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Original Article

Functional outcomes of Tai Chi exercise prescription in women with knee osteoarthritis

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ABSTRACT

Knee Osteoarthritis (KOA) is the most common type of knee joint injury and also a risk factor for multiple health consequences and is prevalent among older women. The updated clinical guidelines for KOA treatment by the American Rheumatism Association recommend Tai Chi exercise. However, a literature review outlined limitations in Tai Chi intervention implementations. This study aimed to address some of the gaps. This study selected thirty female patients to participate in Tai Chi exercises and undergo relevant tests. The subjects were randomly assigned to Tai Chi or education groups. Independent sample t-tests were conducted to compare the difference in health indicators between the two groups after the intervention. The difference-in-differences (DID) regression was performed to assess the difference in the health outcomes between the two groups at baseline and follow-up and the difference in the differences. After the completion of the intervention, the Tai Chi group reported significantly improved KOA symptoms, physical fitness, and health status indicators than the control group. Specifically, the group differences were significantly larger at the baseline than at the follow-up. Our findings provide compelling evidence of the effects of the innovative Tai Chi exercise prescription specifically designed for KOA patients. The empirical evidence on its effectiveness in alleviating KOA symptoms and improving the overall health of middle-aged and elderly women with KOA suggested that Tai Chi intervention exercise has huge prospects for integration in KOA rehabilitation therapy.

Introduction

Knee Osteoarthritis (KOA) is a musculoskeletal degenerative disease prevalent among older adults. The symptoms of KOA include pain and stiffness of lower limbs, reduced muscle strength, muscle atrophy,and abnormal gait, which limit patient engagement in daily activities and further affect their physical functioning.[1,2] Moreover, KOA is well-established as a risk factor for obesity and cardiovascular diseases, affecting life expectancy. Before the age of 50 as the incidence of KOA in men is higher than in women; after the age of 50, the incidence of KOA in women rises significantly and exceeds that of men.[3,4]

Exercise therapy is a cost-effective treatment well-recognized to have significant effects on patients with KOA.[5] Intervention programs focusing on aerobic exercise, strength, and flexibility have been added to the clinical guidelines for KOA treatment updated by the American Rheumatism Association.[6] Among these, in 2012, Tai Chi was officially recommended by the American Rheumatology Association as one of the non-drug clinical treatments for KOA. Over the years, the effects of Tai Chi exercise on KOA have attracted the attention of many researchers.[6,7]

Tai Chi is a martial art in China developed in the 17th century that embodies a low-impact and aerobic form of mind-body therapy. By focusing on breath and relaxation with very slow, gentle, graceful movement, Tai Chi can improve the proprioception of the knee joint,[8] enhance the muscle strength around the knee joint,[9–11] and balance ability.[12,13] Therefore, Tai Chi intervention alleviate the symptoms of KOA[7,14] and improve both patient exercise capacity and quality of life.

However, muscle atrophy limitations in research designs and intervention implementations; It is challenging to reflect Tai Chi theory and method in the treatment plan; Instead, only external movements of Tai

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Abbreviations

KOA	knee Osteoarthritis
DID	Difference-in-differences Regression
OLS	one-leg standing test wiht eyes shut
BMI	Body Mass Index
VAS	Visual Analog Scale
SF-36	Short-Form Health Survey-36
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
Diff-in-Diff	Difference-in-differences
$Diff_1$	Difference at baseline
$Diff_2$	Difference at follow-up
$Diff_2$-$Diff_1$	Difference between baseline and follow-up

Chi were implemented in these studies. Specifically, the Tai Chi movements used in existing studies are mostly based on the Tai Chi routines of the Chen and Yang styles, which have not been clinically designed and formulated for KOA patients or pay sufficient attention to the Tai Chi breathing pattern, which is critical to the movement pattern. In participants already familiar with the basics of Tai Chi, breathing exercises can achieve better health promotion effect.[15] There are three modes of normal breathing: slow exhaling and slow inhaling (when moving at a constant speed), fast exhaling and slow inhaling (when moving from fast to slow) and slow exhaling and fast inhaling (when accelerating force). During the practice of Tai Chi, the slow breathing and slow breathing mode is generally adopted. More information regarding the Tai Chi movement patterns can be accessed on online (https://youtu.be/iqf5dIA6NF0; https://youtu.be/u7V57SypPxs). Moreover, the minimum length of an effective Tai Chi intervention for KOA patients is generally 8–12 weeks. The significant short-term effect has been established; however, some studies on the effects of a 24-week intervention showed that the long-term effect of Tai Chi on KOA was reduced compared with that at 8 and 12 weeks.[16] To date, there is no detailed documentation about the effect of a 36-week intervention.

