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Effects of Tai Chi or Conventional Exercise on Central Obesity in Middle-Aged and Older Adults

A Three-Group Randomized Controlled Trial

Parco M. Siu, PhD*; Angus P. Yu, MPhil*; Edwin C. Chin, BScEd; Doris S. Yu, PhD; Stanley S. Hui, EdD; Jean Woo, MD; Daniel Y. Fong, PhD; Gao X. Wei, PhD; and Michael R. Irwin, MD

Background: Central obesity is a major manifestation of metabolic syndrome, which is a common health problem in middle-aged and older adults.

Objective: To examine the therapeutic efficacy of tai chi for management of central obesity.

Design: Randomized, controlled, assessor-blinded trial. (ClinicalTrials.gov: NCT03107741)

Setting: A single research site in Hong Kong between 27 February 2016 and 28 February 2019.

Participants: Adults aged 50 years or older with central obesity.

Intervention: 543 participants were randomly assigned in a 1:1:1 ratio to a control group with no exercise intervention ($n = 181$), conventional exercise consisting of aerobic exercise and strength training (EX group) ($n = 181$), and a tai chi group (TC group) ($n = 181$). Interventions lasted 12 weeks.

Measurements: Outcomes were assessed at baseline, week 12, and week 38. The primary outcome was waist circumference (WC). Secondary outcomes were body weight; body mass index; high-density lipoprotein cholesterol (HDL-C), triglyceride, and fasting plasma glucose levels; blood pressure; and incidence of remission of central obesity.

Results: The adjusted mean difference in WC from baseline to week 12 in the control group was 0.8 cm (95% CI, −4.1 to 5.7 cm). Both intervention groups showed reductions in WC relative to control (adjusted mean differences: TC group vs. control, −1.8 cm [CI, −2.3 to −1.4 cm]; $P < 0.001$; EX group vs. control: −1.3 cm [CI, −1.8 to −0.9 cm]; $P < 0.001$); both intervention groups also showed reductions in body weight ($P < 0.05$) and attenuation of the decrease in HDL-C level relative to the control group. The favorable changes in WC and body weight were maintained in both the TC and EX groups, whereas the beneficial effect on HDL-C was only maintained in the TC group at week 38.

Limitations: High attrition and no dietary intervention.

Conclusion: Tai chi is an effective approach to reduce WC in adults with central obesity aged 50 years or older.

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For author, article, and disclosure information, see end of text.

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Metabolic syndrome is broadly defined as a cluster of cardiometabolic risk factors, including central obesity, dyslipidemia, hyperglycemia, low high-density lipoprotein cholesterol (HDL-C) level, and high blood pressure, that all increase risk for type 2 diabetes and cardiovascular disease. Overweight and obese persons are more susceptible to cardiometabolic health complications, such as diabetes (1), hypertension (2), and cardiovascular disease (3). Because Asians generally have a higher body fat percentage than Whites of the same age, sex, and body mass index (BMI) (4), the metabolic risks associated with adiposity may be present at a lower BMI for Asians. However, BMI alone may be inadequate for assessing cardiometabolic risk associated with increased adiposity, especially in Asians (5). Recent recommendations have suggested that waist circumference (WC), a commonly used surrogate measure of central obesity, should be considered a vital sign in clinical practice. This is because this simple anthropometric measure shows a strong association with the amount of intra-abdominal or visceral fat (5), which is linked to ectopic fat accumulation, systemic inflammation, metabolic disorders, and increased risk for mortality (6, 7). Waist circumference is also suggested to be a modifiable risk factor for cardiometabolic risk, morbidity, and mortality, independent of the change in BMI (5, 8).

Tai chi is a form of mind–body exercise often described as "meditation in motion". It is practiced in many Asian communities and is becoming increasingly popular in Western countries, with more than 2 million people practicing it in the United States (9). Tai chi is acknowledged to be a suitable activity for older people, even those who are inactive or unfit. It is a moderate-intensity exercise that benefits cardiometabolic health, but it is generally not recommended by exercise guidelines, mainly because of a lack of robust evidence of its benefits (10, 11). Furthermore, systematic reviews of studies investigating the benefits of tai chi for cardiometabolic health have concluded that the quality of the evidence was hampered by methodological flaws, such as inadequate statistical power, inadequate controls or active control groups, and heterogeneity of

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participants (12, 13). The therapeutic effectiveness of tai chi needs to be confirmed by a robust randomized controlled trial with a rigorous design and adequate sample size. To explore the possibility of incorporating tai chi into global exercise guidelines, it is imperative to conduct a stringent evaluation of its effects on central obesity and its secondary effects on blood lipids, glucose, and blood pressure as manifestations of metabolic syndrome defined by the International Diabetes Federation (IDF) (14).

We conducted a large-scale randomized controlled trial to evaluate the therapeutic efficacy of tai chi for management of central obesity in adults aged 50 years or older compared with conventional exercise as an active control group and no treatment as the passive control.

METHODS

Design Overview

This randomized, controlled, assessor-blinded trial adhered to the CONSORT (Consolidated Standards of Reporting Trials) extension for multigroup trials. Participants were enrolled between 27 February 2016 and 17 March 2018, and follow-up ended on 28 February 2019. Written informed consent was obtained on a voluntary basis before the start of the study. The study followed the principles of the Declaration of Helsinki. Ethics approval for the experimental protocol was obtained from the institutional review board of the universities and the regional health care system in Hong Kong (ethics approval number: HSEARS 20140928001; IRB reference number: UW 18-055). Because of an administrative error, the study was retrospectively registered on ClinicalTrials.gov (NCT03107741) on 11 April 2017, after participant recruitment but before data analysis. There were no discrepancies between the approved funding proposal and the trial implementation. A detailed trial protocol is included in the Supplement (available at Annals.org).

Setting and Participants

This study was conducted at a single research site in Hong Kong. Promotional leaflets and posters with the inclusion criteria of the study were distributed in the community. Inclusion criteria were age 50 years or older, Chinese ethnicity, and central obesity as defined by the IDF (WC ≥90 cm [men] or ≥80 cm [women] for ethnic Chinese persons) (14). Exclusion criteria were participation in regular moderate-intensity exercise training or tai chi (>3 times a week for >30 minutes per session), any physical disabilities that precluded participation in the intervention, serious diseases known to affect mobility (such as neurologic diseases, musculoskeletal disorders, and autoimmune diseases), and ongoing treatment for serious chronic diseases (such as cancer).

