Health benefits of Tai Chi for older patients with type 2 diabetes: The "Move It for Diabetes Study" – A randomized controlled trial

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Abstract: Older adults with type 2 diabetes have mobility impairment and reduced fitness. This study aimed to test the efficacy of the "Tai Chi for Diabetes" form, developed to address health-related problems in diabetes, including mobility and physical function. Thirty-eight older adults with stable type 2 diabetes were randomized to Tai Chi or sham exercise, twice a week for 16 weeks. Outcomes included gait, balance, musculoskeletal and cardiovascular fitness, self-reported activity and quality of life. Static and dynamic balance index (-5.8 ± 14.2; $p = 0.03$) and maximal gait speed ($6.2 \pm 11.6\%$; $p = 0.005$) improved over time, with no significant group effects. There were no changes in other measures. Non-specific effects of exercise testing and/or study participation such as outcome expectation, socialization, the Hawthorne effect, or unmeasured changes in health status or compliance with medical treatment may underlie the modest improvements in gait and balance observed in this sham-exercise-controlled trial. This Tai Chi form, although developed specifically for diabetes, may not have been of sufficient intensity, frequency, or duration to effect positive changes in many aspects of physiology or health status relevant to older people with diabetes.

Keywords: Tai Chi, Type 2 diabetes, physical function

Introduction

Type 2 diabetes has been estimated to affect over 100 million people worldwide and its prevalence is expected to increase to 300 million by 2025 (Bjork 2001). The condition is linked to declines in physical and psychosocial health and function (Ozdirenç et al 2003; Paschalides et al 2004). Although moderate-to-vigorous intensity aerobic exercise and resistance training have been shown to improve all aspects of insulin resistance syndrome, most adults with type 2 diabetes do not follow recommended physical activity guidelines (Mokdad et al 2003), and the high prevalence of obesity and osteoarthritis in this cohort may severely limit participation in many standard forms of exercise. The ancient Chinese martial art of Tai Chi is characterized by slow, smooth movements. Tai Chi has previously been reported to improve balance, rate of falls, aerobic capacity, gait, and osteoarthritis symptoms in older people (Wolf et al 1996; Hartman et al 2000; Taggart 2002; Christou et al 2003; Song et al 2003; Thornton et al 2004; Tsang and Hui-Chan 2004). Since older adults with insulin resistance syndrome are at higher risk for mobility disorders, arthritis, sedentariness, impaired aerobic fitness, and reduced quality of life compared to healthy adults (Lakka et al 2003), it is important to know if such benefits extend to diabetic people as well. A low-impact, low-intensity exercise such as Tai Chi may also address poor adoption of and adherence to typical aerobic exercise due to fear of injury in this population.

The aim of this study was to test the efficacy of an already-developed and widely-advocated Tai Chi program which was designed specifically for people with diabetes

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(Lam 2001), on mobility, physical function, and health-related quality of life in older people with type 2 diabetes. The results of the intervention on insulin resistance/glucose homeostasis and body composition have been reported (Tsang et al 2005). In this paper we present the results for the mobility, physical function, and quality of life outcomes, for which it was hypothesized that Tai Chi would improve all measures relative to controls.

Methods

Study design

The study was a single-blind, randomized, sham-exercise-controlled trial with an intention-to-treat design. The study was approved by Human Research Ethics Committee of the Universities of Sydney and New South Wales, Australia, and written informed consent was obtained.

Study population

Thirty-eight sedentary, older subjects with type 2 diabetes were recruited via community advertising. Subject screening included a telephone interview and a medical examination by the study physician. Subjects were eligible if they were ≥50 years of age, sedentary (≤2 exercise sessions/week), ambulatory without assistance, and had stable type 2 diabetes, defined as no change in diabetic medications for at least 3 months prior to study entry. Both aging and type 2 diabetes are related to decline in muscle function and performance (Duckrow et al 1999; Odenheimer et al 1994; Ringsberg et al 1999; Carlson 2000; Willey and Fiatarone Singh 2003) hence this ≥50 year age threshold was chosen. Exclusion criteria included cognitive impairment (MMSE ≤24), severe hip or knee arthritis (causing significant pain within 30 seconds of a semi-squat position), current Tai Chi participation, residence in a nursing home, amputation of a limb, severe visual impairment, and any condition that would have precluded the planned exercises in the opinion of the physician screening subjects.

Randomization

Subjects were randomly allocated to the intervention (Tai Chi) or control (sham exercise) groups. Permuted block randomization in blocks of four, stratified by gender was generated by an investigator not otherwise involved with study subjects using a computerized randomization program (Dallal 2003). Subjects were randomized following baseline assessment by handing them their group allocation in a sealed opaque envelope. They were blinded to the investigators' hypotheses regarding which was the active intervention arm.