To address some of the gaps in the literature, this study developed a Tai Chi exercise prescription for middle-aged and elderly women with KOA. The study conducted 36 weeks of Tai Chi therapy intervention to explore its effect on the symptoms and exercise capacity among female KOA patients. The study aims to provide empirical evidence for future clinical intervention.

Material and methods

Data and sample

Knee osteoarthritis is the most common type of knee joint injury. This study focuses on the Tai Chi exercise prescription for female patients with knee osteoarthritis. The study selected 30 female patients with a medical history of more than 6 months of unilateral joint involvement that satisfied 3 of the following 5 criteria: 1) age $\geq$ 50 years old; 2) morning stiffness time less than 30 min; 3) joint clicks when moving; 4) bone tenderness; 5) knee joint examination suggests skeletal hypertrophy assessment. Study subjects were required to participate in Tai Chi exercises and undergo relevant tests. Patients with hypertension or severe diabetes were excluded. According to the inclusion criteria, we selected 30 subjects from the clinical patients of Peking University Hospital who met both the inclusion and exclusion criteria. Using the random number table method, the subjects were randomly assigned to Tai Chi (intervention) or education (control) groups, with 15 people in each group. 3 people in the Tai Chi group were excluded because their participation rates were lower than 80%. Finally, 15 and 12 people were enrolled in the control and

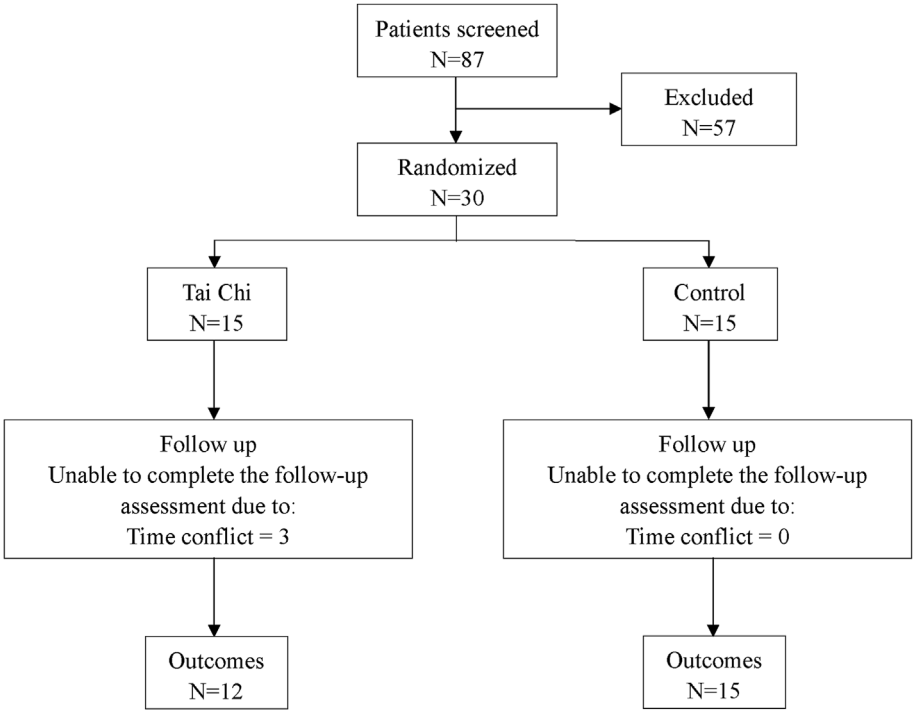

Fig. 1. Flowchart explaining assignment of the participants to Tai Chi and control groups.

Table 1
Participant characteristics at baseline.