Randomization and Interventions

Eligible participants were randomly assigned to 3 groups in a 1:1:1 ratio. Randomization was conducted using an automated permuted block of size 30. The computer-generated randomization sequence was prepared by an independent researcher not involved in the study and was kept in sealed envelopes. Research personnel assigned participants to the 3 groups according to the random sequence. Participants were informed of their assignment after completion of all baseline assessments. Because of the nature of the exercise intervention, instructors and participants could not be blinded to it. Participants were instructed not to disclose their group allocation to the trained assessors during the assessments.

Participants in the control group received no additional intervention beyond their usual care and monthly telephone calls to record their health condition. Participants in the conventional exercise group (EX group) attended a 12-week, instructor-led group exercise program, which included brisk walking and muscle-strengthening activities (for example, arm curl, arm raise, shoulder press, squats, and heel raise) in three 1-hour sessions per week. Participants in the tai chi group (TC group) attended a 12-week, instructor-led group training program that adopted the 24-form Yang style of tai chi, the most common style adopted in the literature. The tai chi program also consisted of three 1-hour sessions per week, which has been the most popular approach in previous studies (15). Attendance was recorded by the instructors as a measure of adherence.

Detailed descriptions of the conventional exercise and tai chi training programs are provided in the Supplement Table (available at Annals.org). The exercise intensity of both interventions was considered moderate. Details on the metabolic equivalents of tasks for the EX and TC groups are provided in the study protocol (Supplement). The interventions were not designed to provoke a pronounced weight loss within 12 weeks and thus did not include major dietary modification.

Outcomes and Follow-up

The trained outcome assessors were blinded to the group allocation of the participants. All outcomes were assessed at baseline, after completion of the interventions (week 12), and at the 6-month postintervention follow-up (week 38).

Waist Circumference

Waist circumference was measured to the nearest 0.1 cm midway between the lowest rib and the superior border of the iliac crest using an inelastic measuring tape on the bare skin, according to the protocol of the World Health Organization (WHO) (16) (see page 3 of the trial protocol [Supplement]).

Secondary Outcomes

Secondary outcomes were body weight; BMI; cardiometabolic parameters of metabolic syndrome defined by the IDF, including HDL-C level, triglyceride level, plasma glucose level, and blood pressure (14); and incidence of remission of central obesity (see pages 3 and 4 of the protocol [Supplement]).

Adverse Events

Any adverse events related to the intervention that were reported by participants were recorded by research personnel or instructors during outcome assessments or intervention contacts.

Statistical Analysis

All statistical analyses were performed using SAS University Edition (SAS Institute). Statistical significance was set at a *P* value less than 0.05.

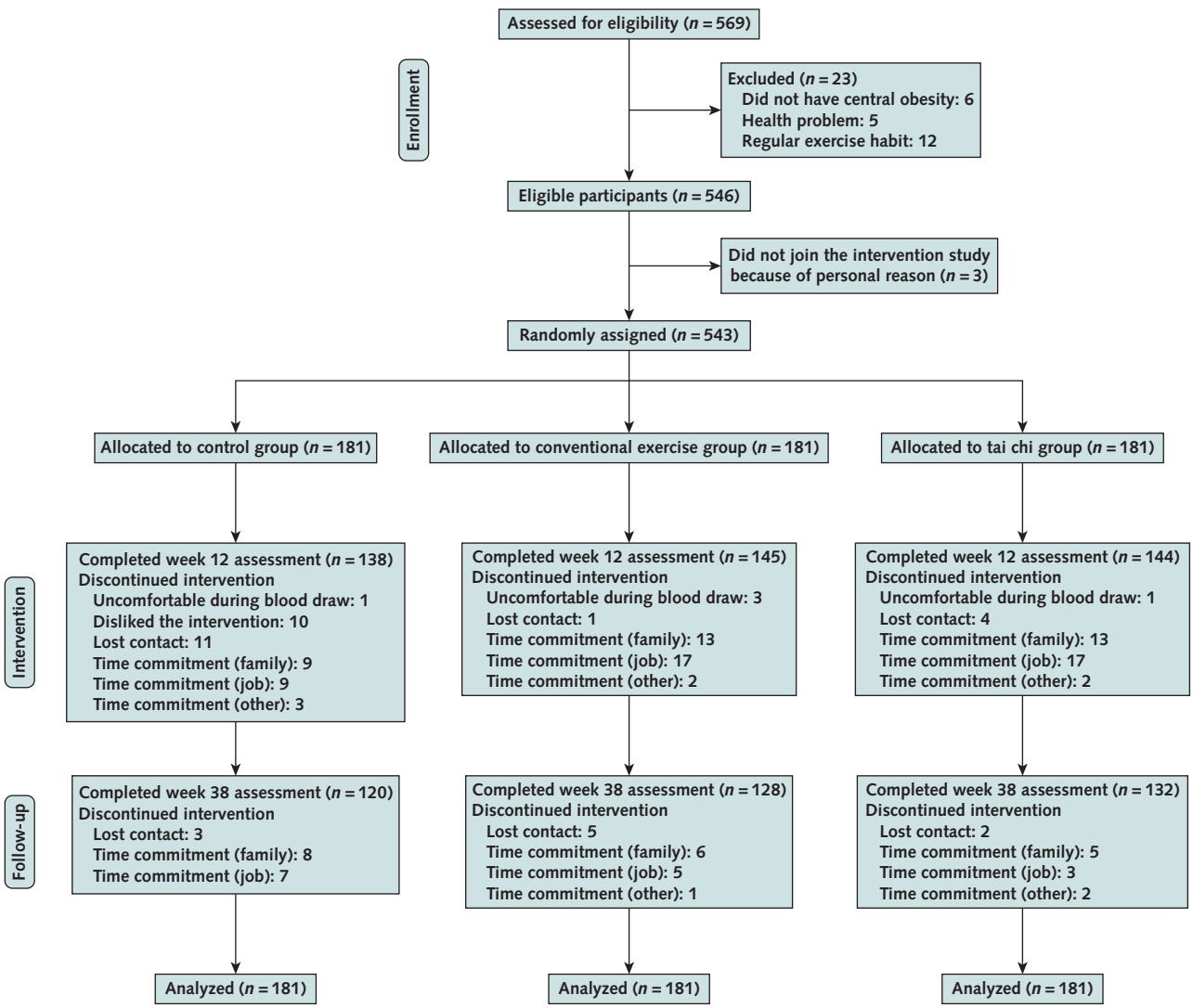
Sample Size

Sample size was estimated on the basis of our preliminary results on changes in WC in response to a 12-week tai chi intervention versus no-exercise controls (17), which showed an effect size (interaction Cohen *d*) of 0.2. We assumed a 30% attrition rate. For a 90% statistical power ($\alpha = 0.05$) to detect a significant effect of tai chi over controls, recruitment of 459 participants was needed.

