63	10.66 ± 12.03	7.47 ± 11.37	13.14 ± 11.94	7.33 ± 11.43	12.46 ± 13.75	6.75 ± 9.36	<.001	.87
Right Leg-Stand (eye-closed, s.)	1.76 ± 1.40	1.72 ± 1.11	2.55 ± 1.80	1.64 ± 1.29	3.39 ± 2.32	1.63 ± 1.10	3.31 ± 2.21	1.56 ± 1.06	<.001	.94
Left Leg-Stand (eye-closed, s.)	1.79 ± 1.30	2.13 ± 3.10	2.54 ± 1.95	1.82 ± 1.72	3.10 ± 2.19	1.58 ± 1.07	3.05 ± 2.17	1.49 ± 0.92	<.001	.52
50-Foot Walk (s.)	14.15 ± 3.42	14.23 ± 3.38	13.00 ± 3.02	14.04 ± 3.53	12.37 ± 3.26	14.12 ± 3.51	12.60 ± 3.14	14.21 ± 3.50	<.001	.006
Up & Go (s.)	9.07 ± 2.35	9.30 ± 2.45	8.60 ± 2.15	9.29 ± 2.56	8.27 ± 2.23	9.31 ± 2.50	8.55 ± 2.16	9.36 ± 2.50	<.001	.001
Fear of Falling (range, 0–3)	0.62 ± 0.28	0.60 ± 0.32	0.37 ± 0.31	0.54 ± 0.35	0.28 ± 0.33	0.52 ± 0.37	0.30 ± 0.33	0.56 ± 0.35	<.001	.05

Notes: * Repeated measures analysis of variance with baseline, midpoint, and intervention termination data (Group × Time interaction).
 † Repeated measure analysis of variance with intervention termination and 6-month postintervention follow-up data (Group × Time interaction).
 SD = standard deviation.

effect indicates that Tai Chi participants maintained better scores on these measures compared with stretching controls.

DISCUSSION

Our results supported our a priori hypothesis that, compared with a low level stretching control activity, 6 months of Tai Chi practiced by older adults decreased the frequency of falls and the risk for falling (by 55%). The proportion of Tai Chi participants who fell during the 6-month intervention was also significantly lower compared with the controls, with the most evident reduction in falls being more pronounced after the initial 3-month exposure. These findings are in part consistent with the findings of the studies by Wolf and associates, which showed a significant reduction in the risk for multiple falls among robust older adults after 15 weeks of Tai Chi exercise (18) and among older, transitionally frail adults after a 3-month latency period of learning Tai Chi in a 48-week trial (32). To this end, this study provides an addition to the limited number of studies of the effectiveness of group-based exercise interventions designed to decrease the number of falls (11).

One of our most salient findings was the reduction in injurious falls at the end of the 6-month intervention. Although the study was not powered for detecting between-intervention groups for injurious falls as an outcome, Tai Chi practice resulted in significant reductions in injurious falls and fewer episodes of medical care associated with falls. This finding on injurious falls adds to the extant fall intervention research (13,21,33–35) by revealing the effectiveness of Tai Chi in reducing the frequency of falls and, more importantly, reducing injuries from falls, which has been considered a significant public health problem (6).

The particular characteristics of Tai Chi exercise, which emphasizes control over one’s displacement of body mass, postural alignment, and range of motion of joints and muscles of the lower body, may be part of a larger mechanism responsible for specific gains in leg strength and postural stability. This mechanism possibly prevents older adults from losing their balance, thereby decreasing the propensity to fall and the likelihood of injury resulting from a fall. However, Tai Chi exercise may have a latent effect in reducing falls. Our results indicate that several months of practice were needed before significant decreases in falls occurred, suggesting that no tangible results in falls should be expected from short-term exposure to Tai Chi (i.e., less than 3 months). However, given the continued downward trend in fall incidence (Figure 2) observed during the 6-month intervention, further decreases in fall incidence may be expected through sustained and frequent daily practice.