	Overall ($n = 27$)	Control group ($n = 15$)	TaiChi group ($n = 12$)	p
Age (years)	64.1 ± 5.4	64.7 ± 6.1	63.4 ± 4.6	0.547
Height (cm)	157.7 ± 5.6	156.9 ± 5.2	158.7 ± 6.2	0.422
Weight (kg)	61.8 ± 12.7	59.8 ± 11.7	64.3 ± 14.0	0.384
BMI (kg/m^2)	24.9 ± 4.6	24.3 ± 4.8	25.6 ± 4.4	0.486

Notes: a) Data reported as mean ± standard deviation (*SD*). b) BMI refers to body mass index. c) There were no significant differences between groups($p > 0.1$).

intervention groups. More detailed information is provided in Fig. 1.

Ethical approval statement

Ethical approval for all study waves was granted by the Institutional Review Board at Peking University. The approval number is IRB20190804. The study participants provided informed written consent and agreed to cooperate with the intervention protocol to complete the study.

Intervention protocol

The study was carried out from February to November 2019. The intervention began one week after the baseline parameters were measured. Tai Chi exercise prescriptions were formulated based on the subjects' health screening and evaluation results, and interventions were implemented for 36 weeks. Tai Chi exercise prescriptions were composed of preparatory, training, and finishing activities, with each stage integrating Tai Chi movements such as Tai Chi warm-up, Tai Chi twining kung fu, Tai Chi stake, and 8 Chen style Tai Chi movements.

Each Tai Chi session lasted for 60 min three times a week for 36 weeks in a group format and a community setting. In the first 4 weeks of the Tai Chi intervention, the participants were taught Tai Chi three times per week, including 5-min warm-up Tai Chi exercise and Tai Chi breathe training, 5-min Tai Chi Can twining (Chan Si), 20-min learning of the movements, 20-min reviewing of the movements, and 10-min cool-down Tai Chi exercise. In the subsequent weeks, each session consisted of 5-min warm-up Tai Chi exercise and Tai Chi breathe training, 5-min Tai Chi twining (Chan Si), 40-min Tai Chi movements, and 10-min cool-down Tai Chi exercise.

Two Tai Chi masters (national champions) with 25 years of extensive training experience were responsible for the instruction of Tai Chi intervention. In addition, both masters completed the required research and human subject protection training prior to initiation of the intervention classes.[2]

The control group participated in a wellness education program with topics ranging from diet and nutrition to physical education and health promotion. Each session lasted for 60 min and was performed once a month for 9 months.

Instrument and measures

The following outcomes were measured at baseline and the end of the 36-week Tai Chi Intervention.

WOMAC/VAS. The Western Ontario and McMaster Universities Osteoarthritis Index is a scoring system for hip and knee joints developed by Bellamy and colleagues. The questionnaire is mainly used to evaluate the severity of pain, stiffness and dysfunction in patients with KOA. The questionnaire comprises 24 questions assessed using a 0–10 cm visual analog scale (VAS) method. The patient was required to fill out the questionnaire based on her pain, stiffness, and dysfunction. It was then measured and recorded by a professional with a VAS scale.

Physical fitness. The tests were performed by the intelligent physical fitness testing machine 2.0 produced by Taishan Sports. The machine conducted normalized, self-service, national physical fitness testing, assessing height, weight, BMI, reaction time, one-leg standing with eyes shut, blood pressure, heart rate, grip strength, vital capacity, etc.

One-leg standing test with eyes shut (OLS). The OLS test was performed in a standing position with the arms alongside the trunk. Participants used their preferred leg for the test. Subjects were asked to keep standing on the same leg for as long as possible, with their eyes shut and without assistance.

The 10 m walk test was used to assess the walking ability of the subjects. The starting point, the 3 m point, the 13 m point, and the endpoint were marked on a straight-line distance of 16 m on flat ground with colored tape. After hearing the "start" command, the subjects were asked to walk from the starting point to the endpoint at the fastest possible walking speed. The evaluator used a stopwatch to record the time it took for each participant to walk from the 3 m mark line to the 13 m point mark line (i.e., 10 m walking time). The recording time was accurate to 0.1 s, and the fastest values of the 2 evaluations were taken (unit: m/s).

The Timed Up and Go (TUG) test was used to assess the subject's flexibility and dynamic balance. The subjects were asked to sit on a chair and place hands on their thighs, with one foot slightly forward and the

Table 2
VAS assessment, SF-36 assessment, and Physical fitness assessment between Tai Chi group and control group before and after the intervention.

