REVIEW ARTICLE

The Effects of Tai Chi on Bone Mineral Density in Postmenopausal Women: A Systematic Review

Peter M. Wayne, PhD, Douglas P. Kiel, David E. Krebs, PhD, Roger B. Davis, ScD, Jacqueline Savetsky-German, MPH, MAOM, Maureen Connelly, MD, Julie E. Buring, ScD

ABSTRACT. Wayne PM, Kiel DP, Krebs DE, Davis RB, Savetsky-German J, Connelly M, Buring JE. The effects of Tai Chi on bone mineral density in postmenopausal women: a systematic review. Arch Phys Med Rehabil 2007;88:673-80.

Objective: To evaluate the evidence for Tai Chi as an intervention to reduce rate of bone loss in postmenopausal women.

Data Sources: Literature search using Medline, Science Citation Index, Cochrane databases, China Biological Medicine Database, and additional manual reference searches of retrieved articles and personal libraries.

Study Selection: Randomized controlled trials (RCTs), prospective cohort studies, and cross-sectional studies that included Tai Chi as an intervention, and had at least 1 outcome related to measurement of bone mineral density (BMD).

Data Extraction: Authors critically reviewed studies, evaluated methodologic quality, and synthesized study results in a summary table.

Data Synthesis: Six controlled studies were identified by our search. There were 2 RCTs, 2 nonrandomized prospective parallel cohort studies, and 2 cross-sectional studies. The 2 RCTs and 1 of the prospective cohort studies suggested that Tai Chi-naive women who participated in Tai Chi training exhibited reduced rates of postmenopausal declines in BMD. Cross-sectional studies suggested that long-term Tai Chi practitioners had higher BMD than age-matched sedentary controls, and had slower rates of postmenopausal BMD decline. No adverse effects related to Tai Chi were reported in any trial.

Conclusions: Conclusions on the impact of Tai Chi on BMD are limited by the quantity and quality of research to date. This limited evidence suggests Tai Chi may be an effective, safe, and practical intervention for maintaining BMD in postmenopausal women. In combination with research that indicates Tai Chi can positively impact other risk factors associated with low BMD (eg, reduced fall frequency, increased musculoskeletal strength), further methodologically sound research is warranted to better evaluate the impact of Tai Chi practice on BMD and fracture risk in postmenopausal women.

Key Words: Bone mineral density; Exercise; Osteopenia; Osteoporosis; Rehabilitation; Tai Chi.

THE 2004 SURGEON GENERAL'S report[1] highlights that among U.S. women, osteoporosis and osteopenia—2 conditions characterized by lower than average bone mineral density (BMD)—are a serious and growing public health issue. In 2002, the number of osteoporotic and osteopenic women over the age of 50 in the United States was estimated at 44 million. Because of baby-boomer driven anticipated changes in demographics, this number is expected to increase substantially in coming years.[1,2]

Tai Chi (also referred to as Tai Chi Chuan, Taijiquan) is a meditative, mind-body exercise that is growing in popularity in the United States. Over the past century, millions of Chinese have practiced Tai Chi's flowing, meditative movements to cultivate and maintain health and well-being. Because of its reputed health benefits, apparent safety, low cost, and growing popularity, Tai Chi has become an increasingly recognized preventive and rehabilitative therapeutic tool by the conventional medical community. Recent studies have begun to address the safety and efficacy of Tai Chi as a therapeutic intervention for a variety of health concerns including: balance and postural stability,[3-11] musculoskeletal strength and flexibility,[6,12-15] coronary artery disease,[16,17] hypertension,[18] general cardiorespiratory fitness and functional status,[13,14,17,19-21] multiple sclerosis,[22] rheumatoid arthritis,[23] osteoarthritis,[24] microcirculation and endothelial function,[25,26] immune function,[27,28] dementia,[29] and general stress management.[30-32] Several Tai Chi review articles[15,33-39] have recently been published. The 2004 Surgeon General's report on osteoporosis specifically recommends Tai Chi as a good exercise for fall prevention,[1] and Tai Chi is increasingly recommended to osteoporotic women as a safe and effective exercise for bone density maintenance. Although the fundamental principles of Tai Chi and some clinical research suggest that it may help to maintain bone density in postmenopausal women, to date there have been few attempts to systematically evaluate the evidence for this claim.

