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Effects of tai chi exercise on posturography, gait, physical function and quality of life in postmenopausal women with osteopaenia: a randomized clinical study

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Objective: To evaluate the effects of tai chi exercise on risk factors for falls in postmenopausal women with osteopaenia through measurements of balance, gait, physical function and quality of life.
Design: A randomized, controlled, single-blinded, 24-week trial with stratification by age and bone mass.
Setting: General community.
Participants: Sixty-one independently living elderly females aged 65 years and older with low bone mass.
Interventions: Subjects were recruited and randomly assigned to 24 weeks of tai chi (60 minutes/session, three sessions/week, $n=30$) or a control group ($n=31$).
Outcome measures: Computerized dynamic posturography, gait, 'timed up and go', five-chair sit-to-stand and quality of life assessed at baseline, 12 and 24 weeks.
Results: After 24 weeks, subjects in the tai chi group demonstrated an increase in stride width ($P=0.05$) and improvement in general health ($P=0.008$), vitality ($P=0.02$) and bodily pain ($P=0.03$) compared with those in the control group. There was no significant difference in balance parameters, 'timed up and go', five-chair sit-to-stand and other domains of quality of life.
Conclusion: Tai chi exercise may reduce risk factors for falls by increasing the stride width, and may improve quality of life in terms of general health, vitality and bodily pain in postmenopausal women with osteopaenia.

Introduction

Osteoporosis is a degenerative bone disease characterized by low bone mass and structural deterioration of bone tissue, leading to bone fragility.[1] It has its highest rate of occurrence in

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postmenopausal women and causes primarily hip and spine fractures leading to high morbidity and mortality.[2] Osteoporosis has been known as a silent disease that may cause no symptoms until a fracture occurs. Falling is a determinant of bone fracture; in fact more than 90% of hip fractures among adults aged 65 and older are caused by falls.[3] Risks of osteoporotic bone fracture can therefore be reduced if risk factors for falls are reduced. If an osteoporotic patient does not fall, fracture may not occur despite a low bone mass density. Particularly in the very elderly, reducing risk factors for falls may be more important than improving the bone strength or bone mass density, because falling presents a much more pressing threat compared with the slow response to bone strength therapy.

To reduce risk factors for falls, older adults with substantial fall risks are recommended to perform exercises that maintain or improve balance.[3] A recent systematic review concluded that exercise can reduce occurrences of falls, fall-related fractures and several risk factors for falls in individuals with low bone mineral density.[4] In particular, it was found that balance exercises improved balance and reduced falls or fall-related fractures, and muscle-strengthening exercises improved lower extremity strength and back extensor strength.[4] It was recommended that exercise interventions for patients with low bone density should include weight-bearing activities, balance exercise and strengthening exercises to reduce fall and fracture risk.[4]

The positive influence of exercise on fracture risk occurs through at least two pathways: (1) exercise can improve postural stability, gait, balance, muscle strength, muscle volume and joint flexibility, which can reduce the prevalence of injurious falls[4,5] and (2) exercise can optimize bone mineral density and improve bone quality by adaptive changes in bone geometry and architecture and, by implication, bone strength.[6]

Among different forms of exercise, tai chi has gained much attention within the rehabilitation and geriatric community. The principles of tai chi exercise include detailed regimens of physical movement, breathing techniques, as well as cognitive tools to strengthen, relax and integrate the body and mind. Tai chi has been shown to increase muscle strength in the legs, stabilize the knee, improve gait, posture control, balance, lower limb response time and reduce the risk of falls in the healthy community-dwelling older person.[7] However, to date, there have not been any published studies on tai chi's influences on the risk factors for falls in postmenopausal women with osteopaenia. The 2004 report of the Surgeon General on osteoporosis emphasizes that osteopaenia is a serious and growing public health concern for women. However, there is limited study addressing the optimal types and regimens of exercise for fracture-related risk factors relevant to women with osteopaenia, such as poor balance, gait or physical function. Therefore, this study was designed to evaluate the effects of 24 weeks of tai chi intervention on risk factors for falls in postmenopausal women with low bone mass via measuring balance, gait and physical function. In addition, the quality of life was also evaluated in this study.

We hypothesized that a 24-week tai chi intervention would improve balance, gait, physical function and quality of life in postmenopausal women with osteopaenia compared with those receiving no tai chi intervention.