Interventions

Both groups completed two supervised one-hour sessions each week for 16 weeks. All classes were run by the same investigator extensively trained in both forms of exercise. This same investigator performed the outcome measures also, due to limited staff availability. The Tai Chi group performed the "Tai Chi for Diabetes" exercise (Lam 2001), a 'hybrid' form of 12 movements from Sun and Yang Tai Chi styles, which utilizes soft, smooth, and subtle movements, with the knees bent in a slight semi-squat position. Each session commenced with specific warm-up exercises for the whole body (10 minutes) and concluded with cool-down exercises (5 minutes). The Tai Chi form was usually performed in its entirety three times each session (45 minutes) and also involved guidance in breathing techniques and visualization. Controls performed sham exercise (calisthenics and gentle stretching), previously shown to have no significant effects on physical or psychological outcomes (Pu et al 2001). Most of the exercises were conducted seated, with 5–10 minutes of standing exercises holding onto the back of their chairs. No resistance was used other than opposing gravity, no sustained isometric contractions, prolonged static stretches, or sustained rapid movements were performed, so as to minimize adaptations in the domains of strength, flexibility, and aerobic capacity. Both forms of exercise were presented to the subjects as being potentially beneficial to them, and naming the program, "Move It for Diabetes" assisted in the blinding of the subjects to the hypothesized beneficial exercise mode.

Adverse events

A weekly questionnaire probing possible adverse events (including falls) and all changes in health status was administered in person or by telephone in both groups throughout the trial. A fall was defined as unintentionally coming to rest on the ground, floor or other lower level object (excluding a chair or bed), whether the subject was hurt or not.

Exercise intensity/compliance

Intensity was monitored once for each subject during weeks 14–16. Heart rate was monitored using a Polar heart rate monitor (Polar Electro, OY, Finland) set to record heart rate every 15 minutes throughout the exercise session, as well as at rest and two minutes post-exercise. The average of all exercise heart rates obtained during the session was

calculated to estimate average exercise session intensity for each subject. The rating of perceived exertion was measured by the Borg scale (6–20). Rating of perceived exertion was recorded approximately every 15 minutes throughout the exercise session (at the same instance that heart rate was recorded) and averaged for each subject. Compliance to the program was determined as the percentage of sessions attended out of a total of 32 sessions, was calculated using the equation: (number of sessions attended ÷ 32) × 100.

Outcomes

Outcome measures were conducted at baseline (before randomization) and at follow-up (completion of 32 sessions). All measures were performed by the same investigator to maintain consistency in technique across all assessments.

Body composition and nutritional status

Fasting (12 hours) anthropometric measures included height (cm), mass (kg), and waist circumference (cm) using the method described by Norton et al (1996). Fat-free mass (kg), fat mass (kg), and total body fat (%BF) (%) was assessed by bioelectrical impedance analysis (RJL systems, Prizum, BIA-101S, MI, USA) using standardized procedures and calculated using the equation of Lukaski et al (1986). All anthropometric measures were assessed in triplicate, and the coefficient of variation (CV) calculated by dividing the standard deviation by the mean.

Physical function

The six-minute walk distance test (CV = 5% (Kervio et al 2003)) was administered as described by the American Thoracic Society. For habitual gait speed, the average of two trials was recorded, while the faster of two trials was recorded for maximal gait speed. Using the duplicate measurements for each subject, the CV for habitual gait speed as well as maximal gait speed was calculated. Both habitual and maximal gait speed were measured over a straight path of six meters (as performed previously in other trials (Gotlin et al 2000; Menz and Lord 2001), with a preceding acceleration lane of two meters, and a two meter deceleration lane following the six meter path. The six meter path was inconspicuously marked (only the researcher was aware of these markers) so the subjects were unaware that they were actually being timed between those points. The path was marked so subjects believed they were being timed from the start of the acceleration lane, until they passed the 'finish line', which

was at the end of the deceleration lane. For habitual gait speed, subjects were asked to walk at their own normal, comfortable speed, and were reminded that this was not a test of their fastest walking speed. Subjects were asked to walk as fast as they possibly could, without running, for the test of maximal gait speed.

Muscle performance

Keiser pneumatic-resistance training equipment modified with K400 software (Keiser Corporation, Keiser, 11–5416, Fresno, CA) was used to measure bilateral knee extensor strength (1 repetition-maximum, 1RM), peak power (the best trial recorded after explosively lifting loads of 40%, 50%, 60%, 70%, 80%, and 90% 1RM), and endurance (number of repetitions at 90% baseline 1RM). For all muscle performance tests, both legs were tested together. Range of motion was limited to 90 degrees, and the concentric phase of the movement was assessed. Subjects were required to lift the loads with good form, only to their full range of motion, which was determined by asking them to lift a minimum load as high as they could by extending their knees. One trial was permitted for each test, and an attempt was made to achieve 1RM within ten repetitions. To determine 1RM, subjects were given 1–2 minutes rest between each repetition, and the load was increased with each repetition performed with good form until failure was reached in approximately 10 repetitions. Failure was reached when the subject could not lift the weight through their full range of motion on at least two attempts, at least 90 seconds apart. For the power test, subjects were instructed to, *"Lift the weight as fast and explosively as you can – like a bullet out of a gun. Then slowly lower it back down."* Before the endurance test, subjects were asked to, *"Slowly lift the weight and lower it down – 3 seconds up, 3 seconds down, until I ask you to stop."* This test was terminated once they could no longer lift the load to their full range of motion in good form, or if they paused between any two repetitions for one second or longer.