Assessment method		Taichi ($n = 12$)			Control ($n = 15$)		
		Baseline	Follow-up	p	Baseline	Follow-up	p
VAS	Pain	10.67 ± 4.03	8.58 ± 3.75	0.001***	8.53 ± 3.66	7.87 ± 3.02	0.086*
	Stiffness	5.25 ± 2.60	3.75 ± 2.53	0.002***	3.20 ± 1.66	2.93 ± 1.49	0.041**
	Physical function	36.58 ± 8.76	27.17 ± 7.72	< 0.001***	26.33 ± 9.00	25.87 ± 8.90	0.264
	Total	52.50 ± 11.19	39.50 ± 12.18	< 0.001***	38.07 ± 12.12	36.67 ± 11.28	0.106
SF-36	Physiological function	76.67 ± 9.13	82.50 ± 6.57	0.052*	81.00 ± 10.04	81.67 ± 9.39	0.164
	Physiological occupation	72.92 ± 29.11	83.33 ± 28.87	0.054*	80.00 ± 27.06	81.67 ± 27.49	0.334
	Physical pain	54.08 ± 10.15	67.67 ± 11.11	0.003***	62.93 ± 17.84	63.60 ± 17.14	0.334
	General health	65.00 ± 13.28	65.42 ± 12.91	0.339	60.13 ± 10.29	60.13 ± 10.29	\
	Energy	77.50 ± 8.39	78.33 ± 8.62	0.166	73.33 ± 21.68	73.33 ± 21.68	\
	Social function	78.70 ± 18.63	83.33 ± 16.07	0.054*	82.96 ± 18.24	85.93 ± 19.91	0.041 **
	Emotional function	75.00 ± 37.94	77.78 ± 32.82	0.586	66.67 ± 35.63	68.89 ± 34.43	0.334
	Mental health	76.00 ± 14.87	76.00 ± 14.87	\	68.80 ± 18.53	69.07 ± 18.91	0.334
	Overall SF-36 score	71.98 ± 12.10	76.80 ± 12.39	0.002***	71.98 ± 10.64	73.04 ± 11.04	0.040 **
Physical fitness	Response time	0.57 ± 0.06	0.56 ± 0.06	0.054*	0.53 ± 0.06	0.54 ± 0.06	0.282
	Grip strength	24.13 ± 3.68	25.05 ± 4.13	0.002***	22.38 ± 3.37	22.93 ± 3.35	< 0.001***
	Flexibility	11.16 ± 6.51	11.97 ± 6.55	0.001***	12.63 ± 9.89	12.67 ± 9.80	0.765
	Vital capacity	2 004.08 ± 759.88	2 082.42 ± 768.95	0.022**	2 039.47 ± 523.31	2 046.00 ± 533.32	0.448
	10 m pace (m/s)	1.50 ± 0.20	1.40 ± 0.19	< 0.001***	1.51 ± 0.12	1.47 ± 0.12	0.001***
	TUG (s)	6.18 ± 0.37	5.82 ± 0.44	< 0.001***	5.94 ± 0.71	5.85 ± 0.67	0.026**
	OLS	3.38 ± 2.88	6.33 ± 3.61	< 0.001***	5.71 ± 5.00	5.49 ± 4.92	0.108

Notes: a) VAS stands for visual analog scale; b) SF-36 refers to Short-Form Health Survey-36 items; c) TUG refers to timed up to go; d) OLS refers to one-leg standing test with eyes shut; e) Data reported as mean ± standard deviation (*SD*); f) Inference: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

body slightly forward. After hearing the "start" command, the subjects were asked to stand up from the chair, walk as fast as possible, go around a cone 3 m away (measured from the farthest side of the cone), and then return to sit on the chair. The timekeeper was asked to press the stopwatch when he/she heard the "start" command and stop the stopwatch the moment the subject returned and sat on the chair. The subjects were allowed to practice once and were then evaluated twice. The best score of the two tests was recorded to the nearest 1/10 s.