Methods

This was a 24-week, prospective, single-blinded, randomized controlled trial with three measurement points (baseline, 12 and 24 weeks) (Figure 1). The assessors were blinded to participants' treatment assignments. Preliminary power analysis indicated that an equal sample size of 30 would be sufficient for each group (tai chi versus control). This study was approved by the Texas Tech University Health Sciences Center Institutional Review Board.

Postmenopausal women aged 65 years or older were recruited through local TV, newspaper advertisement and flyers. All participants provided informed consent before participating in the study. The following inclusion criteria were applied to select participants: (1) diagnosis of osteopaenia, defined as bone mineral density T-score at the spine and/or hip between 1 and 2.5 standard deviation (SD) below the young normal sex-matched bone mineral density of the reference

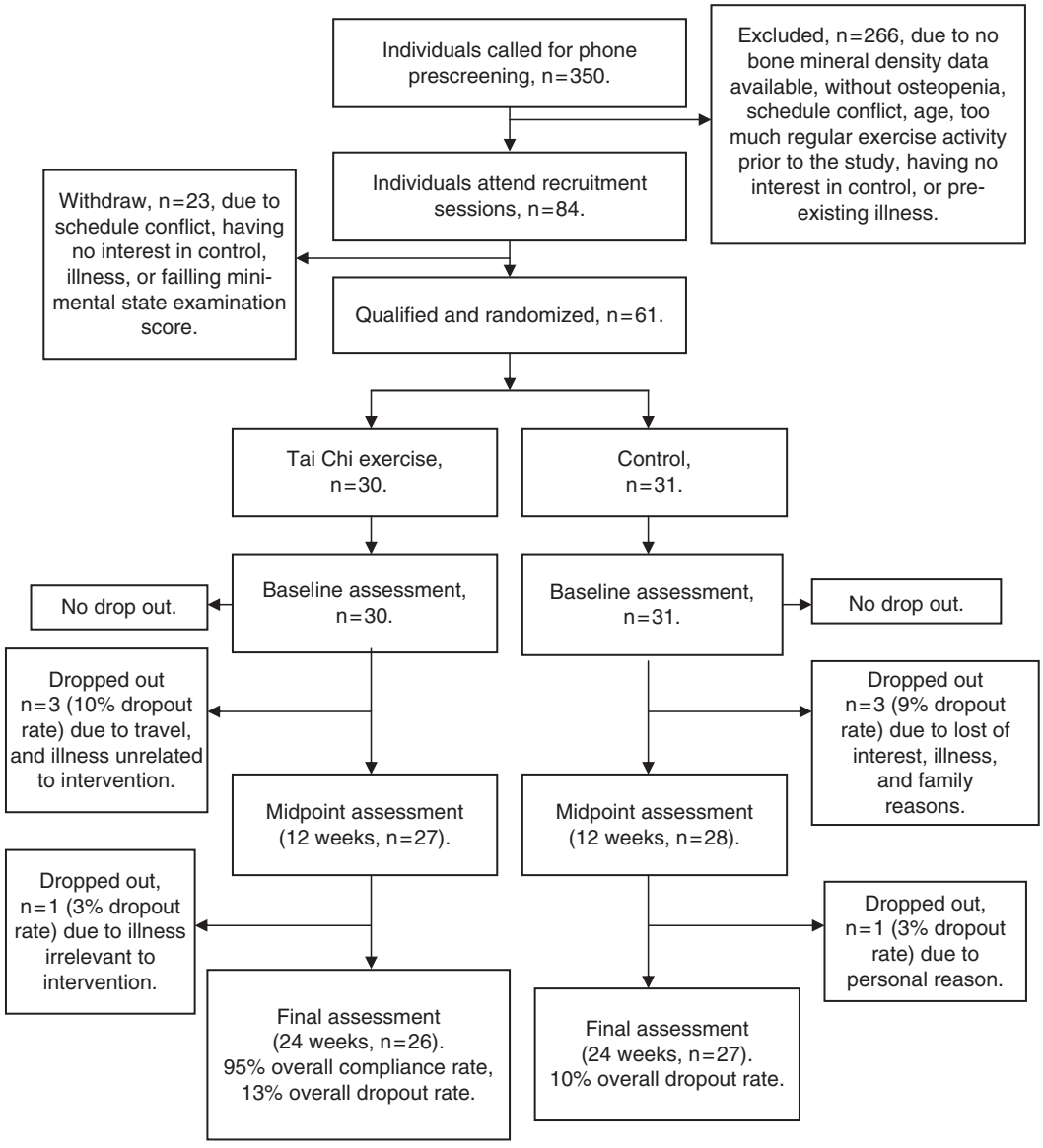

Figure 1 Study design and CONSORT diagram showing the flow of participants.