This review examines the use of Tai Chi as a potential intervention for postmenopausal women with low BMD. We begin by highlighting the growing prevalence and public health impact of osteoporosis and osteopenia, and the current standard of care for these conditions. We then review the fundamental principles of Tai Chi that may make it beneficial for women with low BMD, and critically review clinical studies that have evaluated the impact of Tai Chi on BMD. We also summarize research on the impact of Tai Chi on other risk factors associated with osteoporosis and osteopenia. Last, we offer suggestions for future research that will improve our ability to evaluate the benefits of Tai Chi for both prevention and treatment of low BMD.

Low BMD: Definitions and Prevalence

Osteoporosis is a skeletal disorder characterized by compromised bone strength that predisposes one to an increased risk of

From the New England School of Acupuncture, Watertown, MA (Wayne, Savetsky-German); Institute for Aging Research, Hebrew SeniorLife, Boston, MA (Kiel); MGH Institute of Health Professions, Massachusetts General Hospital, Boston, MA (Krebs); and Osher Institute, Harvard Medical School, Boston, MA (Wayne, Davis, Connelly, Buring).

Supported by the National Center for Complementary and Alternative Medicine (grant no. 5 U19 AT002022-02 and 7 R21 AT003503-02).

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 author(s) or upon any organization with which the author(s) is/are associated.

Reprint requests to Peter M. Wayne, PhD, Harvard Medical School Osher Institute, 401 Park Dr, Ste 22A, Boston, MA 02215, e-mail: *peter_wayne@hms.harvard.edu.*

0003-9993/07/8805-11004$32.00/0
doi:10.1016/j.apmr.2007.02.012

fracture. Bone strength primarily reflects the integration of bone density and bone quality. Because bone density can be easily measured, people are often classified as having osteoporosis or osteopenia based on the value of their BMD. Osteoporosis is technically defined by the World Health Organization as a BMD T score of less than −2.5 (ie, 2.5 standard deviations [SDs] below a healthy, young white adult reference),[40] whereas osteopenia is often used to characterize BMD T scores between −1.0 and −2.5. Because bone tends to be lost with aging, untreated osteopenic women are at risk of losing additional bone and becoming osteoporotic.[1,2] Low BMD is a strong risk factor for future bone fractures in asymptomatic postmenopausal women.[41,42] It is estimated that 4 in 10 white women 50 years or older in the United States will experience a hip, spine, or wrist fracture sometime during the remainder of their life.[43] Models based on meta-analyses indicate a doubling of relative risk for fracture with each SD decline in BMD.[44] A recent prospective study[45] of more than 200,000 women over the age of 50 reported that relative to those with normative BMD, women with osteopenia and osteoporosis had 1.8-fold and 4.0-fold increases in fracture rates, respectively. Although the relative risk of fracture was higher in osteoporotic women, because of the far greater number of osteopenic women (40% vs 7%), the absolute numbers of fractures were much higher among osteopenic women, making osteopenia a potentially more widespread public health issue.[45]

Fractures associated with low bone density are a significant cause of disability.[46,47] The downward spiral in health after osteoporosis-related hip fractures is associated with up to 20% higher mortality rates in the year after a fracture.[48-50] Recent studies[51,52] from Sweden have shown increased mortality after spine fractures as well as hip fractures. Medical costs associated with managing hip and other fractures are high, and were estimated to be $13.8 billion in the United States in 1995, increasing to $17.5 billion in 2002.[47,53]

Despite the high prevalence of osteoporosis and osteopenia, and the substantial burden on the health care system, only limited progress has been made in developing effective, preventive, and sustainable interventions aimed at reducing rates of fractures associated with low BMD. For example, recent findings[54] suggest that although calcium with vitamin D supplementation in relatively healthy women without known osteoporosis may result in modest improvement in hip bone density, it does not reduce the risk of hip fractures, and it may increase the risk of kidney stones. Pharmacologic treatment to "prevent" further bone loss and fractures in women with osteopenia has been shown not to be a cost-effective strategy primarily because of the expense of the drugs.[55]