Health-related Quality of Life (HRQL) assessments were made using the Medical Outcome Study 36-Item Short-Form (SF-36).[17] SF-36 is a self-administered, 36-item questionnaire that assesses the physical functioning and role limitations due to physical problems, bodily pain, general mental health illness, emotional problems, lack of vitality, and general health perceptions. The scores range from 0 to 100, with higher scores indicating better health status.[2,17]

Statistical analysis

This study conducted univariate and bivariate analyses and the difference-in-differences (DID) regression using Stata, version 15 (StataCorp, LLC., College Station, TX). The independent sample *t*-test was used to compare the differences in pain, stiffness and dysfunction, SF-36, and physical fitness between the Tai Chi group and the control group, before and after the intervention. This study employed the DID approach for the difference between two differences. The difference in the outcomes was assessed between the Tai Chi and control groups at baseline (before) and follow-up (after), respectively, and the difference in the differences was evaluated.

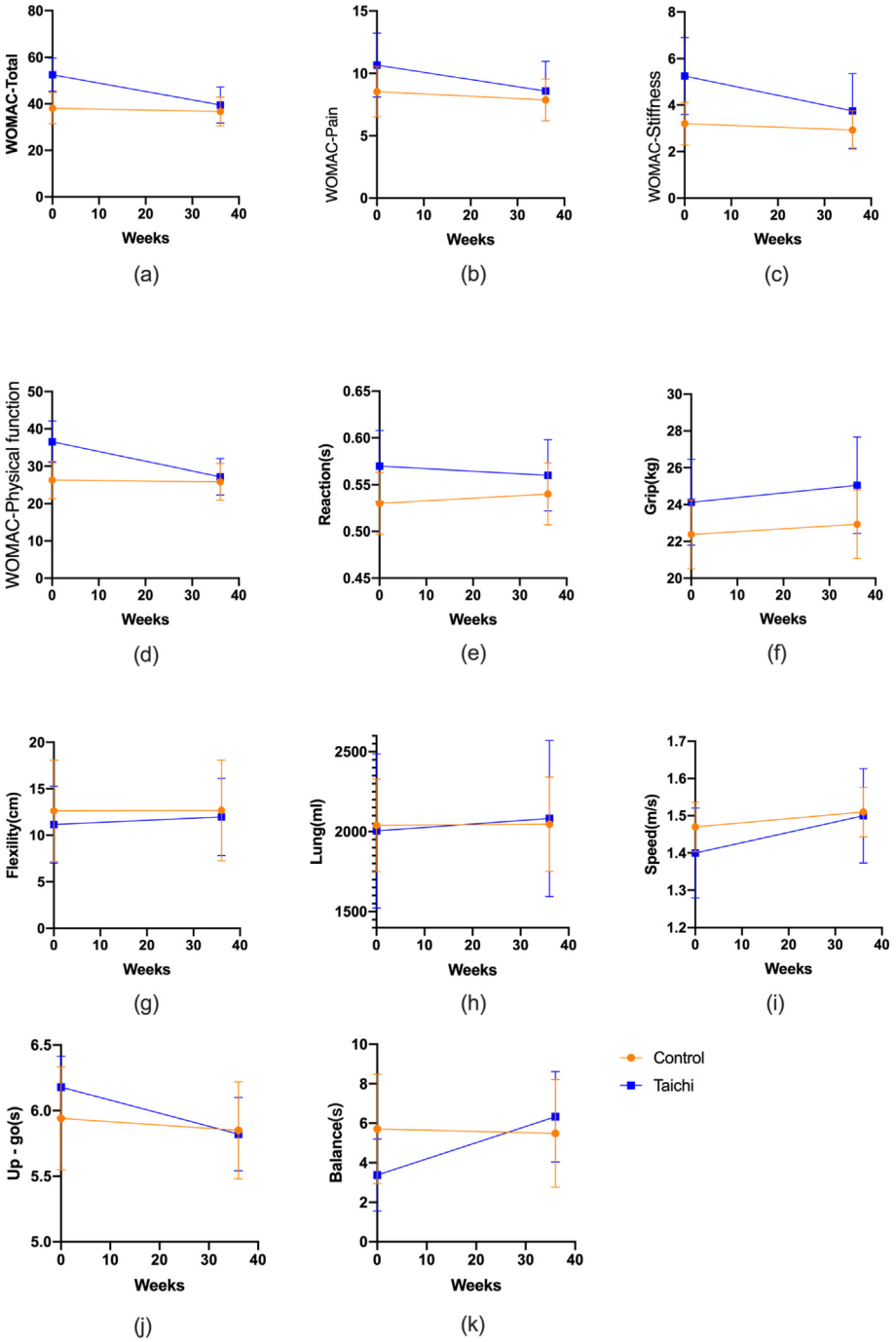

Fig. 2. Comparisons of mean values of WOMAC/VAS and physical fitness between Tai Chi and control groups.