database,[8] (2) willingness to be randomly assigned to either study group and to complete the 24-week study period, and (3) being ambulatory without the use of an assistive device. The exclusion criteria were (1) regular exercise twice weekly or more, (2) a history of illness or a condition that would affect balance (e.g. stroke, Parkinson's disease), (3) inability to safely participate in the exercise programme, (4) shuffling gait, severe joint or muscular disorders (e.g. arthritis, joint replacement) or pain in the lower extremities that interfere with normal gait, (5) any uncontrolled chronic or terminal illnesses, and (6) Mini-Mental State Examination score of 23 or lower.[9] The number

of participants in the treatment arms at each stage of the study are shown in the CONSORT diagram in Figure 1. All participants were provided with elemental calcium and vitamin D (GlaxoSmithKline, PA, USA) to ensure they met recommended daily allowance. All participants were asked to maintain their regular diet, medication if any, normal daily activities and lifestyle throughout the study.

Qualified participants were randomly assigned to either tai chi or control group using a randomization table. Randomization was stratified by age (<70 years and ≥70 years) and T-score of bone mineral density (−1 to −1.5, −1.5 to −2.0, −2.0 to −2.5 based on the hip) to control for the extraneous effects of the attribute variable age/bone mineral density and to avoid discrepancies in distribution of subjects between the tai chi and control groups. After signing a group, each subject received a sealed envelope indicating her group assignment.

Tai chi subjects attended three 60-minute instructed tai chi group sessions each week for 24 weeks (72 hours total). In each session, in addition to 10 minutes of warm-up and 5 minutes of cool-down exercise, the routine of 24-form simplified Yang-style tai chi was repeated six times during the 45-minute training period based on the standard speed of about 7 minutes per routine.[10] The 24-form simplified Yang-style tai chi is a tai chi routine for beginners based on the traditional Yang-style tai chi long form. It consists of 24 movements of martial application performed slowly and gently while breathing deeply and meditating. The instructor explained and demonstrated how the exercise should be performed, and subjects followed. The control subjects did not receive any exercise intervention.

Subjects were assessed for dynamic and static standing balance by computerized dynamic posturography with a NeuroCom SMART EquiTest device, which is a sensitive predictor of falling in the elderly.[11]A battery of three standardized protocols (Sensory Organization Test; Motor Control Test; Adaptation Test) were used to collectively assess the ability of the subjects to maintain standing balance during a variety of static and dynamic perturbations of the environment.[12] Test measures included the time required for the subjects to regain balance following a perturbation of the foot platform.

The Sensory Organization Test measured deficits in a subject's ability to maintain static and dynamic posture and evaluated the role of the visual, vestibular and somatosensory systems in maintaining balance.[12] The Motor Control Test measured the capability of the automatic motor system to respond to sudden translational movements of the foot surface platform forward and backward; this involved maintaining balance in the face of a perturbation.[12] The Motor Control Test latency score measure the time between translation of the foot platform (stimulus) onset and initiation of the subject's active response (force response in both legs as measured by platform force plate on which subjects stood). The Motor Control Test amplitude score measures the magnitude of the postural righting response for both legs during movement of the foot platform. The Adaptation Test evaluated the subject's capacity to minimize postural sway after balance perturbation arising from sudden movement of the foot platform surface in toes-up, ankle dorsiflexion and toes-down, ankle plantarflexion directions,[12] with the dependent variables being latency of postural correction for dorsiflexion (Adaptation Test up) and plantarflexion (Adaption Test down) movements of the subject's ankles.

