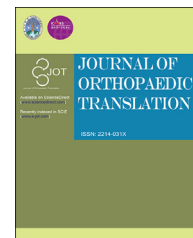




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REVIEW ARTICLE

The effect of Chinese martial arts Tai Chi Chuan on prevention of osteoporosis: A systematic review



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KEYWORDS

Bone mineral density;
Osteoporosis;
Prevention;
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Summary *Background/Objective:* Tai Chi Chuan (TCC) is suggested to have beneficial effects on the musculoskeletal system. The aim of this systematic review is to evaluate the evidence of the effect of TCC on bone mineral density (BMD) and its potential for prevention of osteoporosis.

Methods: A literature search was conducted using PubMed, Embase, and Cochrane databases from inception to January 2017. Randomized controlled studies, case–control trials, prospective cohort studies, and cross-sectional studies which evaluated the effect of TCC on BMD were selected without any subject or language restriction.

Results: Nine articles met the inclusion criteria, including seven randomized controlled trials (RCTs), one case–control trial (CCT), and one cross-sectional study, encompassing a total of 1222 participants. Five studies showed statistically significant improvements in BMD after TCC, three studies showed nonsignificant intergroup differences, and one study provided no statistical evaluation of results. The studies with nonsignificant results tended to have a shorter total duration of TCC practice. Apart from dual-energy X-ray absorptiometry (DXA), two studies additionally used peripheral quantitative computed tomography (pQCT) which showed statistically significant positive effects of TCC on preventing osteoporosis.

Conclusion: TCC is beneficial to BMD and may be a cost-effective and preventive measure of osteoporosis. This beneficial effect is better observed in long-term TCC practice.

The translational potential of this article: The beneficial effect of TCC on BMD is suggested to be clinically translated to its potential for early rehabilitation and prevention of secondary

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osteoporosis in patients after surgical treatment of common osteoporotic fractures. The length of practicing TCC, the form and style of TCC, and the types of patient suitable for TCC are to be investigated in future studies.

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Introduction

Tai Chi Chuan (TCC), a type of meditative and mind–body exercise, mainly consists of a series of slow, relaxed, and graceful physical movements connected together in a smooth and continuous manner [1–4]. Due to the fact that TCC requires little space and equipment, participants can practice it regardless of space and financial limitation [5]. Besides, due to the simple, smooth, and low-impact nature of movements [5], TCC is suitable for most, if not all, age groups with or without previous experience in sports activities.

TCC is beneficial towards balance and coordination of the extremities, with numerous multi-directional movements and positional changes between single- and double-leg stances [6]. It has also been known to contribute to an individual's postural stability and flexibility [7–9]. TCC was also found to be better at preventing risk of falls compared with performing stretching exercises or conventional physical therapy. A randomized controlled trial conducted by Li et al. [10] discovered that TCC resulted in fewer falls. Risk of multiple falls in the TCC group was 55% lower than the stretching control group. TCC participants also made improvements in functional balance, physical performance, and reduced their fear of falling. A similar result was obtained by Tousignant et al. [6].

Evident improvement in balance, strength, and mobility immediately postintervention was discovered in a prospective pilot outcome study by Murphy and Singh [11]. Thirty-one elderly women were involved in a twice weekly, 12-week intervention. The Activities-specific Balance Confidence and One-Legged Stance Test were used as determinants of balance, Repeated Chair Stands for lower body strength, and Timed Up and Go Test for functional mobility. Only strength and mobility improvements were sustained up to 12-month postintervention follow up. The weakening of balance ability mirrors the decline in regular TCC practice, thus TCC must be practiced regularly or for a longer period of time to sustain TCC-associated benefits.

TCC is also shown to be beneficial to our cardiorespiratory functions. In the study of Lan et al. [12], TCC practitioners generally had a higher peak oxygen uptake (VO_{2peak}) during the peak of exercise when compared with their counterparts who had a sedentary lifestyle, with 19% higher VO_{2peak} in the male TCC group and 18% higher VO_{2peak} in the female TCC group. Moreover, TCC is found to be beneficial to other parameters of cardiorespiratory wellness such as blood pressure and lipid profile. In the investigation conducted by Tsai et al. [13], a group of participants with high-normal blood pressure or Stage I hypertension were asked

to complete a 12-week TCC training. The systolic and diastolic blood pressure, as well as total cholesterol level decreased substantially in the TCC exercise group.