Table 3
Difference-in-differences estimation results.

Outcomes	Before			After			*Diff-in-Diff*
	Control ($n = 15$)	TaiChi ($n = 12$)	*Diff*$_1$ (T-C)	Control ($n = 15$)	TaiChi ($n = 12$)	*Diff*$_2$ (T-C)	*Diff*$_2$-*Diff*$_1$
SP36Total	71.979	71.984	0.005	73.035	76.795	3.760	3.755
VAStotal	38.067	52.500	14.433***	36.667	39.500	2.833	−11.600*
Vas1-Pain	8.533	10.667	2.133	7.867	8.583	0.717	−1.417
Vas2-Stiffness	3.200	5.250	2.050**	2.933	3.750	0.817	−1.233
Vas3-Physical function	26.333	36.583	10.250***	25.867	27.167	1.300	−8.950*
Balance	5.713	3.383	−2.330	5.487	6.333	0.847	3.177
Reaction	0.535	0.572	0.037	0.540	0.563	0.023	−0.014
Grip	22.380	24.125	1.745	22.933	25.050	2.117	0.372
Flexibility	12.633	11.158	−1.475	12.667	11.973	−0.694	0.781
Lung	2 039.467	2 004.083	−35.383	2 046.000	2 082.417	36.417	71.800
Speed	1.469	1.397	−0.071	1.511	1.500	−0.011	0.060
Up and go	5.944	6.184	0.240	5.855	5.819	−0.035	−0.276

Notes: a)) SF-36 refers to Short-Form Health Survey-36 items; VAS stands for visual analog scale. b) Means reported in the table were estimated by linear regression; c) Number of observations in the DID analysis was 54, with 30 observations from the control group (15 before and 15 after) and 24 observations from the treatment group (12 before and 12 after); d) Inference: ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Results

Table 1 demonstrated sample description and results of bivariate tests by Tai Chi and control groups. No significant differences in demographic characteristics and BMI were found between the Tai Chi and the control groups at baseline.

KOA symptoms

Table 2 demonstrated the comparisons of functional assessment results between Tai Chi group and control group before and after the intervention.

Results of DID

Fig. 2 shows the changes in the mean values of WOMAC/VAS and physical fitness at baseline and at 36 weeks for both groups, indicating that most indicators in the Tai Chi group were significantly changed after the intervention compared with the control group. Therefore, the DID method was further conducted to compare the differences between the two changes.

As demonstrated in Table 3, at baseline (*Diff*$_1$), the Tai Chi group exhibited significantly higher scores for VAStotal ($p < 0.01$), Vas2-stiffness ($p < 0.05$), and Vas3-physical function ($p < 0.1$) than the control group. However, the differences in the health outcomes between the control and Tai Chi groups at follow-up (*Diff*$_2$) were not statistically significant. The Difference-in-Difference analysis (*Diff*$_2$-*Diff*$_1$) indicated significant differences between the Tai Chi group and the control group for VAStotal ($p < 0.1$) and Vas3 ($p < 0.1$). Specifically, the group differences were significantly larger at the baseline than at follow-up.

Discussion

This study explored the effects of an innovative Tai Chi exercise prescription for KOA patients, integrating Tai Chi warm-up, twining kung fu, Tai Chi routines, Tai Chi stake, and Tai Chi finishing activities.

The study found that Tai Chi exercise prescription effectively alleviated joint pain, stiffness and joint function and significantly improved the overall health of middle-aged and elderly women with KOA. Accordingly, Tai Chi therapy is indicated in knee osteoarthritis to improve causes of KOA such as decreased muscle strength, joint stability, balance ability and proprioception around the knee joint caused by aging and injuries.

Our results suggest that Tai Chi exercise prescription should be integrated into KOA rehabilitation therapy to effectively improve patient physiological functions, relieve physical pain, and ultimately improve their quality of life.

Compared with the baseline data, the Tai Chi group experienced a 19.58% reduction in WOMAC pain score (11.18% greater than the control group). Moreover, the Tai Chi group had a 24.76% improvement in WOMAC overall function score (21.08% greater than the control group). This finding indicated that Tai Chi exercise therapy's core stability and lower limb strength training could help relieve pain and improve physiological functions such as muscle strength, proprioception, joint mobility, and cardiopulmonary function. However, our study did not find significant improvements in the mental health of middle-aged and elderly patients, consistent with the literature.[14,18,19] Future research is recommended to integrate Tai Chi for psychological intervention.