Balance

Six tests of static balance and postural control were measured on a Chattecx Balance System (Balance System Dynamic, Chattecx, 1014, Chattanooga, TN): anterior-posterior sliding (of the platform) with eyes open and closed; anterior-posterior tilting (of the platform) with eyes open and closed; and 1-legged stance (platform stationary) with eyes open and closed. The order of these conditions

were presented to the subjects at random, using the computerized randomization program. Subjects were not told which test to expect next, the only information given to them was whether to stand on one or both legs, with their eyes open or closed. Maximum anterior-posterior and medio-lateral sway amplitude and stance time (up to 30 seconds) were recorded for each condition. The use of the Chattecx Balance System has been widely used in previous studies as a tool for measuring static and dynamic balance (Dickstein and Dvir 1993; Fife and Baloh 1993; Levine et al 1996; Ringsberg et al 1999; Bennell and Hinman 2005). A balance index was derived as a summary score by summating all anterior-posterior and medio-lateral sway measures and time results respectively, to simplify the interpretation of relationships with the 18 balance variables, by allowing us to observe overall balance with a single variable. This method has been previously described and validated to be sensitive to changes during an exercise intervention (Orr et al 2006). The balance index equation was as follows:

$$BalanceIndex = \sum 12 SwayMeasures \\ + \left(180\sec - \sum 6 TimeMeasures\right)$$

A lower balance index reflected less sway, and longer stance duration, hence better balance. From the results obtained from this test, unilateral stance duration was also observed in isolation, to compare any changes to results from previous Tai Chi studies which have utilised single-leg stance as a test of balance (Hartman et al 2000; Song et al 2003).

Dynamic balance was assessed with the tandem walk test administered over a straight path of 3 meters. The duration of the faster of two trials and the number of mistakes made were recorded and summated to give a tandem walk score.

Health status and psychosocial function

Health status was obtained from self-report, physician exam, and medical records review. Cognitive function was determined by Mini-mental State Examination (MMSE) (Folstein et al 1975), and habitual physical activity levels over the previous seven days were assessed using the Physical Activity Scale for the Elderly (PASE) (Washburn et al 1993). Health-related quality of life, determined by the Short Form 36 Health Survey questionnaire (SF36), was comprised of 8 subscale scores (Ware et al 1993, 2000). Attitude towards diabetes was obtained from the Diabetes integration

scale (ATT19) (Welch et al 1996). All questionnaires were interviewer-administered.

Sample size

Sample size was estimated from studies of aerobic and resistance training effects on HbA_{1c} in type 2 diabetes (Boule et al 2001; Castaneda et al 2002), as this was the primary outcome of the study (Tsang et al 2005). A decrease in HbA_{1c} of 1% (absolute change) and a standard deviation of 1% was estimated. Setting the power (1-beta) at 0.8, and an alpha value of 0.05, total sample size required was estimated as 34 (Buchner et al 1997). We estimated a dropout rate of 15%; thus the sample size was increased to 39. This sample size was also large enough to test for outcomes reported here: being appropriate for detecting an increase in leg extensor strength of 78.1 ± 45.8 N (effect size = 1.86); and for observing increases in duration of unilateral stance with eyes closed of 7.5 ± 7.8 s (effect size = 1.03), based on previous reports on Tai Chi in the literature (Christou et al 2003; Song et al 2003).

Statistical methods

Statistical analyses were performed using Statview, version 5.0 (SAS Institute, Cary, NC). Data collected from subjects who did not complete all training sessions were included in all analyses, as per the intention-to-treat design. All data were visually inspected for normality of distribution. Non-normal data were log-transformed. Baseline values are reported as mean ± standard deviation; and non-normally distributed data reported as median (range). Changes over time in outcome measures are reported as mean ± 95% confidence interval (95% CI). At baseline, groups were compared using t tests of continuous variables and by Chi square tests for categorical data. Repeated measures analysis of variance was used to analyze change over time and the main effect of group assignment. Additional analyses of covariance (ANCOVA) models were constructed to include potential confounders for outcomes of interest. Variables that were different between groups at baseline and potentially related to the outcome of interest were used as covariates in ANCOVA models. Between group (relative) effect sizes (ES) for study outcomes were calculated as:

Mean Change/SD (Tai Chi) − Mean Change/SD (Control).

A p value of <0.05 was accepted as statistically significant.

Results

Participant flow

Recruitment and enrolment of 38 subjects occurred from March to July, 2004 (Figure 1). Eighteen subjects were randomized to the Tai Chi group, and twenty were randomly allocated to the sham control group.