Owing to the multitude of benefits gained through regular practice of TCC, millions of people worldwide are practicing TCC. In view of the growing popularity of TCC, factions such as Yang-, Chen-, Sun-, and Yin-style which aimed at promoting TCC were established, with Yang-style being the most popular. Although the factions may possess unique features and integrate different elements into their own systems, the fundamental principles of TCC remain the same [4].

Osteoporosis is defined as “a disease characterized by low bone mass and microarchitectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk” [14]. Osteoporosis is a major health problem on both local and global scales—one in three women over the age of 50 years worldwide will experience osteoporotic fractures [15], whereas ~300,000 postmenopausal women in Hong Kong suffered from osteoporosis, with a projected increasing trend due to the ageing population [16].

Clinically, osteoporosis is diagnosed based on bone mineral density (BMD) assessed using the dual X-ray absorptiometry (DXA) at lumbar spine, proximal femur, and distal radius, based on T-score (T-score ≤ -2.5) [17]. DXA is of high precision and low radiation dose, but only provides a two-dimensional measurement of areal BMD (aBMD) and its value however, can be affected by body size and patient positioning. Contrastingly, high-resolution peripheral quantitative CT (HR-pQCT) and three-dimensional peripheral quantitative CT (3D-pQCT) allows true measurement of volumetric BMD (vBMD) and bone microarchitecture as well [18]. BMD is a resultant of both genetic and environmental factors. Accordingly, many factors may either be beneficial for or impair the bone. The major risk factors of osteoporosis are summarized in Table 1 [19–21].

Osteoporotic fracture is defined as “a fracture disproportionate to forces it is caused by, which occurs after a fall from one's own height, excluding other causes, e.g., the pathologic fracture”, and is affected by risk factors for both osteoporosis and falling itself. Regarding imaging techniques, HR-qRT might be superior to DXA in terms of fracture risk prediction as it evaluates both BMD and bone quality based on available reports. Fracture risk assessment tool (FRAX) is one of the algorithm-based methods often used in conjunction with DXA for fracture risk estimation, taking into account various clinical risk factors such as secondary causes of osteoporosis [22]. However, fall risks are determined by the factors shown in Table 1 [19–21].

Pharmacological options for treatment of osteoporosis could be classified as antiresorptive and anabolic

medications, in combination with calcium and vitamin D supplementation as fundamental therapy. For anti-resorptive drugs, bisphosphonates (such as alendronate) are the most commonly used drugs for treatment of postmenopausal osteoporosis, but there is increasing evidence supporting association of long-term bisphosphonate administration with atypical femoral fractures. Other anti-resorptive agents include RANKL inhibitors (namely denosumab) and calcitonin which also prevent osteoclast-mediated bone resorption [23,24].

For anabolic drugs, human parathyroid hormone analogs (such as teriparatide) enhance osteoblast formation but its use is associated with high osteosarcoma incidence found in animal experiments; Strontium ranelate acts as calcium substitute in bone remodelling but is yet to be approved by the Food and Drug Association, and selective estrogen receptor modulators (SERMs, namely raloxifene) improve BMD via hormone replacement mechanisms but contain side effects including increased stroke and venous thromboembolism risks [25]. Aside from Western medication, alternative medicine such as Traditional Chinese Medicine (TCM) could also be used. TCM, especially from herbal sources, i.e., Chinese herbal medicine has been receiving increasing attention in prevention of osteoporosis. For instance, flavonoids derived from herbal *Epimedium Brevicornum Maxim* have been proven to improve estrogen-deficiency-induced osteoporosis in ovariectomised rats via direct stimulation on osteoblast and inhibition on bone resorption, leading to

an overall anabolic effects on periosteum and trabecula [23].

Aside from pharmacological methods muscle strengthening and weight-bearing exercises, which prevent osteoporosis by increasing bone and muscle strength as well as coordination and balance, are often recommended to patients in addition to bisphosphonates administration, and Tai Chi Chuan (TCC) is one of the balance exercises available [24].