In the gait assessment, a subject walked on a treadmill (Gaitway Mercury; Kistler Instrument Corp., Amherst, NY, USA) for no more than 10 minutes total at three different speeds (0.50 mph, 1.75 mph and 3.00 mph; approximately 2–3 minutes at each speed). The treadmill, which was instrumented with two force platforms, was interfaced to a computerized data acquisition system and recorded spatial and temporal parameters of gait (200 Hz) that have been reported to be related to fall risk: stride length (m), stride width (m), cadence (steps/min), double support time (seconds) and speed (m/s).[13] 'Timed up and go'[14] and five-chair sit-to-stand tests were performed to evaluate functional mobility and leg muscle strength.[15]

All participating subjects were asked to answer questions regarding frequency of falls in the past six months, in which fall was defined as any unplanned, unexpected contacts with a supporting surface (ground, chair, wall, step, etc.). Because a

greater risk of falls is associated with back pain and musculoskeletal pain,[4–7] the degree of back and hip pain was recorded using the visual analogue scale.[16] The severity of back and hip pain during the week preceding each data collection session was quantitatively measured using a 10-cm visual analogue scale with a scale from 0 (no pain) to 10 (unbearable pain) for maximum and overall back and hip pain.[16]

General health status was measured with the Medical Outcomes Study 36-item short form Health Survey (SF-36, version 2) at baseline, 12 and 24 weeks of study. SF-36 has been reported to have good validity, internal consistency and reliability in the assessment of physical and mental health status of subjects and their progression.[16,17] The SF-36 consists of eight dimensions of health (physical function, bodily pain, general health, vitality, mental health, social function, and role of physical and emotional health in the conduct of daily activity).[16] Two discrete higher order summary scores that measure mental (mental component summary or MCS) and physical health (physical component summary or PCS) status were calculated from these eight health dimensions. Reliability estimates were $\alpha = 0.72$ and $\alpha = 0.73$ for PCS and MCS, respectively.[16]

Statistical analysis was conducted using SAS version 8.0 (SAS Inc., Cary, NC, USA). Descriptive data were reported as mean $\pm$ SD for baseline characteristics. Paired *t*-tests were conducted to compare continuous variables between groups at baseline, while chi-square test was conducted to compare categorical variables between groups at baseline. Each outcome measure of balance, gait, physical function and quality of life domain was presented as mean $\pm$ SD.

For the analyses of physical function and quality of life, independent ANOVA test was employed to show the main effect between the tai chi and the control group. In addition, for each domain of quality of life, the changes (%) relative to baseline between the tai chi and the control group were also analysed. A value of $\alpha = 0.05$ was used to define significance.

To examine whether the tai chi group demonstrated more improvement than the control group in terms of balance parameters, the averages of temporal changes in the two groups were compared. For each subject, the change in the outcome measures of computerized dynamic posturography performance, for example, the Sensory Organization Test composite score, were calculated as the difference between the 12-week data and baseline. An independent group *t*-test was performed to assess whether the change scores differed between the tai chi group versus the control group. The same analyses were conducted for the difference between the 24-week data and baseline. To protect from alpha inflation due to multiple *t*-tests, Bonferroni alpha adjustments were made based on the number of *t*-tests comparisons within the family of analyses for each computerized dynamic posturography test. For example, Sensory Organization Test involved 10 *t*-tests and the adjusted alpha for statistical significance was $0.05/10 = 0.005$. Motor Control Test and Adaption Test involved four *t*-test each, so alpha was adjusted to $0.05/4 = 0.0125$ for statistical significance.

Results

Table 1 summarizes the demographic characteristics and medical status of the subjects. Baseline comparability tests confirmed no significant differences between the control and tai chi groups in all demographic variables and medical status. Sporadic complaints of minor muscle soreness and foot and knee pain were made mainly during the first few days of the intervention. No other adverse effect associated with the practice of tai chi was reported by the participants.

Sixty-one subjects were recruited and initially enrolled in the study and randomly assigned to 24 weeks of tai chi ($n = 30$) or control ($n = 31$). Details of attrition are shown in Figure 1. Analysis showed no significant difference in the demographic and baseline measures between the drop-outs and the participating subjects ($P > 0.05$). Eight subjects dropped out (4 in tai chi and 4 in control) (13% attrition), due to time conflict, travel, illnesses unrelated to the intervention and family/private reasons, before completing the study. Twenty-six women completed the study with 94% compliance for the 24-week tai chi programme. In addition, subjects were asked to report at each measurement session any change in any medication or additional exercise regimen during