Participant characteristics

Baseline participant characteristics are shown in Tables 1, 2 and 3. The cohort had a mean age of 65 ± 8 years, and had been diagnosed with type 2 diabetes for 8.5 (0–50) years. Based on the National Cholesterol Education Program (NCEP) guidelines 23.7% of participants were overweight, and an additional 63.1% were obese, with only 13.2% presenting with a BMI within the normal range. Calculated CV's for height and weight were 0.06% and 0.07% respectively. The subjects had many co-morbidities, primarily osteoarthritis, hypertension, dyslipidemia, and coronary artery disease (Table 1). In the cohort, 81.6% displayed metabolic syndrome, as defined by NCEP (2002), and 40% had one or more diabetic complications (peripheral vascular disease, neuropathy, nephropathy, or retinopathy). Pharmacologic treatment (7.4 ± 4.0 medications per day) consisted of antihypertensives other than diuretics (76.3% of subjects), oral hypoglycemics (68.4%), primarily metformin (63.2%), hypocholesterolemics (55.3%), anti-inflammatories (31.6%), and diuretics (21.1%).
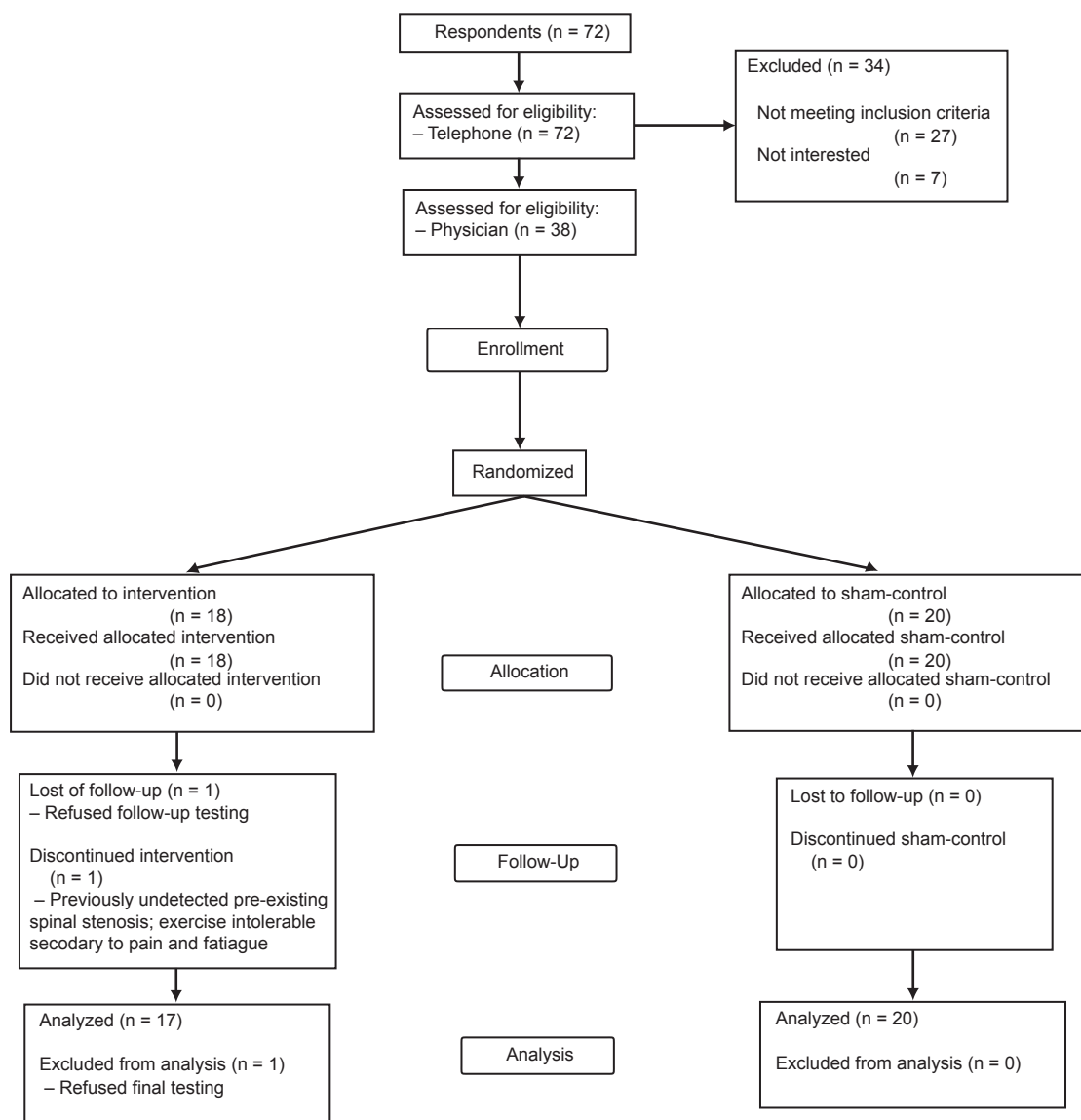
Figure 1 Participant flow through the study.