Over the past 25 years, TCC has grown in popularity and gained worldwide recognition for its health benefits. One of the latest review articles which mainly concentrated on evaluating the impacts of TCC on BMD in peri- and postmenopausal women was published in 2007 [2]. The aim of the present study is to review the effect of TCC on BMD. In order to gain a better understanding on the most updated development on this aspect, the current available academic research will be summarized and evaluated.

Materials and methods

Data sources

A systematic literature search was conducted using three electronic databases PubMed, Cochrane, and Embase from inception to January 2017 and references of all studies included in the systematic review. Searches were done

Table 1 Major risk factors of osteoporosis and osteoporotic fracture (adopted from [19–21]).

	Osteoporosis	Osteoporotic fracture
Genetic or constitutional	White or Asiatic ethnicity Family (maternal history of fractures) Small body frame Premature menopause (< 45 y) Late menarche	BMD Bone turnover Trabecular architecture Skeletal geometry Bone quality Age > 80 y
Lifestyle & nutritional	Nulliparity Prolonged secondary amenorrhea Smoking Excessive alcohol intake Inactivity Low body weight	History of falls Impaired activities of daily living
Medical disorders	Anorexia nervosa Malabsorption due to gastrointestinal & hepatobiliary diseases Endocrine disorders e.g., primary hyperparathyroidism, hypogonadism, hypercortisolism Osteogenesis imperfecta Rheumatoid arthritis Chronic obstructive lung disease Chronic neurological disorders Chronic renal failure Type 1 diabetes	Muscle weakness Gait & balance deficit Visual impairment Arthritis Depression Cognitive impairment
Drugs	Chronic corticosteroid therapy Excessive thyroid therapy Anticoagulants Chemotherapy Gonadotropin-releasing hormone agonist or antagonist	

BMD = bone mineral density.

without any restrictions on publication date, languages, and participant characteristics such as age and sex. Search strategy includes using keywords: Tai Chi Chuan or Tai Chi or Tai Ji or Tai Ji Chuan, and bone mineral density.

Study selection

Studies were selected based on the study designs, outcome measures, and relevance to the topic, i.e., the effect of Tai Chi Chuan (TCC) on bone mineral density (BMD). For study designs, all randomized controlled studies, case-control trials, prospective cohort studies, and cross-sectional studies were included. For outcome measures, only those studies using BMD as outcome measures are included. For relevance to the topic, all studies irrelevant to TCC are excluded. There is no language preference.

Data extraction

The data are extracted according to the study design, location of study, sample size, participants, and their mean ages, interventions for experimental group and control group (Table 2). All statistical analysis was done using Microsoft Excel software (Microsoft Corporation, Redmond, WA, USA).

Results

A literature search was done. A total of 51 papers were identified, dating from inception of the included databases to January 2017. After screening the abstracts and full text, nine papers (Table 2) were selected for review and 42 were excluded due to any of the following reasons: study designs not fulfilling the criteria, outcome measures not being BMD, and irrelevant to TCC. These include seven randomized controlled trials (RCTs), one prospective case control study (CCT), and one cross-sectional study, encompassing a total of 1222 participants. Eight studies were conducted in Asia, and one study in the USA. The study participants were restricted to females in eight studies, although the remaining two studies included participants of both genders. Results from most papers were in the form of BMD at the proximal femur as measured by DXA. Two studies included peripheral quantitative computed tomography (pQCT) measurements of the tibia in addition to DXA. The CCT included long-term TCC practitioners, although the others introduced TCC as an intervention to participants without prior TCC experience.

The methodology and results of the studies were analyzed. Of the nine papers included in this study, three showed nonsignificant intergroup differences between TCC interventions and controls, and five showed significant beneficial effects of TCC, either in retarding bone loss or in increasing BMD. One study did not provide *p*-values for the data. Interestingly, both of the studies which used pQCT, a more accurate measure for BMD than DXA, found statistically significant positive results for the effect of TCC on BMD. However, concurrent DXA yielded inconsistent results. Both papers had follow-up periods of 12 months, and it may be the case that BMD changes during this period were not sufficient for detection by DXA, but could be detected by the more sensitive pQCT. One paper by Song et al. [26] did

not include values for statistical significance. The study included 94 inactive women aged 55–65, assigned to three interventions of dancing, brisk walking, and TCC (208 hours over a period of 12 months). Bone quality index (BQI) was used to assess bone quality, using DXA measurements of calcaneal aBMD. No evaluations of statistical significance were given, though all three groups experienced increases in BQI, of lesser magnitude than the standard deviations. No inactive control group was used for comparison, posing a problem in interpretation of the results.