Table 1 Baseline characteristics

Characteristic	Tai chi ($n=30$)	Control ($n=31$)	*P*-value*
Age, years, mean ± SD	72.4 ± 6.2	71.3 ± 6.0	0.45
Weight, kg, mean ± SD	65.6 ± 11.3	67.9 ± 12.3	0.47
Height, m, mean ± SD	1.59 ± 0.08	1.61 ± 0.06	0.38
Body mass index, kg/m^2, mean ± SD	26.12 ± 3.54	26.11 ± 5.41	0.99
BMD at hip, T-score, mean ± SD	−1.69 ± 0.41	−1.62 ± 0.61	0.58
BMD at spine, T-score, mean ± SD	−1.16 ± 1.10	−0.97 ± 0.75	0.48
Years after menopause, mean ± SD	47.5 ± 6.3	44.9 ± 6.9	0.15
'How is your general health condition?'			0.46
Good	16 (53%)	21 (67%)	
Satisfactory	13 (43%)	10 (33%)	
Not good	1 (3%)	0 (0%)	
'Have you had a routine exercise programme for the past 5 years?'			0.55
Yes	9 (30%)	11 (35%)	
No	20 (67%)	20 (65%)	
Don't remember	1 (3%)	0 (0%)	
'Do you have a family history of osteoporosis?'			0.40
Yes	18 (60%)	15 (48%)	
No	9 (30%)	9 (29%)	
Don't know	3 (10%)	7 (23%)	
'As an adult, have you ever had a bone fracture?'			0.44
Yes	15 (50%)	11 (36%)	
No	14 (46%)	20 (64%)	
Don't remember	1 (4%)	0 (0%)	
'Do you have any history of metabolic bone diseases?'			0.79
Yes	3 (10%)	4 (13%)	
No	20 (67%)	18 (58%)	
Don't know	7 (23%)	9 (29%)	
'Have you been diagnosed for uncontrolled chronic or any terminal illness?'			0.43
Yes	2 (7%)	4 (13%)	
No	27 (90%)	27 (87%)	
Don't know	1 (3%)	0 (0%)	
'Have you taken steroid or glucocorticoid medication?'			0.33
Yes	12 (40%)	10 (31%)	
No	18 (60%)	19 (62%)	
Don't know	0 (0%)	2 (7%)	
'Do you suffer from severe joint or any muscular disorder (i.e. arthritis, rheumatoid) arthritis?'			0.12
Yes	19 (77%)	18 (60%)	
No	7 (20%)	13 (40%)	
Don't know	1 (3%)	0 (0%)	
'Do you usually have sleep disturbance problems?'			0.70
Yes	17 (56%)	15 (48%)	
No	13 (44%)	16 (52%)	

SD, standard deviation; BMD, bone mineral density.
**P*-values of paired *t*-test for continuous or chi-square test for categorical variables.

the intervention period. No changes were reported by the subjects.

At the baseline, there was no significant difference in any computerized dynamic posturography parameters between the tai chi and control groups. From baseline to the conclusion of the 24-week intervention, the subjects in the tai chi group showed an increase of 50% in Sensory

Table 2 Data of computerized dynamic posturography tests

	Baseline		12 weeks		24 weeks	
	Tai chi	Control	Tai chi	Control	Tai chi	Control
Parameters	($n=30$)	($n=31$)	($n=26$)[a]	($n=26$)[a]	($n=25$)[a]	($n=26$)[a]
Sensory Organization Test (SOT)						
SOT-composite	65.8 ± 9.2	69.4 ± 11.7	73.3 ± 8.4	74.5 ± 10.2	73.4 ± 9.9	73.9 ± 9.6
SOT-somatosensory	97.0 ± 1.9	96.7 ± 2.8	96.2 ± 3.8	96.5 ± 3.6	97.2 ± 2.9	97.0 ± 3.0
SOT-visual	74.9 ± 11.0	76.5 ± 14.2	85.0 ± 4.7	82.4 ± 10.5	84.2 ± 11.6	82.2 ± 11.5
SOT-vestibular	41.5 ± 24.0	52.3 ± 22.1	58.5 ± 23.9	61.9 ± 18.1	62.5 ± 20.0	62.6 ± 17.9
SOT-visual preference	105.8 ± 14.3	100.5 ± 11.3	102.0 ± 15.3	102.1± 10.8	99.1 ± 14.4	99.5 ± 11.5
Motor Control Test (MCT)						
MCT-latency (ms)	162.4 ± 12.7	161.6 ± 11.3	162.8 ± 13.8	160.6 ± 11.6	162.0 ± 12.4	158.9 ± 9.4
MCT-amplitude (degrees/s)	3.73 ± 0.54	3.93 ± 0.59	4.00 ± 0.71	3.86 ± 0.88	3.83 ± 0.57	3.72 ± 0.69
Adaptation Test (ADT)						
ADT-up (ms)	66.4 ± 12.9	61.1 ± 10.2	66.1 ± 15.7	63.3 ± 17.0	73.3 ± 19.3	65.7 ± 17.1
ADT-down (ms)	56.0 ± 16.3	46.0 ± 9.4	55.5 ± 16.4	49.1 ± 10.2	60.3 ± 21.9	46.9 ± 9.6
ADT-falls (number of falls)	0.96 ± 1.11	1.04 ± 1.65	1.12 ± 1.33	0.88 ± 1.45	0.68 ± 0.99	0.58 ± 0.99