Table 1 Baseline demographics and health status

Characteristic	Tai Chi (n = 18)	Control (n = 20)	Total (n = 38)	p value
Age (y)	66 (8)	65 (8)	65 (8)	0.7
Female (%)	88.9	70.0	78.9	0.2
Ethnicity (% Caucasian)	94.4	85.0	89.5	0.6
Duration of diagnosed diabetes (y)	8.5 (0–25.0)	9.0 (0.7–50.0)	8.5 (0–50.0)	0.9
Medications/day (n)	8.2 (3.8)	6.5 (3.2)	7.4 (3.6)	0.2
Chronic medical diagnoses (n)	3.7 (2.0)	2.7 (1.7)	3.2 (1.9)	0.1
Osteoarthritis, n (%)	16 (89)	16 (80)	32 (84)	0.5
Coronary artery disease, n (%)	7 (39)	6 (30)	13 (34)	0.6
Arrhythmia, n (%)	3 (17)	4 (20)	7 (18)	0.8
Hypertension, n (%)	13 (72)	16 (80)	29 (76)	0.6
Dyslipidemia, n (%)	11 (61)	14 (70)	25 (66)	0.6
Subjects taking any oral hypoglycaemic, n (%)	10 (56)	16 (80)	26 (68)	0.1
Insulin, n (%)	4 (22)	5 (25)	9 (24)	0.8
HbA$_{1c}$ (%)	7.1 (0.9)	6.9 (0.9)	7.0 (0.9)	0.4
Fasting glucose (mmol/L)	7.6 (3.9–15.6)	7.9 (5.6–13.9)	7.6 (3.9–15.6)	0.2
Fasting insulin (mU/L)	17.9 (8.5–45.3)	15.9 (4.0–35.2)	16.1 (4–45.3)	0.5
Faller, n (%)[b]	8 (44)	6 (30)	14 (37)	0.2
Cognitive status (0–30)[c]	28.4 (1.5)	27.1 (2.2)	27.7 (1.9)	0.05[a]
Quality of Life: Social function Sub-scale (0–100)[d]	71.3 (29.6)	87.5 (19.5)	80.1 (25.6)	0.054

Note: All data presented as mean (standard deviation) for normally distributed data or median (range) for non-normally distributed data unless otherwise specified.
[a]Indicates a significant difference between Tai Chi and Control groups (p ≤ 0.05). Continuous variables analyzed by t test or Mann-Whitney U test for non-normally distributed data. Categorical variables analyzed by Chi square test.
[b]Number of subjects with ≥1 fall in the past year.
[c]The Mini-Mental State Examination (MMSE) was administered to screen cognitive function. A score of ≤24 suggests impaired cognitive function (Folstein et al 1975).
[d]The Short form general health survey (SF36) assessed quality of life in eight different subcategories. The maximum possible score in each subcategory is 100, where a higher score reflects better quality of life (Ware et al 1993, 2000). All other scores were comparable between groups at baseline.

Insulin was used by 9% of subjects, and 18.4% were not taking any medications for their diabetes.

Compared to controls, subjects randomized to Tai Chi had greater total body and central fat (measured via waist circumference (CV = 0.13%)) estimates (p = 0.03), higher cognitive scores, lower social function, and lower self-reported recreational and work-related activity, (Tables 1, 2 and 3). Overall in our cohort, men reported more physical activity than women (PASE score 170.2 [95%CI: 88.6–251.8] in men vs. 111.2 [95%CI: 88.8–133.6] in women) (f = 4.6, p = 0.04), and had lower %BF (34.3 [95%CI: 26.7–41.9] in men vs. 41.5 [95%CI: 39.0–44.0] in women) (f = 6.3, p = 0.02).

Compliance

The median number of weeks taken to complete the trial (up to 32 sessions) was 16 (0.3–21.4) weeks. There was one dropout in the Tai Chi group (at week 4) who refused follow-up testing due to illness and difficulty with transport. The median attendance rate was 100 (6–100)% and 100 (0–100)% in Tai Chi and controls respectively (p = 0.7), inclusive of this dropout. Seventy-six percent of subjects completed >80% of the scheduled classes. Reasons for non-compliance included other commitments, moving away, and transport issues.

Adverse events

One subject (with pre-existing spinal stenosis) in the Tai Chi group found the exercise intolerable secondary to pain and fatigue, and did not attend after session 1. This condition was not symptomatic during the screening or baseline assessment, hence was not detected before randomization. Only the body composition and questionnaire data was included in the analyses for this subject, due to inability to perform any physical tests at follow-up.

Over the 16 weeks 0 (0–2) falls per person were reported in Tai Chi, and 0 (0–2) in controls (p = 0.2).