Of the publications finding a statistically significant effect of TCC on BMD, two performed comparisons between inactive participants and long-term TCC practitioners. One cross-sectional study by Qin et al. [27], involving 99 participants, found that among postmenopausal female long-term TCC practitioners who had been regularly practicing the sport for > 3 hours a week for > 3 years, DXA measurements of aBMD were significantly higher at the nondominant proximal femur and lumbar spine compared with controls. The highest percentage difference was seen at the greater trochanter, with 7.2% higher vBMD in the TCC group than in age-, sex-, height-, weight-, and BMI-matched controls.

An earlier study published in 2002 by the same author had similar results. Qin et al. [28] investigated 31 postmenopausal women (mean, 53.8 years), including 16 long-term TCC practitioners who had been regularly practicing TCC > 3.5 hours per week for 4 years. Baseline measurements showed significantly higher aBMD in TCC practitioners as measured by DXA at the lumbar spine and three sites of the proximal femur (femoral neck, intertrochanteric region, and Ward's triangle), and one site out of four as measured by pQCT [ultradistal trabecular BMD (tBMD)]. The greatest difference found was 14.8%, at the Ward's triangle ($p = 0.021$). Further measurements were also taken for both groups after 12 months without intervention in either group's lifestyle, at which time pQCT showed a significantly reduced rate of bone loss in the TCC group, at the ultradistal tibia tBMD and distal tibia diaphysis cortical BMD (cBMD). However, DXA showed inconsistent results across the two groups with no clear trend. It may be the case that the follow-up period was too short, and the changes between both groups were too minute to be detected by DXA.

There are a wide variety of participant inclusion criteria in the reviewed studies. Four out of nine studies recruited postmenopausal women; two out of nine studies recruited inactive participants; the remaining three recruited elderly, obese women, and patients with osteoarthritis respectively. These types of participants can be correlated clinically to different types of osteoporosis. Postmenopausal women can be correlated to postmenopausal osteoporosis. Inactive participants and patients with osteoarthritis are at risk of developing disuse osteoporosis. Elderly participants are at risk of ageing osteoporosis. Therefore, the selected studies covered participants who are at risk of different types of osteoporosis.

It was found that BMD changes only being detected by higher-sensitivity modalities other than DXA. This was reflected in a study by Chan et al. [29]. A sample of 108 Chinese women, at least 10 years after onset of menopause and without regular participation in physical exercise, were included in the study. The observation group underwent

Table 2 Summary of studies evaluating the effect of Tai Chi Chuan on bone mineral density.