Analytical Approach

Double data entry and verification were performed by 2 independent research personnel to ensure data quality. Data were expressed as observed means and SDs. Intention-to-treat analysis was conducted with all randomly assigned participants included in the analysis. To account for missing values and correlation among repeated measurements, we used weighted generalized estimating equations (WGEE) (SAS PROC GEE) to compare the metabolic parameters (WC, body weight, BMI, HDL-C level, triglyceride level, fasting plasma glucose level, and blood pressure) among groups. Assessments conducted at baseline, week 12, and week 38 were included as outcomes in the WGEE analysis. The covariates were the baseline measurement, time (the number of weeks from baseline), group (control group, EX group, or TC group), and group-by-time interaction. The group-by-time interaction, which indicates the difference for a given outcome between interventions over time, was considered our primary measure of the intervention effect.

Figure. Schematic presentation of the flow of participants through screening, randomization, and the interventions.



The incidence of remission of central obesity was examined by logistic regression (SAS PROC LOGISTIC). Pairwise treatment comparisons were performed by linear contrasts using the Holm procedure to adjust for the multiple comparisons. Details on the statistical analysis are provided in the **Appendix** (available at Annals.org).

Missing Data

Missing values of quantitative data were not replaced because WGEE can accommodate missing data under the assumption that they are missing at random (18). Missing values of the incidence of remission of central obesity were handled by multiple imputation (SAS PROC MI) given that these observations would otherwise be omitted from the logistic regression analysis.

Sensitivity Analyses

We repeated the analysis for the primary outcome using 3 analytical approaches involving multiple imputation to assess the robustness of our conclusions to assumptions about missing data and our model. First, we imputed values for missing WC observations and used the GEE model with the same covariates used in the primary analysis. Second, we included the baseline variables that differed between participants who dropped out and those who completed the study (body weight and BMI) as additional covariates in the GEE model of the primary analysis. Finally, we included only time and group-by-time interaction as covariates in the GEE model (19). Details on the sensitivity analyses are provided in the Appendix.

Role of the Funding Source

The Health and Medical Research Fund had no role in study design, conduct, or analysis or the decision to submit the manuscript for publication.

RESULTS

Baseline Characteristics of Participants

A total of 569 persons were recruited to the study after giving informed consent and undergoing screening for central obesity (**Figure**). All 543 eligible participants were randomly assigned to the control (n = 181), EX (n = 181), and TC (n = 181) groups and were included in the data analysis. At baseline, 75% of participants were overweight or obese according to the WHO Asian BMI threshold (23 kg/m^2) (20), 52.3% had hypertension, 14.5% had type 2 diabetes, and 51.2% had dyslipidemia. Baseline characteristics of participants did not differ substantively between groups (**Table 1**). No medication changes were reported during the 38-week study period. Among the 543 participants, 427 (138 in the control group, 145 in the EX group, and 144 in the TC group) completed the assessment at week 12, and 380 (120 in the control group, 128 in the EX group, and 132 in the TC group) completed the assessment at week 38. The adherence rates in the TC and EX groups, measured as class attendance, were similar (70% and 67%, respectively).

Table 1. Baseline Characteristics of Participants

Characteristic	Control Group (n = 181)	EX Group (n = 181)	TC Group (n = 181)
Female, *n (%)*	143 (79.0)	140 (77.3)	140 (77.3)
Mean age (SD), *y*	61.0 (5.7)	62.2 (6.6)	62.6 (6.2)
Mean height (SD), *cm*	158.5 (8.1)	158.1 (7.8)	157.8 (8.6)
Mean body weight (SD), *kg*	64.3 (11.3)	64.5 (12.1)	63.8 (12.0)
Mean BMI (SD), *kg/m^2*	25.5 (3.4)	25.7 (3.9)	25.5 (3.6)
Participants with metabolic disorder, *n (%)*			
Hypertension*	86 (47.5)	104 (57.5)	94 (51.9)
Diabetes†	24 (13.3)	29 (16.0)	26 (14.4)
Dyslipidemia‡	86 (47.5)	102 (56.4)	90 (49.7)
Taking medication for metabolic disorder, *n (%)*			
Antihypertensive	38 (21.0)	58 (32.0)	46 (25.4)
Antidiabetic	18 (9.9)	20 (11.0)	17 (9.4)
Antihyperlipidemic	30 (16.6)	44 (24.3)	35 (19.3)
IDF-defined cardiometabolic risk factors for diagnosis of metabolic syndrome			
Mean waist circumference (SD), *cm*	91.6 (8.4)	92.3 (9.0)	92.4 (8.5)
Mean HDL-C level (SD), *mmol/L*§	1.51 (0.35)	1.54 (0.40)	1.54 (0.40)
Mean triglyceride level (SD), *mmol/L*§	1.46 (0.84)	1.54 (0.80)	1.41 (0.71)
Mean fasting plasma glucose level (SD), *mmol/L*§	5.6 (1.3)	5.6 (1.1)	5.5 (1.1)
Mean systolic blood pressure (SD), *mm Hg*	126.9 (15.0)	128.2 (17.6)	127.8 (16.6)
Mean diastolic blood pressure (SD), *mm Hg*	76.6 (9.5)	75.9 (9.9)	76.8 (10.6)

BMI = body mass index; EX = conventional exercise; HDL-C = high-density lipoprotein cholesterol; IDF = International Diabetes Federation; TC = tai chi.

* Participants with systolic blood pressure ≥130 mm Hg or diastolic blood pressure ≥85 mm Hg at baseline and those using an antihypertensive medication were considered to have hypertension.

† Participants with fasting plasma glucose level ≥7 mmol/L and those using an antidiabetic medication were considered to have diabetes.

‡ Participants with a low HDL-C level (<1.03 mmol/L [men] or <1.29 mmol/L [women]), those with hypertriglyceridemia (triglyceride level ≥1.7 mmol/L), and those using an antihyperlipidemic medication were considered to have dyslipidemia.

§ To convert HDL-C values to mg/dL, divide by 0.0259. To convert triglyceride values to mg/dL, divide by 0.0113. To convert glucose values to mg/dL, divide by 0.0555.