Data represent mean ± standard deviation.
[a]Two subjects from each group (tai chi and control) were physically incapable of performing the balance test.

Table 3 Data of gait parameters

	Baseline			12 week			24 week		
Parameters	Tai chi	Control	*P*-value	Tai chi	Control	*P*-value	Tai chi	Control	*P*-value
Stride length (m)	0.699 ± 0.058	0.703 ± 0.080	0.85	0.707 ± 0.066	0.719 ± 0.074	0.54	0.694 ± 0.076	0.721 ± 0.054	0.15
Stride width (m)	0.092 ± 0.017	0.088 ± 0.028	0.55	0.103 ± 0.022	0.089 ± 0.025	0.03	0.097 ± 0.021	0.084 ± 0.024	0.03
Cadence (steps/min)	85.05 ± 7.70	85.51 ± 10.39	0.85	84.44 ± 7.99	83.30 ± 8.44	0.62	86.35 ± 9.24	82.94 ± 6.55	0.13
Double support time (seconds)	0.244 ± 0.036	0.243 ± 0.025	0.92	0.245 ± 0.033	0.245 ± 0.024	0.96	0.239 ± 0.035	0.245 ± 0.023	0.50
Speed (m/s)	0.491 ± 0.009	0.494 ± 0.014	0.47	0.494 ± 0.013	0.493 ± 0.013	0.89	0.495 ± 0.013	0.497 ± 0.014	0.50

Data represent mean ± standard deviation.

Organization Test vestibular compared with 19% increase in the control group (Table 2). However, there was no difference between the tai chi group and the control group in other balance parameters (Table 2).

At baseline, there was no significant difference in any gait parameters (including stride length, stride width, cadence, double support time and speed) between the tai chi and the control groups (Table 3). Subjects in the tai chi group had a greater stride width compared with those in the control group after 12 weeks of tai chi intervention, and this trend was sustained at 24 weeks (Table 3). Other gait parameters were not significantly affected by the treatment (Table 3).

At baseline, there was no significant difference in functional strength, pain scale and number of falls between the tai chi group and the control group (Table 4). Throughout the 24-week intervention period, (1) neither the tai chi nor the control group demonstrated any significant change in functional strength as determined by 'timed up

Table 4 Data of physical function, pain, and fall measures

Parameters	Baseline			12 weeks			24 weeks		
	Tai chi	Control	*P*-value	Tai chi	Control	*P*-value	Tai chi	Control	*P*-value
	($n=31$)	($n=31$)		($n=27$)	($n=29$)		($n=26$)	($n=28$)	
'Timed up and go' (seconds)	11.3 ± 2.0	11.4 ± 2.3	0.85	10.1 ± 1.8	10.1 ± 1.8	0.94	9.7 ± 1.7	9.7 ± 1.7	0.97
Five-chair sit-to-stand (seconds)	14.6 ± 4.0	15.5 ± 3.4	0.37	14.1 ± 4.6	14.8 ± 3.4	0.51	13.1 ± 3.4	14.1 ± 2.8	0.23
VAS maximal pain in back	3.8 ± 2.8	3.0 ± 3.0	0.29	3.6 ± 2.9	3.5 ± 3.1	0.98	2.9 ± 2.5	2.6 ± 2.6	0.66
VAS maximal pain in hip	3.1 ± 2.9	2.2 ± 2.2	0.19	2.3 ± 1.8	2.8 ± 2.8	0.40	2.2 ± 2.2	2.2 ± 2.0	0.96
Number of falls	4.3 (9.8)	1.6 (3.7)	0.16	0.9 (1.3)	1.4 (3.9)	0.54	1.5 (2.4)	2.5 (5.2)	0.35

Data represent mean ± standard deviation.