This is also the first randomized controlled study that considered a host of functional ability measures in a single trial with positive results. Contrary to findings from a laboratory-based balance study (36), our study showed improvements on clinic-based functional balance measures purported to be clinically relevant for fall interventions (37), and these results are generally congruent with those reported in cross-sectional and nonrandomized Tai Chi studies (38–40). Thus, although direct comparisons among studies are impossible because of test conditions, training protocols, sample sizes, and intervention length, the findings of this

study generally support the proposition that Tai Chi improves balance and postural control. Objective physical performance measures, which have rarely been evaluated in previous randomized controlled Tai Chi trials, also showed improvements during the 6-month intervention. This is in comparison to the results by Hartman and colleagues (41), who reported marginal improvements on similar physical performance measures through a twice-weekly exposure to Tai Chi in a 12-week trial involving older adults with osteoarthritis. Our results are also consistent with two previous Tai Chi trials on the evaluation of physical function (42,43). Taken together, the consistent findings across all our (clinic-based) functional measures have substantiated the effectiveness of Tai Chi for improving functional balance and physical performance in older adults.

Our results on fear of falling were consistent with those reported by Wolf and colleagues (18), which showed a significant reduction in fear of falling (assessed through a falls efficacy measure [44]) in Tai Chi compared with the control group. The current study, however, used a relatively new valid measure of fear of falling that contained a broader range of activities involving activities of daily living, mobility, and social activity (28,45), and provides further evidence that Tai Chi reduces levels of fear of falling in older adults.

It was also encouraging to observe that during the postintervention follow-up, improvements in our primary and secondary outcomes were maintained. To our knowledge, this is the first study to show that physical and psychological benefits achieved through Tai Chi can be maintained for at least 6 months after a formal in-class intervention period. A recent follow-up analysis showed that improved functional balance among Tai Chi participants during the 6-month trial was able to predict subsequent reductions in falls (46). In addition, our postintervention surveys indicated that most Tai Chi participants (66%) maintained some regular Tai Chi practice during the 6-month follow-up period, suggesting the acceptance and long-term feasibility of Tai Chi practice as an exercise choice by these older adults.

The consistent and positive change observed on balance and physical performance measures, combined with the results from a recent study on strength (47), suggest that Tai Chi may be an effective means of improving deficits in balance and functional limitations and, therefore, may serve as a therapeutic exercise for balance and strength for older persons. In reducing fear of falling among our study participants, Tai Chi may also be considered an exercise that generates confidence building to counteract this fear (48). Beyond these benefits, Tai Chi has the added advantages of being convenient and easily implementable in clinical care settings. Given the need for developing intervention strategies to reduce the rate of falling (4,7,49), current accumulated evidence suggests that Tai Chi can be delivered as a stand-alone regimen or be part of broader injury prevention programs in general medical practice or local health services.

Although increasing evidence shows that Tai Chi improves balance and postural control, and subsequently decreases the number of falls and the risk for falling, the underlying mechanism remains largely unknown. This calls for controlled and systematic evaluation of the character-

istics of movement kinematics, kinetics, and neuromuscular activity in Tai Chi and the need for better understanding of the integration of muscular, skeletal, and neural functioning and their interplay in the execution of Tai Chi movements. This will be important to provide increased knowledge of the way in which Tai Chi improves physical deficits (i.e., poor balance and strength) occasioned by senescence, and to open opportunities for an integrated approach to the analysis of multifaceted fall problems and their prevention. The question of costs (e.g., costs per fall prevented) also must be investigated before Tai Chi can be considered as a fall prevention program for the wider community.

This study has limitations related mainly to our ability to make generalizations based on our findings. First, 5 of the 13 research assessors were aware of some participants' intervention status during functional assessment sessions, which was a potential source of bias in these assessments. However, none of the research assistants was aware of any participants' previous scores, and most of our tests used objective criteria. Furthermore, no examiners conducting functional assessments were involved in any data entry or analysis of fall data, including the number of injurious falls or medical visits. Second, a substantial proportion (62%) of persons screened did not meet the entry criteria and were not recruited. Thus, the results should be considered in the context of the specific eligibility criteria set by the study. Finally, the effect of Tai Chi on several important geriatric syndromes, such as sarcopenia, chronic pain, and dementia, remains untested. Future trials that target frail elders with specific disease risk characteristics, involving collaborative trials with primary care providers in health care settings, will be required to broaden the general applicability of the effects of this intervention.