Exercise intensity

Proficiency was achieved in 6–12 sessions in the Tai Chi group, and 1–2 sessions in controls, as determined subjectively by the instructor. The average HR during Tai Chi sessions was 83.3 [95% CI: 76.3–90.3] beats/min, and 81.0 [95% CI: 75.5–86.5] beats/min during control sessions

Table 2 Baseline nutritional status

Variable	Tai Chi (n = 18)	Control (n = 20)	Total (n = 38)	p value
Body mass (kg)	87.5 (13.7)	80.7 (16.1)	83.9 (15.2)	0.2
Body mass index (kg/m²)	33.7 (5.0)	30.9 (7.2)	32.2 (6.3)	0.2
Waist circumference (cm)	106.1 (14.6)	98.4 (12.6)	102.7 (13.5)	0.03[a]
Body fat (%)	43.0 (4.8)	37.3 (8.4)	40.1 (7.3)	0.02[a]
Fat free mass (kg)[b]	49.6 (6.9)	49.8 (8.3)	49.7 (7.5)	1.0
Fat mass (kg)[b]	37.9 (8.8)	31.1 (11.7)	34.5 (10.8)	0.06

Note: All data presented as mean (standard deviation) for normally distributed data or median (range) for non-normally distributed data unless otherwise specified.
[a]indicates a significant difference between Tai Chi and Control groups (p ≤ 0.05).
[b]Fat free mass and percent body fat estimated by bioelectrical impedance (Lukaski et al 1986)

(p = 0.5). The mean Borg scale rating of perceived exertion was 11 [95% CI: 10–12] and 10 [95% CI: 9–11] for Tai Chi and controls respectively (p = 0.3).

Physical performance

Modest, significant improvements over time were seen in maximal gait speed (CV = 2.09%) in both groups (6.6 [95%CI: 1.5–11.7]% in Tai Chi, and 5.9 [95%CI: −0.1–11.9]% in controls; f = 9.2, p = 0.005; between group ES = 0.18)). Similarly, significant improvements were observed in the balance index (−3.9 [95%CI: −11.5–3.7] in Tai Chi vs. −7.4 [95%CI: −13.7–1.1] in. controls; f = 5.4, p = 0.03; between group ES = 0.3). There were no significant differences between groups (Table 3) or group effects in ANCOVA models adjusted for baseline group differences (%BF, PASE score, MMSE, and baseline values of maximal gait speed or balance index).

No significant changes over time or between groups were observed in the other physical performance measures (six-minute walk distance, tandem walk, single-leg stance duration, muscle strength, power, and endurance, or habitual gait speed (CV = 3.16%)) (Table 3).

Habitual physical activity level

There was a significant group effect in physical activity score, with an increase in habitual physical activity of 18 [95%CI: −7.4–43.4] units in the Tai Chi group, and decrease of 35 [95%CI: −58.4–11.6] units in controls (f = 9.96, p = 0.003; between group ES = 0.35). However, after adjusting for baseline differences in potential confounders (PASE score, %BF, and social function), the difference in physical activity level between groups was no longer significant (p = 0.2).

Quality of life

A significant group effect was observed in Social Function sub-scale score, with Tai Chi improving their score by 6.6

[95% CI: −7.3–20.5] and controls worsening by 14.2 [95% CI: −28.1–0.3] (f = 4.6, p = 0.04; between group ES = 0.24), but this group difference was attenuated and no longer significant after change in social function was adjusted for %BF, and physical activity levels (f = 3.7, p = 0.07). None of the other domains measured in the SF36, or ATT19 score were significantly changed after the intervention over time or between groups.

Discussion

Habitual gait speed and a summary static/dynamic balance index improved similarly and significantly in both Tai Chi and control groups after 16 weeks. There was a tendency for Tai Chi practice to be associated with improvement in habitual activity level and Social Function relative to sham-exercise participation, but these trends did not lead to differential benefits in terms of physical function or mobility. Neither the "Tai Chi for Diabetes" form nor sham exercise improved muscle function, endurance capacity, cognition, or other aspects of health-related quality of life in older sedentary adults with type 2 diabetes. The strength of this study compared to some previous investigations lies in the use of a sham exercise rather than non-treatment control condition and the randomized design and intention-to-treat analysis.