Author (y)	Study design (allocation concealment)	Location	Sample size (analyzed)	Participants (mean age, y), other criteria	Control group	Observation group (total intervention duration)	Measurement parameter, method, site	Results	Authors' conclusion
Paulin et al. (2015) [abstract] [32]	RCT (n.r.)	USA	13 (13)	Obese women (61.5) Clinically obese (mean BMI, 34.3)	(A) Diet education. 45 mins/wk, 16 wk (12 h).	(B) TCC. 45 mins/day, 3×/wk, 16 wk (36 h) + (A)	BMD (g/cm ³), DXA. Total body & femur.	Total BMD: NS. (A) 1.08 ± 0.3 −1.09 ± 0.3, vs. (B) 0.93 ± 0.3 −1.00 ± 0.08 Femoral BMD: NS. (A) 0.98 ± 0.12 −0.97 ± 0.05, vs. (B) 1.00 ± 0.9 −1.00 ± 0.08.	The combination of diet education & TCC did not impact BMD > diet education alone.
Hui et al. (2015) [33]	Cluster RCT (yes)	Hong Kong	374 (353)	Inactive persons [(A) 45.9, (B) 44.9]	(A) No exercise training.	(B) TCC 30 min/d, 5×/wk, 12 wk (30 h). (C) Brisk walking. 30 min/d, 5×/wk, 12 wk (30 h).	BMD (mg/cm ²), DXA. Femoral neck, intertrochanteric area, total hip, lumbar spine (L1-L4), total body.	Total body BMD: NS. (A) −0.33, (B) −0.39, (C) −1.65.	TCC & brisk walking interventions had no apparent effect on BMD.
Wang et al. (2015) [34]	RCT (n.r.)	Shanghai	119 (106)	Postmenopausal women (58.5)	(A) No exercise training.	(B) Simplified TCC with resistance, 1 h/d, 4×/wk, 12 mo (208 h). (C) Traditional TCC (Yang style), 1 h/d, 4×/wk, 12 mo (208 h).	BMD (g/cm ²), DXA. Hip (femoral neck, Ward's triangle), lumbar spine (L2-L4).	Femoral neck: $p = 0.0131$. (A) −0.0300 ± 0.0388, (B) −0.0004 ± 0.0281, (C) −0.0045 ± 0.0800. Ward's triangle: $p = 0.0013$. (A) −0.0397 ± 0.0467, (B) −0.0047 ± 0.0337, (C) −0.0171 ± 0.0365. L2-L4: $p = 0.0464$. (A) −0.0038 ± 0.0300, (B) +0.0182 ± 0.0434, (C) +0.0105 ± 0.0361.	No significant difference in absolute BMD between three groups. Statistically nonsignificant trend for higher L2-L4 BMD in (B), $p = 0.06$.

Song et al. (2014) [26]	RCT (n.r.)	Jiaozuo City, Henan, China	105 (94)	Inactive women	(A) Dancing, 40 min/d, 6×/wk, 12 mo (208 h). (B) Brisk walking, 40 min/d, 6×/wk, 12 mo (208 h).	(C) TCC, 40 min/d, 6×/wk, 12 mo (208 h).	Bone quality index BQI: (BQI), DXA calcaneus.	(A) 71.37 ± 13.27 preintervention vs. 79.03 ± 14.37 postintervention. (B) 70.81 ± 14.75 vs. 78.50 ± 15.82. (C) 71.03 ± 16.30 vs. 81.54 ± 15.71.	General improvement in (C) is better than in (A) & (B). [in terms of BQI, balance, & strength].
Qin et al. (2005) [27]	CS (N/A)	Hong Kong	99 (99)	Postmenopausal women (55.9)	(A) Exercise < 0.5 h/wk.	(A) TCC > 3 h/wk for > 3 y (> 468 h)	BMD (g/cm ²), DXA nondominant femur (femoral neck, greater trochanter, Ward's triangle), lumbar spine (L2–L4).	Femoral neck: NS, (A) 0.716 ± 0.095 vs. (B) 0.740 ± 0.098, 3.4% difference Greater trochanter: $p = 0.02$. (A) 0.572 ± 0.085 vs. (B) 0.613 ± 0.091, 7.2% difference Ward's triangle: $p = 0.05$. (A) 0.518 ± 0.102 vs. (B) 0.555 ± 0.086, 7.1% difference L2–L4: $p = 0.03$. (A) 0.804 ± 0.122 vs. (B) 0.861 ± 0.142, 7.1% difference	Significantly higher BMD was shown at the spine, greater trochanter, & Ward's triangle of regular TCC practitioners compared with anthropometrically matched controls.
Qin et al. (2002) [28]	CCT (N/A)	Hong Kong	34 (30)	Postmenopausal women [(A) 53.8, (B) 54.1]	(A) Exercise < 30 min/wk	(B) TCC > 3.5 h/wk (> 182 h at 12-mo)	BMD, DXA nondominant femur (Ward's triangle, intertrochanteric region), spine (neck, L2–L4) pQCT (mg/cm ³): Distal tibia.	At 12-month follow-up pQCT Ultradistal tibia tBMD: $p = 0.044$. (A) -2.18 ± 1.60 vs. (B) -1.10 ± 1.26. Distal tibial diaphysis cBMDT: $p = 0.031$. (A) -1.86 ± 0.93% vs. (B) -0.90 ± 1.36. All others NS.	At follow-up after 12 months, Ward's triangle measurement of (A) showed significant decrease compared with nonsignificant decrease in (B). The only significant intergroup differences were in ultradistal tibia tBMD & distal tibial diaphysis cBMDT. (continued on next page)