Primary Outcome

Table 2 presents our primary and secondary results. Waist circumference was greater at weeks 12 and 38 relative to baseline in the control group but not in the intervention groups. Both the TC and EX groups showed a statistically significant relative reduction in WC compared with the control group; there was not a substantial advantage in the TC group versus the EX group.

Secondary Outcomes

Compared with the changes in the control group from baseline to week 38, both the TC and EX groups showed more favorable though modest changes in body weight and BMI at weeks 12 and 38, with no significant differences between groups (Table 2). With the exception of HDL-C, metabolic parameters were relatively stable for all groups during the study period.

Although it appears a higher proportion of participants achieved remission of central obesity in the TC group than in the control group at week 12, the differences in remission among groups did not reach statistical significance after the Holm adjustment (Table 2). Only the EX group showed a significantly higher proportion of participants achieving remission relative to the control group at week 38 (Table 2). No significant differences in incidence of remission were found between the TC and EX groups at weeks 12 and 38 (Table 2).

Sensitivity Analyses

Baseline body weight was significantly higher among participants who dropped out than among those who completed the study at week 12, whereas baseline BMI was significantly higher among those who dropped out at weeks 12 and 38 (Appendix Table 1, available at Annals.org). Thus, body weight and BMI at baseline were also considered in the adjustment. The results of the 3 sensitivity analyses were consistent with those from the primary analysis (Appendix Table 2, available at Annals.org).

Adverse Events

No adverse events were observed in the experimental period.

Habitual Physical Activity

Compared with the changes in the control group from baseline to week 38, similar increases in habitual physical activity were observed in the TC and EX groups. No significant difference in habitual physical activity was found between groups at weeks 12 and 38 (Appendix Table 3, available at Annals.org). There was no significant difference in sedentary time among groups (Appendix Table 3).

Discussion

Our study showed that a 12-week tai chi program or a conventional exercise program in adults aged 50 years or older with central obesity could mitigate increases in WC over time, suggesting that both interventions can prevent progression of central obesity. These interventions impeded the decrease in HDL-C level observed in the control group of participants who received no intervention. However, neither intervention affected triglyceride level, fasting plasma glucose level, or blood pressure. Both tai chi and conventional exercise led to a modest reduction in body weight. No adverse events were reported in the experimental period. Our data suggest that tai chi, a gentle mind–body exercise, can be an effective alternative to conventional exercise in the management of central obesity.

Studies investigating the effects of tai chi on WC and body weight in older adults with central obesity are scarce. However, our findings on the beneficial effects of tai chi and conventional exercise on reducing WC and body weight are in line with those of studies conducted in older persons with obesity (21, 22) and middle-aged adults (23). One study found that tai chi did not decrease WC and body weight in adults with central obesity and depression (24); this might be attributable to use of antidepressants, which are known to be associated with weight gain (25), in addition to the heterogeneity of the participants' age and medical conditions. Although some preliminary studies suggested that tai chi led to favorable changes in cardiometabolic parameters (12, 23, 26), the current study did not replicate the beneficial effects on those parameters in older adults with central obesity, except for HDL-C. Further studies addressing how cardiovascular risk factors affect tai chi's effects on metabolic parameters are needed to provide a more comprehensive understanding of tai chi for modulation of cardiometabolic risks.

Waist circumference, a highly accessible anthropometric proxy for central obesity, can indicate amassed visceral and ectopic fat, which is strongly associated with systemic inflammation, insulin resistance, dyslipidemia, and the pathogenesis of metabolic syndrome (27). A previous study found that half of a cohort with central obesity developed metabolic syndrome at the 3.9-year follow-up, and 75% developed metabolic syndrome by 7.7 years (28). Another study showed a strong association between central obesity measures and incidence of type 2 diabetes, with a pooled odds ratio of 2.14 (29). Other studies found that for every 1-cm increase in WC, there was a 3.2% increase in risk for cardiovascular disease (30), and for every 5-cm increase in WC, there were 7% and 9% increases in mortality risk in males and females, respectively (7). Any intervention that can effectively ameliorate central obesity will have a substantial effect on health and health care by alleviating cardiometabolic risk factors and subsequent cardiovascular diseases and diabetes, which in turn reduces risk for premature death. A meta-analysis concluded that exercise is a more efficacious lifestyle intervention for reducing visceral fat compared with dietary interventions (31).

The BMI of the participants with central obesity in this study was modest compared with the threshold of 30 kg/m^2 used to define obesity in many Western countries, including the United States. Notably, 75% of our participants were categorized as overweight or obese according to the WHO Asian BMI thresholds for overweight (23 kg/m^2) and obesity (25 kg/m^2) (20). The lower thresholds reflect data showing that adiposity levels in Asians are generally higher than in