It is possible that the modest improvements in balance over time represented a learning effect, as repeated trials were not given at baseline, rather than a specific result of exercise. Tai Chi involves the practice of shifting to the limits of stability (thus training someone to increase sway), whereas the balance index penalizes those who sway when perturbed. Several previous Tai Chi trials have measured static balance improvements with the one-legged stance duration test (Hartman et al 2000; Song et al 2003), which is one small component of our balance index measure. However, when we examined only the static stance time in isolation, there was neither improvement over time nor

Table 3 Baseline and follow-up outcomes

Variable	Tai Chi group (n = 17)		Control group (n = 20)		Baseline comparison	Change over time		Group effect	
	Baseline	Follow-up	Baseline	Follow-up	p	f	p	f	p
Balance									
Balance Index[b] -Unilateral stance, eyes open (s)	111.1 (23.1)	107.3 (23.1)	111.5 (22.2)	104.1 (22.2)	0.7	5.4	0.03[a]	0.5	0.5
-Unilateral stance, eyes open (s)	13.6 (13.1)	16.9 (13.2)	19.4 (12.7)	19.4 (12.1)	0.2	0.8	0.4	0.7	0.4
-Unilateral stance, eyes closed (s)	3.9 (0.4–19.6)	2.8 (0.1–14.0)	2.2 (0.6–6.0)	2.0 (0–8.3)	0.5	$3.0e^{-5}$	1.0	1.5	0.2
Tandem walk score[c]	19.1 (7.0)	18.1 (8.3)	18.5 (6.3)	17.2 (6.2)	0.8	2.0	0.2	0.15	0.8
Physical Performance									
6 minute walk distance (m)	474.0 (76.1)	481.8 (83.0)	456.6 (117.8)	470.1 (118.2)	0.7	3.9	0.06	0.3	0.6
Habitual gait speed (m/s)	1.0 (0.7–1.6)	1.2 (0.7–1.5)	1.1 (0.8–1.5)	1.2 (0.8–1.8)	0.3	4.0	0.054	0.4	0.6
Maximal gait speed (m/s)	1.6 (0.3)	1.7 (0.3)	1.6 (0.3)	1.7 (0.3)	0.9	9.2	0.005a	0.03	0.9
Muscle Performance									
Strength (Nm)[d]	91.3 (31.5)	97.8 (24.8)	89.7 (30.3)	90.7 (33.8)	0.9	1.0	0.3	0.6	0.5
Peak power (W)	215.9(75.4)	220.9 (64.9)	221.7 (74.5)	217.4 (74.5)	0.5	0.004	1.0	0.6	0.5
Endurance (number of repetitions)	5 (3)	5 (4)	5 (3)	4 (4)	0.9	1.4	0.3	0.6	0.4
Habitual physical activity[e]	94.9 (65.8)	112.6 (66.8)	143.1 (66.2)	107.8 (44.3)	0.02[a]	1.1	0.3	10.0	0.003[a]
Health related quality of life[f]									
Social Function (0–100)	71.3 (29.6)	77.9 (26.7)	88.2 (19.7)	73.9 (32.7)	0.054	0.6	0.4	4.6	0.04[a]

Notes: Values are mean (SD) or median (range).

[a]p ≤ 0.05

[b]Balance index = sum 12 sway measures + (180 − sum 6 time measures), with lower scores indicating better overall balance performance.

[c]Tandem walk score = time taken to complete course (s) + number of errors made during test (Cho et al 2004). A lower score indicates better dynamic balance.

[d]Knee extensor strength was assessed by determining the maximum load that could be lifted correctly for only one repetition (1 repetition maximum).

[e]Physical Activity Scale for the Elderly (PASE) was used to determine a score for habitual physical activity, based on the leisure time, household, and work-related activities performed in the previous seven days. A higher score reflect more energy expenditure (Washburn et al 1993).

[f]SF36 Health Survey: possible scores for each subscale range from 0–100, where a higher score reflects better quality of life (Ware et al 1993, 2000)

effect of group assignment. The lack of improvement in the tandem walk test after the intervention was unexpected, as it was thought that the heel-down-first action of the feet and weight-shifting in the Tai Chi form was somewhat similar to that required in the tandem walk test, and may have therefore been transferable between the two. The speed of movement, and distance between the feet however are different between Tai Chi and tandem walking, which may explain the lack of improvement in this measure which required both speed and accuracy. No other controlled trial of Tai Chi has tested dynamic balance with the tandem walk test, or the exact balance platform measure we employed, thus preventing direct comparisons to balance outcomes in other studies. However, the Atlanta FICSIT study (Wolf et al 1993) also reported no improvement in computerized balance platform testing after a Tai Chi form found effective for fall prevention. As in our testing paradigms, the FICSIT subjects were penalized for swaying, suggesting that this mode of testing is insufficiently sensitive to the kinds of balance improvements targeted by the practice of Tai Chi.

It is unlikely that a ceiling effect on the balance index explains the lack of group differences.

In another recent study by Orr et al (2006) we have reported improvements in balance index in healthy older adults, of similar age to this cohort, after power training. The subjects in the present study had poorer balance scores at baseline (a mean balance index of 110.8), compared to the mean score of 89.4 by those in the study by Orr et al (2006), suggesting that these diabetic subjects had sufficient impairments in balance to respond to a balance-enhancing intervention.