Table 2 (continued)

Author (y)	Study design (allocation concealment)	Location	Sample size (analyzed)	Participants (mean age, y), other criteria	Control group	Observation group (total intervention duration)	Measurement parameter, method, site	Results	Authors' conclusion
Chan et al. (2004) [29]	RCT (n.r.)	Hong Kong	132 (108)	Postmenopausal Chinese women (54)	(A) No exercise	(B) TCC (Yang style). 45 min/d, 5×/wk, 12 mo (185 h).	BMD, DXA, & pQCT. DXA (g/cm ²): nondominant femur (femoral neck, trochanter), lumbar spine (L2-L4). pQCT (mg/cm ³): nondominant distal tibia.	DXA Femoral neck: NS, (A) 1.80 ± 3.52% vs. (B) 0.94 ± 3.85%. Greater trochanter: NS, (A) -0.56 ± 0.32% vs. (B) -1.19 ± 3.12%. L2-L4: NS, (A) -0.89 ± 4.01% vs. (B) +0.10 ± 3.12%. pQCT Ultradistal tibia: tBMD, <i>p</i> < 0.01 (A) -1.46 ± 1.84% vs. (B) -0.53 ± 1.49%. iBMD, <i>p</i> < 0.01 (A) -1.58 ± 1.58% vs. (B) -0.61 ± 1.70%. Distal tibia diaphysis: <i>p</i> < 0.01, (A) -1.40 ± 1.38% vs. (B) -0.39 ± 1.49%.	A significant 2.6- to 3.6-fold retardation of bone loss in (B) compared with (A) as measured by pQCT, at both trabecular & cortical compartments of distal tibia.
Woo et al. (2007) [30]	RCT (yes)	Hong Kong	180 (166)	Elderly (68.9)	(A) No exercise training	(B) TCC (Yang style, 24 forms). 3×/wk, 12 mo. (C) Resistance training, 3×/wk, 12 mo.	BMD (g/cm ²), DXA Total hip & total spine.	Male Total hip: NS. (A) -0.15 ± 0.38%, (B) -0.48 ± 0.37%, (C) -1.20 ± 0.38%. Total spine: NS. (A) +0.54 ± 0.42%, (B) +1.35 ± 0.40%, (C) +1.27 ± 0.42%. Female Total hip: <i>p</i> = 0.01. (A) -2.25 ± 0.60%, (B) +0.07 ± 0.64%, (C) +0.09 ± 0.62%. Total spine: <i>p</i> = 0.04. (A) +0.98 ± 0.47%, (B) +0.10 ± 0.50%, (C) +1.98 ± 0.48%.	No benefit of TCC to BMD in men. TCC retarded bone loss at hip in elderly women.

Song et al. (2010) [31]	RCT (yes)	South Korea	82 (65)	Women >55 y with osteoarthritis [(A) 61.20, (B) 63.03]	(A) Self-help education program designed for arthritic patients. 2 h/mo, 6 mo.	(B) TCC (Yang style), 40 min/d, 2x/wk for 3 wk; followed by 40 min/wk for remainder of the 6-month intervention (~ 21 h). Also encouraged to practice for 20 min/d at home.	BMD (T-score), DXA Left proximal femur.	Femoral neck: $p = <0.01$. (A) -0.10 (-1.32 ± 0.78 to -1.42 ± 0.74), vs. (B) $+0.09$ (-1.49 ± 1.05 to -1.40 ± 1.01). Greater trochanter: $p < 0.01$. (A) -0.05 (-0.78 ± 0.78 to -0.83 ± 0.72), vs. (B) $+0.07$ (-0.80 ± 1.03 to -0.73 ± 1.06). Ward's triangle: $p = 0.02$. (A) -0.04 (-2.31 ± 0.76 to -2.37 ± 0.72), vs. (B) $+0.04$ (-2.27 ± 1.14 to -2.22 ± 1.19).	BMD was significantly higher in TCC group compared with the control group.
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BMD = bone mineral density; CCT = case-control trial; CS = cross-sectional studies; DXA = dual energy X-ray absorptiometry; N/A = not applicable; n.r. = not reported; NS = no significant difference; PCT = prospective cohort study; pQCT = peripheral quantitative computed tomography; RCT = randomized controlled trial; TCC = Tai Chi Chuan.