Table 2. Primary and Secondary Outcomes*

Outcome	Control Group (*n* = 181)	EX Group (*n* = 181)	TC Group (*n* = 181)	Group-by-Time Interaction Effect	TC Group vs. Control Group		EX Group vs. Control Group		TC Group vs. EX Group	
					Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value
Mean waist circumference (SD), *cm*										
Week 0	91.6 (8.4)	92.3 (9.0)	92.4 (8.5)	<0.001	–	–	–	–	–	–
Week 12	93.3 (8.5)	91.6 (9.1)	89.8 (8.3)	–	−1.8 (−2.3 to −1.4)	**<0.001**	−1.3 (−1.8 to −0.9)	**<0.001**	−0.5 (−1.0 to −0.1)	0.029
Week 38	94.4 (8.0)	91.0 (9.3)	90.2 (8.2)	–	−4.3 (−5.3 to −3.3)	**<0.001**	−3.6 (−4.7 to −2.6)	**<0.001**	−0.7 (−1.7 to 0.3)	0.160
Secondary outcomes										
Mean body weight (SD), *kg*										
Week 0	64.3 (11.3)	64.5 (12.1)	63.8 (12.0)	0.006	–	–	–	–	–	–
Week 12	63.7 (10.8)	63.6 (11.6)	62.4 (11.5)	–	−0.2 (−0.4 to −0.1)	**0.003**	−0.3 (−0.5 to −0.1)	**<0.001**	0.1 (−0.1 to 0.2)	0.48
Week 38	64.4 (10.8)	63.7 (12.2)	62.9 (11.6)	–	−0.7 (−1.1 to −0.3)	**0.001**	−0.9 (−1.4 to −0.5)	**<0.001**	0.3 (−0.1 to 0.6)	0.171
Mean BMI (SD), kg/m^2										
Week 0	25.5 (3.4)	25.7 (3.9)	25.5 (3.6)	0.010	–	–	–	–	–	–
Week 12	25.4 (3.3)	25.5 (3.8)	25.0 (3.4)	–	−0.09 (−0.15 to −0.02)	**0.015**	−0.10 (−0.16 to −0.03)	**0.006**	0.01 (−0.06 to 0.07)	0.65
Week 38	25.7 (3.4)	25.3 (3.9)	25.1 (3.5)	–	−0.26 (−0.43 to −0.10)	**0.004**	−0.38 (−0.55 to −0.20)	**<0.001**	0.11 (−0.04 to 0.27)	0.125
Mean HDL-C level (SD), *mmol/L*†										
Week 0	1.51 (0.35)	1.54 (0.40)	1.54 (0.40)	0.002	–	–	–	–	–	–
Week 12	1.44 (0.34)	1.55 (0.41)	1.54 (0.38)	–	0.04 (0.02 to 0.06)	**<0.001**	0.03 (0.01 to 0.05)	**0.004**	0.01 (−0.01 to 0.03)	0.29
Week 38	1.41 (0.32)	1.52 (0.39)	1.54 (0.39)	–	0.10 (0.05 to 0.15)	**<0.001**	0.05 (0.01 to 0.10)	0.027	0.04 (−0.002 to 0.09)	0.061
Mean triglyceride level (SD), *mmol/L*†										
Week 0	1.46 (0.84)	1.54 (0.80)	1.41 (0.71)	0.21	–	–	–	–	–	–
Week 12	1.54 (0.92)	1.40 (0.69)	1.31 (0.56)	–	−0.10 (−0.15 to −0.04)	**<0.001**	−0.08 (−0.13 to −0.02)	**0.007**	−0.02 (−0.06 to 0.02)	0.38
Week 38	1.47 (0.77)	1.38 (0.67)	1.34 (0.63)	–	−0.15 (−0.25 to −0.05)	**0.005**	−0.15 (−0.26 to −0.04)	**0.006**	0.01 (−0.09 to 0.10)	0.91
Mean fasting plasma glucose level (SD), *mmol/L*†										
Week 0	5.6 (1.3)	5.6 (1.1)	5.5 (1.1)	0.53	–	–	–	–	–	–
Week 12	5.4 (1.2)	5.5 (1.0)	5.4 (1.3)	–	−0.02 (−0.09 to 0.05)	0.53	0.02 (−0.05 to 0.08)	0.62	−0.04 (−0.11 to 0.03)	0.28
Week 38	5.3 (1.1)	5.5 (1.0)	5.3 (0.9)	–	−0.07 (−0.26 to 0.12)	0.47	0.05 (−0.14 to 0.24)	0.59	−0.12 (−0.25 to 0.01)	0.065
Mean systolic blood pressure (SD), *mm Hg*										
Week 0	126.9 (15.0)	128.2 (17.6)	127.8 (16.6)	0.53	–	–	–	–	–	–
Week 12	126.0 (14.4)	127.1 (15.3)	126.3 (15.0)	–	−0.4 (−1.5 to 0.7)	0.46	−0.2 (−1.3 to 0.9)	0.77	−0.3 (−1.4 to 0.9)	0.67
Week 38	128.6 (12.9)	128.4 (15.2)	128.4 (15.8)	–	−1.2 (−3.6 to 1.3)	0.35	−1.5 (−4.0 to 1.0)	0.23	0.3 (−2.2 to 2.8)	0.79
Mean diastolic blood pressure (SD), *mm Hg*										
Week 0	76.6 (9.5)	75.9 (9.9)	76.8 (10.6)	0.120	–	–	–	–	–	–
Week 12	75.8 (9.9)	75.1 (9.9)	75.6 (10.4)	–	−0.4 (−1.1 to 0.4)	0.32	−0.5 (−1.2 to 0.2)	0.151	0.1 (−0.6 to 0.9)	0.72
Week 38	77.5 (7.9)	76.2 (9.8)	76.3 (10.9)	–	−1.3 (−2.8 to 0.2)	0.095	−1.1 (−2.6 to 0.5)	0.172	−0.2 (−1.8 to 1.4)	0.78

Outcome	Control Group (*n* = 181)	EX Group (*n* = 181)	TC Group (*n* = 181)	Group Effect	TC Group vs.Control Group		EX Group vs. Control Group		TC Group vs. EX Group	
					Mean Difference (95% CI)	*P* Value	Mean Difference (95% CI)	*P* Value	Mean Difference (95% CI)	*P* Value
Participants achieving remission of central obesity (95% CI), %‡										
Week 12	4.9 (4.5 to 5.3)	13.3 (12.0 to 14.5)	15.5 (14.7 to 16.2)	0.007	10.6 (9.7 to 11.5)	0.014	8.4 (7.1 to 9.7)	0.199	2.2 (1.5 to 2.9)	0.55
Week 38	3.9 (3.3 to 4.5)	14.5 (13.7 to 15.3)	11.4 (10.5 to 12.3)	0.008	7.5 (6.3 to 8.8)	0.195	10.6 (9.4 to 11.8)	**0.008**	−3.1 (−3.5 to −2.7)	0.38

BMI = body mass index; EX = conventional exercise; HDL-C = high-density lipoprotein cholesterol; TC = tai chi.
* Intervention effects on these outcomes were examined by weighted generalized estimating equations with baseline measurement, time (number of weeks since baseline), group (control, conventional exercise, and tai chi), and group-by-time interaction as the covariates. A significant group-by-time interaction indicated a significant difference for a given outcome between interventions over time. Pairwise treatment comparisons were performed by linear contrasts using the Holm procedure to adjust for multiple comparisons. *P* values in boldface indicate significance after the Holm adjustment.
† To convert HDL-C values to mg/dL, divide by 0.0259. To convert triglyceride values to mg/dL, divide by 0.0113. To convert glucose values to mg/dL, divide by 0.0555.
‡ Remission was defined as waist circumference <90 cm (men) or <80 cm (women). Intervention effects on the incidence of remission of central obesity were examined using logistic regression after multiple imputation.

non-Asian counterparts with the same age, sex, and BMI (4). Our data indicated that the interventions reduced WC and, to a lesser degree, body weight. Additional studies are warranted to further investigate the mechanisms that explain the favorable effects of tai chi on WC.