Table 5 Data of quality of life parameters

Parameters	Baseline		12 weeks		24 weeks	
	Tai chi	Control	Tai chi	Control	Tai chi	Control
Physical function	42.27 ± 8.51	43.07 ± 8.6	40.68 ± 9.19	41.59 ± 9.17	43.43 ± 7.65	43.43 ± 8.61
Role-physical	42.42 ± 10.89	44.22 ± 11.91	46.29 ± 11.81	46.24 ± 11.10	48.90 ± 7.87	47.74 ± 10.68
Bodily pain	47.64 ± 8.17	50.74 ± 8.35	49.20 ± 6.67	49.99 ± 8.03	51.55 ± 6.09*	49.69 ± 7.57
General health	48.21 ± 7.96	50.19 ± 10.12	50.32 ± 8.21	50.26 ± 9.80	51.59 ± 7.93*	49.40 ± 10.09
Vitality	49.05 ± 8.67	52.57 ± 9.46	51.60 ± 8.46	51.91 ± 8.66	54.42 ± 7.99*	53.11 ± 7.05
Social function	50.03 ± 8.84	51.19 ± 9.12	51.11 ± 8.16	52.83 ± 7.73	53.38 ± 6.65	51.32 ± 7.23
Role-emotional	46.31 ± 13.36	49.37 ± 9.85	48.32 ± 11.31	49.17 ± 9.13	50.07 ± 9.06	50.45 ± 8.83
Mental health	51.46 ± 8.60	54.47 ± 7.13	53.73 ± 8.41	54.44 ± 6.61	53.24 ± 9.14	54.50 ± 7.06
PCS	43.29 ± 9.02	44.60 ± 10.06	44.11 ± 9.05	44.39 ± 9.53	47.09 ± 7.07	45.17 ± 9.39
MCS	51.82 ± 11.2	55.01 ± 8.30	54.43 ± 9.31	55.40 ± 7.49	55.03 ± 8.76	55.30 ± 6.07

Data represent mean ± standard deviation. For each domain of quality of life, the changes (%) relative to baseline between the tai chi and the control group were also analysed.
PCS, physical component summary; MCS, mental component summary.
*Indicates the difference ($P<0.05$).

and go' and five-chair sit-to-stand (Table 4), (2) there was no significant difference in maximum pain level in the back or hip, as evaluated by visual analogue scale between the tai chi group and the control group (Table 4), and (3) based on the self-report data of fall numbers, there was no significant difference in the number of falling episodes between the tai chi group and the control group throughout the study (Table 4).

There was no significant difference in any parameters of quality of life at baseline, as assessed by SF-36 questionnaires, between the tai chi and the control groups (Table 5).

General health, vitality and bodily pain components of the SF-36 questionnaire for the tai chi and control groups are presented in Table 5 for the course of the 24-week intervention. Compared with the control group, after 24 weeks of intervention subjects in the tai chi group reported a significant improvement in general health, vitality and bodily pain than those in the control group (Table 5). However, there was no significant difference in other domains of quality of life including physical function, role-physical, social functioning, role-emotional, mental health, PCS and MCS (Table 5).

Discussion

The present investigation was the first study to show that a 24-week tai chi exercise intervention improved stride width and quality of life, in terms

of general health, vitality and bodily pain in postmenopausal women with osteopaenia.