Herein, we substantiated that the newly developed Tai Chi exercise prescription could improve the dynamic and static balance ability, 10 m walking speed, Timed Up and Go results, vital capacity, and flexibility of female KOA patients. KOA patients commonly experience joint pain and reduced physical activity, resulting in decreased strength of quadriceps and gluteal muscles and stiffness of quadriceps and calf triceps. These problems may affect the stability and proprioception of the knee joint, cause functional dysfunction, a common symptom most KOA patients experience,[20] and increase the possibility of falls. The Tai Chi-related movements in the treatment plan were specifically formulated based on patient characteristics. When the patient was practicing Tai Chi, the tangling strength of Tai Chi twining, the transformation of the body's center of gravity, body rotation, and single-leg standing in different fist postures repeatedly trained joint control and muscle coordination, which significantly improved the one-leg stading time with eyes closed and the timed up and go results among middle-aged and elderly women with KOA. This finding corroborated Tai Chi's effectiveness in reducing the risk of falls.[12,18,21–23]

The current Tai Chi exercise prescription also emphasizes optimizing the patient's breathing pattern. Training on breathing patterns, body structure, and the coordinated activation of muscles can alleviate pain and posture problems in the neck, shoulder, and waist caused by respiratory compensation. The deep and slow abdominal breathing used in this prescription, the convex and concave shape of the abdomen (fitting), and the all-round, intensive training on the lower pubic region of the human body (deep activation) could effectively strengthen the body's feedforward mechanism, and significantly increase the patient's vital capacity, which in turn improve their quality of life. This phenomenon has been confirmed by previous studies.

An increasing body of evidence suggests that 8–12 weeks of Tai Chi intervention is the "onset time" for the intervention effect; however, the effect at 24 weeks or 48 weeks gradually wore off, resulting in no significant difference between intervention and control groups. This study implemented 36 weeks of Tai Chi. Although a significant difference was detected between the two groups before and after the intervention, consistent with previous studies,[16,24] the significance of the differences

in many indicators was marginal ($p < 0.1$). Indeed, further studies with larger sample size are warranted to increase the robustness of these findings.

Several limitations were present in this study. First, the study subjects were recruited from the same hospital and community, which may lead to sample bias and restricted representativeness of the data. Moreover, limited by the size of the training room and the one-to-one training ability of 2 trainers, only 40 people were included in this research. In the future, we will continue to improve the exercise prescription for KOA patients in orderwill be improved to include more subjects for exercise intervention to support the results of this study. Besides, our research only focused on the difference between the newly developed Tai Chi exercise prescription for KOA and the control group; we did not compare the new intervention with the traditional Tai Chi treatment plan or other exercise therapies. Indeed, the study design and intervention plan should be optimized to make up for the shortcomings and limitations of this research in future research.

The high prevalence and health consequences of knee osteoarthritis warrant clinical research on the effectiveness of the specifically designed Tai Chi exercise intervention for KOA patients. This study filled the knowledge gaps by conducting a 36-week Tai Chi therapy intervention that integrated clinically designed Tai Chi movements and breathing patterns for KOA patients. The effectiveness of this newly developed Tai Chi exercise intervention on the symptoms and physical fitness among female KOA patients was demonstrated.

Funding

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Ethical approval statement

Informed consent was obtained from each participate, and the study was reviewed by the author's institution and received approval to implement the study and include any institutional approval numbers (IRB approval number: 20190804) given by the institution review committee.

Submission statement

Authors declare that the manuscript has not been published previously and is not under consideration for publication elsewhere. Its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If accepted, it will not be published elsewhere including electronically in the same form, in English or in any other language, without the written consent of the copyright-holder.

Authors' contribution

GC, DW, and NK contributed to the conception of the study; DW, ZZ, and DM performed the experiment; NK, YW, and CG contributed significantly to analysis and manuscript preparation; GC, and NMH provided constructive comments for results interpretation and discussions.

Conflict of interest

The authors declare that they have no direct or indirect interests that are in direct conflict with the conduction of the study.

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