No training-related adverse events or withdrawals were reported in this study. This suggests that the instructor-led tai chi and conventional exercise programs can be safely prescribed to middle-aged and older adults with central obesity. Overall, we showed that tai chi had health benefits similar to those of conventional exercise and thus provides an alternative and more amenable exercise modality for middle-aged and older adults to manage central obesity. There are important health care implications for older people who might be averse to conventional exercise because of physical limitations or comorbidities. Tai chi is a gentle, low-impact activity that is commonly acceptable to middle-aged and older adults and is a favorable approach for them to adhere to the WHO physical activity recommendations.

Our study had limitations. First, 30% of participants were lost to follow-up over the course of the study, and multiple comparisons were evaluated. We tried to mitigate these by including the missing data in the data analysis and adjusting the multiple comparisons by using the Holm procedure. Second, physical activity and choice of diet are critical to the success of management of central obesity; our interventions included only an exercise component, and we did not monitor the dietary intake of our participants because our focus was to compare the efficacy of tai chi versus conventional exercise relative to no intervention. Third, we did not systematically assess risk for adverse events, although participants did not report harms; nonetheless, given the high dropout rates, we cannot rule out the possibility of adverse events. Fourth, this study did not provide direct measures on subcutaneous and visceral adiposity. Fifth, cultural differences and acceptance of tai chi practice could limit its use. However, many studies have been done in other countries, including the United States, Australia, France, and Thailand (12, 13); these studies preliminarily showed that tai chi had cardiometabolic benefits, suggesting that it could be implemented across cultural environments.

In this study, we showed that tai chi mirrors the beneficial effects of conventional exercise by reducing WC in middle-aged and older adults with central obesity. Our findings suggest that tai chi is an effective approach for management of central obesity. This study has great translational significance because our findings support the notion of incorporating tai chi into global physical activity guidelines for middle-aged and older adults with central obesity.

From The University of Hong Kong, Pokfulam, Hong Kong, China (P.M.S., A.P.Y., E.C.C., D.S.Y., D.Y.F.); The Chinese University of Hong Kong, Shatin, Hong Kong, China (S.S.H., J.W.); Chinese Academy of Sciences, Beijing, China (G.X.W.); and University of California, Los Angeles, Los Angeles, California (M.R.I.).

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Data Sharing Statement: Individual participant data used in the reported results have been deidentified. The data, study protocol, and statistical analysis plan will be shared beginning 3 months and ending 5 years after publication of this article. Data will be shared with researchers who provide a methodologically sound proposal with achievable aims. Proposals should be directed to pmsiu@hku.hk, and those requesting access to the data will need to sign a data access agreement.

Corresponding Author: Parco M. Siu, PhD, School of Public Health, The University of Hong Kong, Room 3-01C, 3/F, HKJC Building for Interdisciplinary Research, 5 Sassoon Road, Pokfulam, Hong Kong, China; e-mail, pmsiu@hku.hk.

Current author addresses and author contributions are available at Annals.org.

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Current Author Addresses: Dr. Siu: School of Public Health, The University of Hong Kong, Room 3-01C, 3/F, HKJC Building for Interdisciplinary Research, 5 Sassoon Road, Pokfulam, Hong Kong, China.
Mr. Yu and Mr. Chin: School of Public Health, The University of Hong Kong, Room 3-01, 3/F, HKJC Building for Interdisciplinary Research, 5 Sassoon Road, Pokfulam, Hong Kong, China.
Drs. Yu and Fong: School of Nursing, The University of Hong Kong, 4/F, William M.W. Mong Block, 21 Sassoon Road, Pokfulam, Hong Kong, China.
Dr. Hui: Department of Sports Science and Physical Education, The Chinese University of Hong Kong, G/F, Kwok Sports Building, Shatin, Hong Kong, China.
Dr. Woo: Department of Medicine & Therapeutics, The Chinese University of Hong Kong, 9/F, Lui Che Woo Clinical Sciences Building, Prince of Wales Hospital, Shatin, Hong Kong, China.
Dr. Wei: Institute of Psychology, Chinese Academy of Sciences, 16 Lincui Road, Beijing, China, 100101.
Dr. Irwin: Cousins Center for Psychoneuroimmunology and Department of Psychiatry and Biobehavioral Sciences, University of California, Los Angeles, 300 UCLA Medical Plaza #3109, Los Angeles, CA 90095.

Author Contributions: Conception and design: P.M. Siu, S.S. Hui, G.X. Wei.
Analysis and interpretation of the data: P.M. Siu, A.P. Yu, E.C. Chin, D.S. Yu, D.Y. Fong, M.R. Irwin.
Drafting of the article: P.M. Siu, A.P. Yu, S.S. Hui, J. Woo, M.R. Irwin.
Critical revision of the article for important intellectual content: P.M. Siu, A.P. Yu, D.S. Yu, S.S. Hui, J. Woo, M.R. Irwin.
Final approval of the article: P.M. Siu, A.P. Yu, E.C. Chin, D.S. Yu, S.S. Hui, J. Woo, D.Y. Fong, G.X. Wei, M.R. Irwin.
Provision of study materials or patients: A.P. Yu.
Statistical expertise: A.P. Yu, D.Y. Fong.
Obtaining of funding: P.M. Siu, D.S. Yu, S.S. Hui.
Administrative, technical, or logistic support: P.M. Siu, A.P. Yu, E.C. Chin, S.S. Hui.
Collection and assembly of data: P.M. Siu, A.P. Yu, E.C. Chin.

Appendix: Statistical Analysis

Data Analysis of Primary Outcome and Quantitative Secondary Outcomes

Data analyses of WC; body weight; BMI; HDL-C, triglyceride, and fasting plasma glucose levels; and systolic and diastolic blood pressures were performed by WGEE analysis (SAS PROC GEE). This approach was used because it accounts for correlation among repeated measurements over time, it can accommodate missing data and provide unbiased estimates under the assumption that the data are missing at random, and it does not require a distributional assumption. It comprises the missingness model to estimate the weights and the main model.

Missingness Model

This was a logistic regression of missingness on a set of observed covariates for estimating the weights (that is, the inverse probability of observing a measurement) under the missing-at-random assumption. The specified covariates were assessment time epochs; baseline measurements of WC, body weight, BMI, HDL-C level, triglyceride level, fasting plasma glucose level, and systolic and diastolic blood pressures; and the interactions of group with baseline measures of WC, body weight, BMI, HDL-C level, triglyceride level, fasting plasma glucose level, and systolic and diastolic blood pressures.