TCC intervention over a period of 12 months, totaling 195 hours of TCC. Again, no trends or statistically significant results were detected with DXA, but all pQCT measurements at distal tibia (ultradistal tibia tBMD and iBMD; cBMD at distal tibial diaphysis) returned statistically significant results reflecting a 2.6–3.6 fold retardation of bone loss in the TCC group compared with controls.

The effect of TCC on BMD may have a sex preference. A study by Woo et al. [30] found positive results of TCC on BMD only in females. The study participants consisted of 88 males and 88 females, all elderly (mean age, 68.9 years). Two interventions, TCC and resistance training, were carried out three times per week for 12 months, though the length of each session and thus the total TCC contact time was not reported. At 12-month follow-up, there was no observed benefit of TCC on BMD of male participants; however, female participants in both TCC and resistance training groups experienced a statistically significant increase in total hip BMD compared with sedentary controls (+0.07% for TCC and +0.09% for resistance training, compared with -2.25% for controls, $p = 0.01$). However, this effect was not seen for the total spine BMD (+0.10% for TCC, +1.98% for resistance training, compared with +0.98% for controls, $p = 0.04$). From the data, it appears that TCC mainly exerts effects on hip BMD, and overall has less effect on BMD than resistance training. No analyses were done comparing the effect sizes between the TCC and resistance training groups. The authors postulated the sex-specific effects seen may be due to higher fitness in male participants, and thus the exercise intensity of TCC being insufficient to induce significant changes in bone metabolism of this group.

One of the studies which found positive effects from TCC had disease-specific inclusion criteria. Song et al. [31] included only women with osteoarthritis, aged 55 years but with no requirement on menopause status. The observation group was assigned to a 19-hour TCC intervention over the span of 6 months. Patients were also encouraged to practice at home each day, though the compliance rate for this unsupervised practice was not reported. BMD changes were then compared with a control group assigned to a self-help program for arthritis. At follow-up, there were statistically significant intergroup differences; the TCC group had increased T-score at all measured sites (left femoral neck, greater trochanter, and Ward's triangle) compared with the control group, which saw decreased T-score across all measured sites. However, 19 hours is a relatively short duration of intervention, and it is interesting that this study found statistically significant results whereas Paulin et al. [32] and Hui et al. [33], with 36 hours and 30 hours of TCC exposure, respectively, did not.

Discussion

The effect of total hours of Tai Chi Chuan (TCC) intervention and duration of intervention period on bone mineral density (BMD).

Among the studies reviewed, it is observed that a longer period of TCC practice may help improve BMD (Table 3). Of the three studies [32–34] which showed nonsignificant intergroup differences, two had relatively short duration of the TCC intervention. Paulin et al. [32] included only 36 hours of TCC intervention in total, over a period of 4 months, and the sample size was relatively small at only 13 participants. Hui et al. [33] concluded that both TCC and brisk walking interventions had no apparent effect on BMD; however, the TCC intervention consisted of only 30 hours of TCC intervention in total, which is relatively short compared with the TCC intervention times of papers which reported positive correlation between TCC and BMD. It is possible that the intervention was merely too short to exert measurable effects on BMD. Wang et al. [34] was the exception, with a 12-month intervention comprising a total of 208 hours. At 12-month follow-up, no statistically significant difference could be found in absolute changes in BMD of the TCC and control group. However, there was an observed difference in the trends between TCC interventions and the inactive control; the inactive control experienced statistically significant bone loss at all measured sites, whereas both TCC interventions experienced less bone loss. A statistically insignificant trend of increased BMD at L2-L4 could be seen in the modified TCC group.

However, of the six studies which showed significant intergroup differences, five had relatively long duration of the TCC intervention [26–29,31] and the remaining one did not state the exact duration of TCC practice [30]. From Table 3, the median total hours of TCC intervention among these studies is 185 hours, five times more than those without significant BMD improvement (36 hours) and the median total duration of intervention period is 12 months, which is three times more than those without significant BMD improvement (4 months). Therefore, to obtain an improvement of BMD and prevent osteoporosis, it is suggested that the duration of TCC intervention should add up to a total of ~185 hours lasting for ~12 months. However, further studies are necessary to verify the exact length of TCC practice needed for BMD improvement.