The smaller than expected improvements in balance in our Tai Chi group may also be related to their co-morbidities, in addition to the methodological issues discussed above. Almost all of our subjects were overweight or obese (86.8%) and 89% had osteoarthritis, both of which likely impaired their ability to perform the proper weight-shifting or semi-squat position that was intended during Tai Chi. The low exercise HR observed (83.3bpm compared to 116bpm in a previous study (Lan et al 1998)) may also be attributed to these factors, though Jin (1989) also noted similar HR's in beginners of Tai Chi when practicing in the morning and evening (87.4bpm and 94.1bpm respectively). The BMI of our cohort was greater than that of patients with osteoarthritis who had BMI's within the normal range, (Song et al 2003). Those subjects demonstrated a significant improvement in one-legged stance duration after Tai Chi training, in contrast to the overweight-to-obese subjects in Hartman et al (2000)

and the present study, both of which found no significant change in balance measures compared to controls. It would be of interest for future studies to directly compare balance adaptations to Tai Chi between overweight and normal weight or sarcopenic individuals to identify characteristics of high responders.

Muscle function did not improve in either group in our study. Previous Tai Chi studies have reported significant improvements in isokinetic and isometric knee extensor strength ranging from 13.5%–46.2% after 12–52 weeks of training in older adults with no previous Tai Chi experience (Lan et al 1998; Lan et al 2000; Christou et al 2003; Choi et al 2005). Six months of Tai Chi practice 3–4 times per week improved the endurance ratio of the knee extensors by 9.6%–18.8% in healthy, community-dwelling adults (Lan et al 2000), whereas no change in endurance was observed in our study. The frequency of training in these studies ranged from 3–7 sessions per week (though requested daily home practice was not monitored in these studies), which may explain why we saw only a non-significant 12.9% improvement in strength, and no significant changes in muscle power or endurance after Tai Chi. As noted, most of our subjects also presented with osteoarthritis, and therefore maintained a higher stance during Tai Chi practice to avoid exacerbation of their condition, thus possibly not providing their knee extensors a large enough stimulus to promote strengthening of the muscles at an angle which would contribute to a knee extensor one repetition maximum (performed from 90 degrees of flexion through full extension). It is also possible that the benefits of the isometric contractions of Tai Chi were not reflected in the dynamic strength tests we used, due to specificity of training adaptations.

Small but significant improvements were seen in maximal gait speed in both groups, though based on the relative ES's calculated, our study may have been underpowered to identify between group differences in maximal gait speed. The gait speed tests were performed twice at baseline and follow-up however, so learning is unlikely to be the mechanism of benefit. We had hypothesized that only the Tai Chi group would improve their gait velocity, but it is possible that changes in other unmeasured factors such as self-efficacy, depression, or arthritis symptoms explained these improvements in both groups. Several other studies have also reported no benefits of Tai Chi on gait speed or walking endurance. Wolf et al (1996) found that 15 weeks of Tai Chi training *decreased* the distance walked in 12 minutes, perhaps due to the emphasis on slow movements during the Tai Chi training. Neither Wolfson et al (1996)

nor Hartman et al (2000) found significant changes in habitual gait speed, similar to our results. Compared to age and gender norms for gait speed (Bohannon 1997), our cohort had slightly slower habitual and maximal gait speed at baseline than age-matched peers, suggesting some degree of gait impairment. However it is possible that our subjects, selected for diabetes rather than frailty, mobility disorders, or falls risk, did not have sufficient impairment in habitual gait to improve this outcome, whereas the more stressful maximal gait speed test allowed room for improvement.

Limitations in this study include the non-blinded assessment of outcomes, lack of specificity of outcomes for the physiological characteristics of this form of Tai Chi, and the intervention intensity, duration and frequency. Isometric as well as dynamic strength measures in future studies may shed light on the specific adaptations in muscle function attributable to Tai Chi. Reduction in stride-to-stride gait variability, which has been shown to be predictive of falls (Hausdorff et al 2001) may be more likely to improve after Tai Chi than simple measures of habitual velocity. A more frequent Tai Chi intervention (3–4 times a week) should be considered to allow for further progression in the intensity of performance (for example, lowering the stance as the subject is able). The use of a chair or bar for support during initial training of the stances and foot/leg movements may be considered. Additionally, it is possible that more time spent guiding the internalization of the exercises would improve physical and psychosocial function to a greater degree.

In conclusion, twice-weekly, supervised participation in a Tai Chi program utilizing the "Tai Chi for Diabetes" form for 16 weeks or a sham exercise class both improved maximal gait speed and overall balance modestly, perhaps due to non-specific effects of study participation or learning effects. However, habitual gait speed, muscle strength, static balance, walking endurance, and self-reported physical function or mental health did not improve in older sedentary adults with type 2 diabetes. Our results should not be extrapolated to cohorts differing significantly from ours in terms of health status, age, or obesity. Tai Chi may be an appropriate exercise to explore further in relation to its potential benefits for individuals who may be reluctant to participate in some traditional exercise modalities due to physical and/or psychological characteristics. Tai Chi forms vary widely, as does ability to master complex movements, and thus generalizations of benefits observed between different Tai Chi forms or between different cohorts should not be assumed without empirical evidence of benefit.

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