Main Model

Baseline, week 12, and week 38 measurements were included as outcomes. The covariates were the baseline measurements, time (number of weeks from baseline [continuous variable]), group (control, EX group, and TC group [categorical variable]), and the group-by-time interaction. The WGEE analysis was then done using the weights obtained from the missingness model and the first-order autoregressive working correlation matrix.

Pairwise treatment comparisons at weeks 12 and 38 were performed by linear contrasts using the Holm procedure to adjust for the multiple comparisons. To conduct the Holm procedure, we first obtained the raw *P* values for the 6 pairwise comparisons (TC group vs. control, EX group vs. control, and TC group vs. EX group at weeks 12 and 38). These were then ranked from smallest to largest, with their significance examined sequentially. Specifically, the smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 6). If it was significant, the second-smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 5), and so on. If a *P* value was insignificant, the procedure was stopped and the rest of the *P* values were considered insignificant.

Multiple Imputation and Data Analysis for the Incidence of Remission of Central Obesity

Multiple imputation (SAS PROC MI) was used to impute values for missing observations of the incidence of remission of central obesity. Specifically, 5 imputed data sets were generated using the fully conditional specification method with the number of iterations set to 20 on the following variables: group (control, EX group, and TC group); WC, body weight, BMI, HDL-C level, triglyceride level, fasting plasma glucose level, and systolic and diastolic blood pressures at baseline, week 12, and week 38; and incidence of remission of central obesity at weeks 12 and 38.

For the analysis of the incidence of remission of central obesity at weeks 12 and 38, logistic regression (SAS PROC LOGISTIC) was separately performed using each imputation data set with group (control, EX group, and TC group) as the main effect. Pairwise treatment comparisons were performed by linear contrasts. The results were then pooled using the Rubin rule. The Holm procedure was applied to the pooled *P* values to adjust for the multiple comparisons at weeks 12 and 38. This was done by first obtaining the raw *P* values for the 6 pairwise comparisons of interest (TC group vs. control, EX group vs. control, and TC group vs. EX group at weeks 12 and 38) and ranking them from smallest to largest. The smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 6). If it was significant, the second-smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 5), and so on. If a *P* value was insignificant, the procedure was stopped and the rest of the *P* values were considered insignificant.

Sensitivity Analyses

The analysis of the primary outcome, WC, was repeated using 3 analytical approaches. First, multiple imputation (SAS PROC MI) was used to impute missing WC values before applying GEE. Specifically, 20 imputed data sets were generated using the fully conditional specification method with the number of iterations set to 20 for the following variables: time (number of weeks from baseline); group (control, EX group, and TC group); and measurements of WC, body weight, BMI, HDL-C level, triglyceride level, fasting plasma glucose level, and systolic and diastolic blood pressures.

For each generated data set, we applied the GEE with the first-order autoregressive working correlation matrix (SAS PROC GEE). Specifically, the baseline, week 12, and week 38 measurements were included as outcomes, with baseline measurement, time, group, and group-by-time interaction as covariates. Pairwise treatment comparisons were performed by linear contrasts. The results were then pooled using the Rubin rule. The Holm procedure was applied to the pooled *P* value to adjust for the multiple comparisons, as previously detailed in the description of the analysis of the primary outcome.

The second approach was the same as the first approach, except baseline body weight and baseline BMI were used as additional covariates in the GEE analysis. The third approach was also identical to the first approach, except the covariates in the GEE analysis were time and group-by-time interaction only.

Data Analysis of Habitual Physical Activity

The habitual physical activities of participants were assessed using the International Physical Activity Questionnaire (IPAQ).

For the same reasons stated in the description of the analysis of the primary outcome, the IPAQ-Activity and IPAQ-Sitting were also analyzed using WGEE (SAS PROC GEE). The missingness model for habitual physical activity was also a logistic regression of missingness on the assessment time epochs, baseline measurements of IPAQ-Activity and IPAQ-Sitting, and the interactions of group with the baseline IPAQ-Activity and baseline IPAQ-Sitting measures.

The main model included baseline, week 12, and week 38 measurements as the outcomes and baseline measurements, time (number of weeks from baseline [continuous variable]), group (control, EX group, and TC group [categorical variable]), and group-by-time interaction as the covariates. Again, a first-order autoregressive correlation matrix was used. Pairwise treatment comparisons at weeks 12 and 38 were performed by linear contrasts using the Holm procedure to adjust for the multiple comparisons. To do this, we first obtained the raw *P* values for the 6 pairwise comparisons (TC group vs. control, EX group vs. control, and TC group vs. EX group at weeks 12 and 38). These were then ranked from smallest to largest, with their significance examined sequentially. Specifically, the smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 6). If it was significant, the second-smallest *P* value was determined to be significant if it was smaller than (0.05 ÷ 5), and so on. If a *P* value was insignificant, the procedure was stopped and the rest of the *P* values were considered insignificant.

Appendix Table 1. Association of Baseline Characteristics With Missingness at Weeks 12 and 38*

Characteristic	Week 12		Week 38	
	Completed Study (*n* = 427)	**Dropped Out (*n* = 116)**	**Completed Study (*n* = 380)**	**Dropped Out (*n* = 163)**
Female, *n (%)*	334 (78.2)	89 (76.7)	294 (77.4)	129 (79.1)
Mean age (SD), *y*	62.0 (6.2)	61.5 (6.3)	61.9 (6.2)	62.1 (6.2)
Mean waist circumference (SD), *cm*	91.7 (8.3)	93.4 (9.7)	91.8 (8.3)	92.8 (9.3)
Mean HDL-C level (SD), *mmol/L*†	1.54 (0.39)	1.50 (0.36)	1.52 (0.39)	1.56 (0.38)
Mean triglyceride level (SD), *mmol/L*†	1.45 (0.72)	1.54 (1.00)	1.47 (0.73)	1.48 (0.91)
Mean fasting plasma glucose level (SD), *mmol/L*†	5.5 (1.0)	5.8 (1.6)	5.6 (1.0)	5.7 (1.4)
Mean systolic blood pressure (SD), *mm Hg*	127.3 (16.3)	129.0 (16.8)	127.4 (16.0)	128.1 (17.3)
Mean diastolic blood pressure (SD), *mm Hg*	76.2 (9.8)	77.5 (10.5)	76.3 (9.7)	76.8 (10.6)
Mean body weight (SD), *kg*	63.5 (11.4)	**66.6 (12.7)**	63.8 (11.5)	65.1 (12.5)
Mean BMI (SD), *kg/m*^{2}	25.4 (3.5)	**26.4 (4.0)**	25.4 (3.5)	**26.0 (3.9)**

BMI = body mass index; HDL-C = high-density lipoprotein cholesterol.