Sensory Organization Test data related to tai chi has reported previously that tai chi improves balance control performance.[18,19] Tsang *et al.*[18] reported that long-term tai chi practitioners improved balance control in the elderly population with an increased reliance on visual and vestibular (but not somatosensory) systems. Tsang *et al.*[19] further demonstrated that four weeks of intensive tai chi training are sufficient to improve balance control as shown by the vestibular score in elderly subjects. The vestibular score reflects dynamic standing balance performance under conditions in which the subject has to rely primarily on vestibular input for balance control, since the test conditions involve the eyes being closed and inaccurate somatosensory information being conveyed. The improved vestibular score after tai chi training may explain in part why the risk of multiple falls was reduced by 47.5% in the elderly tai chi practitioners.[20] Although the present study showed that the tai chi group had a greater improvement of vestibular score (50% increase relative to the baseline) than those in the control group (19% increase relative to the baseline), we were not able to observe a significant difference between the tai chi and control groups after employing Bonferroni alpha adjustments for statistical significance. We speculated that in addition to a small sample size and a larger standard deviation in the present study, the dose of the current tai chi intervention may be too low to show any significant benefit in vestibular score in this population.

Our findings that 24 weeks of tai chi exercise did not improve somatosensory score and visual score in subjects is consistent with the report of Tsang *et al.*[19] Practising tai chi involves head movements that could stimulate the vestibular system through many head and body rotations, constant weight shifting with different arm movements, changes in the base of support from double to single leg standing, and fixation of the eyes on the hand during the practice of its many forms.[21]

The Motor Control Test was incorporated into the computer dynamic posturography protocols in this study to assess tai chi's potential to improve recovery after perturbations that more realistically simulate the slips from activities of daily living. Postural control and balance responses require muscle activation and force production to increase the stiffness of body segments and to return the centre of gravity to a centralized position over the base of support.[22] We speculated that the sensorimotor system and its ability to activate musculature may be altered by the mechanical and neural effects of tai chi movements in a fashion similar to what has been demonstrated with Chinese martial arts practice.[23] These alterations may affect postural control and balance through a change in the peripheral afferent system, the central nervous system, or both.[24] More specifically, the mechanical and neural effects of tai chi movement may affect the latency or magnitude of muscle force production by changing reflexive responses mediated through short spinal pathways, automatic postural responses mediated through both spinal and central pathways, or volitional control mediated through the central and cognitive pathways.[24] However, in the present study, there was no significant difference between groups. We think that situations requiring a quick recovery from abrupt perturbations, with concomitant reduction in peak response, may represent a more challenging task than standing under conditions of sensory distortion to our target population, consisting of apparently healthy postmenopausal women.

Gait characteristics have been shown to change with normal ageing, such as decreases in gait speed, stride length and cadence, and concomitant increase in double support time.[25] These changes may be more significant in individuals who fall.[13] While changes in these gait characteristics are not necessarily believed to be causative factors of falling, they are thought to be sensitive to alterations in neuromotor control that may influence dynamic balance during gait. Tai chi's effects on stride length, frequency and gait speed have been investigated in patients including transitionally frail older adults.[26] In postmenopausal women with low bone mass, the current result showed that tai chi training increased stride width compared with those in the control group. It has been found that one characteristic of gait in hospitalized fallers is narrow stride width.[27] Older fallers with a tendency to fall sideways exhibited narrower stride widths, and side-faller who have narrower stride widths compared to those who fall in other directions may not be adapting their gait to

compensate for lateral instability.[28] Although a greater stride width may be related to reduction of the risk factors for falls, no significant reduction in the number of falling episodes was observed in the present study.

Back pain influences balance and functional mobility. In the present study, none of the tests of strength, pain and function showed improvements as a result of the tai chi exercise. The lack of significance in these results of physical function tests may be due to a ceiling effect, as the sit-to-stand test score at baseline was close to that of normative data for elderly subjects,[29] and the 'timed up and go' value of 11.3 seconds at baseline was also close to the normal value of 10 seconds for healthy elderly subjects.[30] The 'timed up and go' improved from 11.3 seconds at baseline to 9.7 seconds after 24 weeks; however, the improvement was not statistically significant.

There are some limitations in the present study. We realized that this study has a relatively small sample size. In order to determine if tai chi exercise would reduce the risk of falls, the number of falls among subjects before and after intervention should be considered in a much larger study. Another limitation was the lack of an active intervention for the control group. Subjects in the tai chi group improved their stride width and some quality of life aspects by enhancing their physical conditioning levels more than those in the control group.

Clinical messages

- Tai chi exercise may reduce risk factors for falls by increasing stride width and some quality of life parameters in postmenopausal women with osteopaenia.
- The lack of significance in the results of physical function tests may be due to an already high performance in the subjects at baseline.

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Competing interests

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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