Conclusion

Older persons can decrease the number of falls and injurious falls by participating in a regular program of Tai Chi. Additional concomitant benefits of Tai Chi include improved functional balance and physical performance and reduced fear of falling, indicating the utility of Tai Chi for maintaining and promoting health and functional mobility among older adults. The sustained benefits of Tai Chi justify advocating long-term practice. With this accumulated evidence, the time is near for Tai Chi to be recommended as a preferred exercise for balance training and to be routinely prescribed for older patients at risk for falling after appropriate screening (4).

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REFERENCES

1. Alexander N. Falls. In: Beers MH, Berkow R, eds. *The Merck Manual of Geriatrics*, 3rd Ed. Whitehouse Station, NJ: Merck; 2000:195–212.
2. Fuller GF. Falls in the elderly. *Am Fam Physician*. 2000;61:2159–2168.

3. Sattin RW. Falls among older persons: a public health perspective. *Annu Rev Public Health*. 1992;13:489–508.
4. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. *J Am Geriatr Soc*. 2001;49:664–672.
5. Stevens JA, Hasbrouck L, Durant TM, et al. Surveillance for injuries and violence among older adults. *MMWR Morb Mortal Wkly Rep*. 1999;48:27–50.
6. King MB, Tinetti ME. A multifactorial approach to reducing injurious falls. *Clin Geriatr Med*. 1996;12:745–759.
7. Tinetti ME. Preventing falls in elderly persons. *N Engl J Med*. 2003;348:42–49.
8. Covinsky KE, Kahana E, Kahana B, et al. History and mobility exam index to identify community-dwelling elderly persons at risk of falling. *J Gerontol Med Sci*. 2001;56A:M253–M259.
9. Gardner AW, Montgomery PS. Impaired balance and higher prevalence of falls in subjects with intermittent claudication. *J Gerontol Med Sci*. 2001;56A:M454–M458.
10. Cumming RG. Intervention strategies and risk-factor modification for falls prevention: a review of recent intervention studies. *Clin Geriatr Med*. 2002;18:175–189.
11. Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH. *Interventions for Preventing Falls in Elderly People* (Cochrane Review). In: The Cochrane Library, Issue 3, 2003. Oxford: Update Software.
12. Gregg EW, Pereira MA, Gaspersen CJ. Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. *J Am Geriatr Soc*. 2000;48:883–893.
13. Province MA, Hadley EC, Hombrook MC, et al. The effects of exercise on falls in elderly patients. *JAMA*. 1995;273:1341–1347.
14. Hong Y, Li JX, Robinson PD. Balance control, flexibility and cardiorespiratory fitness among older Tai Chi practitioners. *Br J Sports Med*. 2000;34:29–34.
15. Lan C, Lai JS, Chen SS, et al. A 12-month Tai Chi training in the elderly: its effects on health fitness. *Med Sci Sports Exerc*. 1998;30:344–351.
16. Li F, Fisher KJ, Harmer P, et al. A simpler eight-form easy Tai Chi for elderly adults. *J Aging Phys Act*. 2003;11:206–218.
17. Yan JH, Downing JH. Tai Chi: an alternative exercise form for seniors. *J Aging Phys Act*. 1998;6:350–362.
18. Wolf LS, Barnhart HX, Kutner NG, et al. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. *J Am Geriatr Soc*. 1996;44:489–497.
19. Pfeiffer E. Short portable mental status questionnaire. *J Am Geriatr Soc*. 1975;23:433–441.
20. China National Sports Commission. *Simplified Taijiquan*. Beijing, China: People's Sports, 1983.
21. Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. *N Engl J Med*. 1994;331:821–827.
22. Tinetti, ME, Doucette JT, Claus EB. The contribution of predisposing and situational risk factors to serious fall injuries. *J Am Geriatr Soc*. 1995;43:1214–1221.
23. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. *Can J Public Health*. 1992;83:S7–S11.
24. Shumway-Cook A, Wollacott M. *Motor Control: Theory and Practical Applications*. Baltimore: Williams & Wilkins; 1995.
25. Duncan PW, Weiner DK, Chandler J, et al. Functional reach: a new clinical measure of balance? *J Gerontol A Biol Sci Med Sci*. 1990;45:M192–M197.