* The Mann–Whitney *U* test was used to examine the difference in baseline characteristics between those who completed the study and those who dropped out. Values in boldface indicate a significant difference from those who completed the study.

† To convert HDL-C values to mg/dL, divide by 0.0259. To convert triglyceride values to mg/dL, divide by 0.0113. To convert glucose values to mg/dL, divide by 0.0555.

Appendix Table 2. Sensitivity Analyses of the Primary Outcome*

Analysis	Mean Waist Circumference (SD), *cm*			Group-by-Time Interaction Effect	TC Group vs. Control Group		EX Group vs. Control Group		TC Group vs. EX Group	
	Control Group (*n* = 181)	EX Group (*n* = 181)	TC Group (*n* = 181)		Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value
Multiple imputation										
Week 0	91.6 (8.4)	92.3 (9.0)	92.4 (8.5)	<0.001	–	–	–	–	–	–
Week 12	93.2 (8.4)	91.6 (9.0)	90.0 (8.4)	–	−1.8 (−2.4 to −1.2)	<**0.001**	−1.1 (−1.7 to −0.5)	**0.004**	−0.7 (−1.3 to −0.03)	0.108
Week 38	93.9 (8.3)	91.1 (9.1)	90.3 (8.4)	–	−4.0 (−5.3 to −2.8)	<**0.001**	−3.1 (−4.4 to −1.8)	<**0.001**	−1.0 (−2.1 to 0.2)	0.169
Multiple imputation with adjustment for baseline measures of body weight and BMI										
Week 0	91.6 (8.4)	92.3 (9.0)	92.4 (8.5)	<0.001	–	–	–	–	–	–
Week 12	93.2 (8.4)	91.6 (9.0)	90.0 (8.4)	–	−1.6 (−2.2 to −1.0)	<**0.001**	−1.1 (−1.7 to −0.5)	**0.004**	−0.5 (−1.2 to 0.1)	0.144
Week 38	93.9 (8.3)	91.1 (9.1)	90.3 (8.4)	–	−3.9 (−5.1 to −2.7)	<**0.001**	−3.0 (−4.3 to −1.8)	<**0.001**	−0.9 (−2.0 to 0.3)	0.21
Multiple imputation without baseline adjustment										
Week 0	91.6 (8.4)	92.3 (9.0)	92.4 (8.5)	<0.001	–	–	–	–	–	–
Week 12	93.2 (8.4)	91.6 (9.0)	90.0 (8.4)	–	−1.0 (−1.4 to −0.6)	<**0.001**	−0.8 (−1.2 to −0.4)	<**0.001**	−0.2 (−0.6 to 0.2)	0.38
Week 38	93.9 (8.3)	91.1 (9.1)	90.3 (8.4)	–	−3.1 (−4.4 to −1.9)	<**0.001**	−2.5 (−3.8 to −1.3)	<**0.001**	−0.6 (−1.7 to 0.6)	0.38

BMI = body mass index; EX = conventional exercise; TC = tai chi.

* The sensitivity analyses assessed the robustness of the results across 3 analytical approaches. The first was multiple imputation plus a generalized estimating equations analysis of baseline, week 12, and week 38 measurements on baseline, time, group, and group-by-time interaction. The second was multiple imputation plus a generalized estimating equations analysis of baseline, week 12, and week 38 measurements on baseline, time, group, group-by-time interaction, baseline body weight, and baseline BMI. The third was multiple imputation plus a generalized estimating equations analysis of baseline, week 12, and week 38 measurements on time and group-by-time interaction. A significant group-by-time interaction indicated a significant difference for waist circumference between interventions over time in all 3 approaches. Pairwise treatment comparisons were performed by linear contrasts using the Holm procedure to adjust for the multiple comparisons. *P* values in boldface indicate significance after the Holm adjustment.

Appendix Table 3. Habitual Physical Activity*

Outcome	Mean Estimated Daytime Energy Expenditure (SD), *MET-min/wk*			Group-by-Time Interaction Effect	TC Group vs. Control Group		EX Group vs. Control Group		TC Group vs. EX Group	
	Control Group (*n* = 181)	EX Group (*n* = 181)	TC Group (*n* = 181)		Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value	Adjusted Mean Difference (95% CI)	*P* Value
IPAQ-Activity										
Week 0	845.9 (560.2)	879.1 (482.8)	877.5 (538.6)	<0.001	–	–	–	–	–	–
Week 12	971.3 (581.7)	2153.0 (788.4)	2219.4 (798.6)	–	527.75 (476.81 to 578.69)	<**0.001**	508.06 (455.06 to 561.06)	<**0.001**	19.69 (−44.99 to 84.36)	0.55
Week 38	981.2 (679.1)	1789.7 (956.2)	1778.3 (884.9)	–	819.72 (699.9 to 939.54)	<**0.001**	832.41 (700.99 to 963.83)	<**0.001**	−12.69 (−160.44 to 135.07)	0.87
IPAQ-Sitting										
Week 0	2575.7 (373.5)	2576.5 (376.3)	2551.3 (379.2)	0.098	–	–	–	–	–	–
Week 12	2519.0 (379.9)	2239.5 (384.8)	2213.8 (384.6)	–	−112.89 (−137.01 to −88.77)	<**0.001**	−116.22 (−141.53 to −90.91)	<**0.001**	3.33 (−21.50 to 28.16)	0.79
Week 38	2514.8 (425.7)	2342.8 (407.8)	2348.2 (379.4)	–	−160.79 (−225.41 to −96.17)	<**0.001**	−179.83 (−246.87 to −112.79)	<**0.001**	19.04 (−42.09 to 80.16)	0.54

EX = conventional exercise; IPAQ-Activity = estimated daytime energy expenditure during physical activity, assessed by the International Physical Activity Questionnaire; IPAQ-Sitting = estimated daytime energy expenditure during rest, assessed by the International Physical Activity Questionnaire; MET = metabolic equivalent of task; TC = tai chi.

* Intervention effect on habitual physical activity level was examined using weighted generalized estimating equations with baseline, time, group, and group-by-time interaction used as covariates. A significant group-by-time interaction indicated a significant difference for a given outcome between interventions over time. Pairwise treatment comparisons were performed by linear contrasts using the Holm procedure to adjust for the multiple comparisons, and raw *P* values are presented. *P* values in boldface indicate significance after the Holm adjustment.