Limitations of the reviewed papers

There are a few limitations in some of the reviewed studies. In the study by Song et al. [31], TCC was learned from video and

Table 3 The effect of total hours of Tai Chi Chuan (TCC) intervention and duration of intervention period on bone mineral density (BMD).

	Studies without significant BMD improvement [32–34]	Studies with significant BMD improvement [26–29,31] ^a
Median total hours of TCC intervention	36 h	185 h
Median total duration of intervention period	4 mo	12 mo

TCC = Tai Chi Chuan.

^a Study by Woo et al. [30] is not considered here because the exact duration of TCC intervention is not stated.

book learning materials; and the methodology of the paper is unclear over whether the interventions were carried out by patients by themselves, or under supervision, or if any formal training was provided by qualified instructors. If indeed no formal training or supervision was provided, patient compliance and also the participants' TCC technique, and hence the quality of the TCC intervention, may have been affected, thus attenuating any potential benefits of TCC on BMD.

In the study by Woo et al. [30], the authors adjusted for different confounding factors in evaluating significance for the male and female groups. For male participants, the confounding factors adjusted for were age, smoking status, and flexibility at baseline, whereas adjustment for female participants were age, quadriceps strength, and spine BMD at baseline, and hence there is difficulty in direct comparison of results for males and females.

TCC in combination with antiosteoporotic agents

TCC may have a synergistic effect when used with green tea polyphenols (GTP) or calcium supplements. As mentioned, the most commonly used antiosteoporotic agent is bisphosphonates. However, up to now, there are nearly no studies available to investigate the efficacy of TCC in combination with other antiosteoporotic agents (e.g., bisphosphonates), except GTP and calcium supplement. TCC in combination with GTP seems to improve the bone health and possibly prevent osteoporosis. Shen et al. [35] evaluated 171 postmenopausal osteopenic women after randomly assigning them into four groups: (1) GTP; (2) TCC + placebo; (3) TCC+GTP; and (4) placebo. Results showed that Tai Chi Chuan in combination with green tea polyphenols supplementation increased bone formation and/or reduced bone resorption. It may suggest a synergistic effect between TCC and GTP on increasing bone mineral density but further studies are needed to confirm it.

Apart from GTP, the effect of TCC in combination with calcium supplements was studied in the past. Zhou et al. [36] conducted a study in which 64 postmenopausal women were randomly divided into four groups: (1) TCC + calcium; (2) TCC; (3) calcium; and (4) control. The bone mineral density of TCC + calcium group improved significantly ($p < 0.05$) whereas other groups did not. Mao [37] conducted a similar study on 80 postmenopausal women and found that TCC in combination with oral calcium supplement improved BMD significantly whereas other groups did not. Zhang [38] also conducted a similar study on osteoporotic and osteopenic patients. He found a significant difference in the BMD after 24 weeks of treatment of TCC plus Caltrate D when compared with Caltrate D alone. Overall, TCC combined with calcium supplement was shown to improve BMD and reduce bone loss in osteoporosis and postmenopausal women in various studies in the past. Further research to investigate TCC in combination with different doses of calcium supplement is expected in the future.

Future studies and the translational potential of this article

This article has some implications. Although osteoporosis is commonly assessed using dual-energy X-ray absorptiometry

which measures bone mineral density, other study end-points such as the risk of fragility fracture can be adopted to study the effect of TCC. Moreover, apart from GTP and calcium supplement, the efficacy of TCC in combination with antiosteoporotic agents such as bisphosphonates could be studied in the future. In addition, as practicing TCC requires no specific space, it is also highly recommended to translate its potential for inclusion into early rehabilitation exercise program and prevention of secondary osteoporosis in patients after surgical treatment of common osteoporotic fractures.

Conclusion

TCC is shown to be beneficial to bone mineral density (BMD) in various studies and thus prevent osteoporosis. TCC seems to be time-dependent so that a longer period of TCC practice is required to improve BMD.

Conflicts of interest

The authors have no conflicts of interest to declare.

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