26. Reuben DB, Siu AL. An objective measure of physical function of elderly outpatients: the Physical Performance Test. *J Am Geriatr Soc*. 1990;38:1105–1112.
27. Podsiadlo D, Richardson S. The timed 'up & go': a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc*. 1991;39:142–148.
28. Lachman ME, Howland J, Tennstedt S, et al. Fear of falling and activity restriction: the Survey of Activities and Fear of Falling in the elderly (SAFFE). *J Gerontol Psychol Sci*. 1998;53:P43–P50.
29. Wei JJ, Lin DY, Weissfeld L. Regression analysis of multivariate incomplete failure time data by modeling marginal distributions. *J Am Stat Assn*. 1989;84:1065–1073.
30. SAS Institute, Inc. *SAS/STAT User's Guide*, version 6, 4th ed. Cary, NC: SAS Institute; 1996.
31. SPSS. *SPSS Reference Guide*. Chicago: SPSS; 1990.
32. Wolf SL, Sattin RW, Kutner M, O'Grady M, Greenspan AI, Gregor RJ. Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial. *J Am Geriatr Soc*. 2003;51:1693–1701.
33. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Tilyard MW, Buchner DM. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *BMJ*. 1997;315:1065–1069.
34. Campbell AJ, Robertson MC, Gardner MM, Norton RN, Buchner DM. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. *Age Ageing*. 1999;28:513–518.
35. Robertson MC, Campbell AJ, Gardner MM, Devlin N. Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. *J Am Geriatr Soc*. 2002;50:905–911.
36. Wolf SL, Barnhart HX, Ellison GL, Coogler CE. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques. *Phys Ther*. 1997;77:371–381; discussion 382–384.
37. Rogers ME, Rogers NL, Takeshima N, Islam MM. Methods to assess and improve the physical parameters associated with fall risk in older adults. *Prev Med*. 2003;36:255–264.
38. Tse SK, Bailey DM. T'ai chi and postural control in the well elderly. *Am J Occup Ther*. 1992;46:295–300.
39. Wong AM, Lin YC, Chou SW, Tang FT, Wong PY. Coordination exercise and postural stability in elderly people: Effect of Tai Chi Chuan. *Arch Phys Med Rehabil*. 2001;82:608–612.
40. Yan JH. Tai Chi practice improves senior citizens' balance and arm movement control. *J Aging Phys Act*. 1998;6:271–284.
41. Hartman CA, Manos TM, Winter C, Hartman DM, Li B, Smith JC. Effects of T'ai Chi training on function and quality of life indicators in older adults with osteoarthritis. *J Am Geriatr Soc*. 2000;48:1553–1559.
42. Li F, Fisher KJ, Harmer P, Irbe D, Tarse RG, Weimer C. Tai chi and self-rated quality of sleep and daytime sleepiness in older adults: a randomized controlled trial. *J Am Geriatr Soc*. 2004;52:892–900.
43. Li F, Harmer P, McAuley E, et al. An evaluation of the effects of Tai Chi exercise on physical function among older persons: a randomized controlled trial. *Ann Behav Med*. 2001;23:139–146.
44. Tinetti ME, Richman D, Powell L. Falls efficacy as a measure of fear of falling. *J Gerontol Biol Sci Med Sci*. 1990;45:P239–P243.
45. Li F, Fisher KJ, Harmer P, McAuley E, Wilson NL. Fear of falling in elderly persons: association with falls, functional ability, and quality of life. *J Gerontol B Psychol Sci Soc Sci*. 2003;58:P283–P290.
46. Li F, Harmer P, Fisher KJ, McAuley E. Tai Chi: improving functional balance and predicting subsequent falls in older persons. *Med Sci Sports Exerc*. 2004;36:2046–2052.
47. Christou EA, Yang Y, Rosengren KS. Taiji training improves knee extensor strength and force control in older adults. *J Gerontol Biol Sci Med Sci*. 2003;58A:763–766.
48. Li F, Fisher KJ, Harmer P, et al. Falls self-efficacy as a mediator of fear of falling in an exercise intervention for older adult. *J Gerontol B Psychol Sci Soc Sci*. 2005;60:P34–P40.
49. Preventive Services Task Force. *Guide to Clinical Preventive Services: Report of the U.S. Preventive Services Task Force*, 2nd ed. Baltimore: Williams & Wilkins, 1996:659–685.

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