Current guidelines for the treatment of osteoporotic and osteopenic women generally include the recommendation of regular exercise.[1,2] There is currently no consensus regarding the optimal types and regimens of exercise for treating low BMD, however, or for addressing other risk factors associated with osteoporosis and osteopenia (eg, poor balance, decreased muscle strength, diminished agility). Moreover, among postmenopausal women, compliance with conventional exercise regimens is often low, due to health factors that may limit certain types of exercise, lack of motivation, and inability to sustain long-term interest, among other reasons.[56,57] The 2004 Surgeon General's report[1] on osteoporosis stresses the need for new, creative, sustainable exercise programs for women at risk for low BMD.

Tai Chi and Its Rationale as a Treatment for Women With Low BMD

Tai Chi has its roots in the martial arts; yet for the past century millions of Chinese have practiced its flowing, meditative movements to cultivate and maintain health. Considered one of the treasures of Chinese medicine, Tai Chi is based on the same basic principles that underlie acupuncture and Chinese herbal therapies. It employs detailed regimens of physical movement, breathing techniques, and cognitive tools (both visualization and focused internal awareness) to strengthen the body, calm the mind, and "balance the flow of Qi" (life force).[58-61]

A number of characteristics of Tai Chi practice that might make it an effective therapy for maintaining bone density and improving postural control have been explored in recent reviews.[33,36,38,62,63] These intended characteristics and their purported effects include: (1) a constant shifting of weight from 1 leg to the other, which facilitates improved lower-extremity strength and/or mechanical load and dynamic standing balance; (2) an emphasis on maintaining a vertical posture with an extended head and trunk position, which promotes a less flexed posture; (3) the use of different parts of the body taking turns playing the role of stabilizer and mover, which enables movements to be executed smoothly without compromising balance and stability; (4) a continuous, slow, even tempo that facilitates sensory awareness of the speed, force, trajectory, and execution of movements, as well as awareness of the external environment; (5) the symmetrical and diagonal arm movements of Tai Chi, which promote arm swing in gait and increase trunk rotation around the waist; (6) moderate knee flexion, which lowers the body's center of gravity; and (7) flowing circular and spiraling movements, which promote joint flexibility. Although we are not aware of any studies that have been explicitly designed to examine Tai Chi's impact on mechanical load and BMD in postmenopausal women, a handful of studies have shown that Tai Chi improves lower-extremity biomechanic efficiency during activities of daily living.[9,64-66] Such changes are likely to translate into increased mechanical load on key regions of the skeleton including the femur, hip, and lower spine.

METHODS

Clinical Trials Examining Tai Chi's Effect on BMD in Postmenopausal Women

To systematically review the evidence evaluating Tai Chi for reducing rates of postmenopausal BMD loss, we conducted a literature search using Medline, Science Citation Index, and Cochrane Database of Randomized Controlled Trials. Search strategies for each of these databases included using the following statements and key words: *Tai Chi* or *Tai Chi Chuan* or *Taijiquan* and *bone* or *osteoporosis* or *menopause*, and included the period 1966 through April 2006. We also conducted a separate literature search using China Biological Medicine Database for Chinese-language randomized trials using the key words *Taijiquan*, *bone*, and *osteoporosis*. Finally, we manually searched the bibliographies of retrieved articles and our personal libraries for additional relevant citations.

Because only a small number of the studies we retrieved were randomized controlled trials (RCTs), and because RCTs employing Tai Chi interventions are not amenable to double-blinding, we chose not to use a more traditional instrument (eg, Jadad score)[67] to evaluate study methodologic quality. Rather, study quality was descriptively characterized with respect to reporting of the following criteria: randomization (yes or no); details of randomization methods; clear inclusion and exclu-

Table 1: Quality of Design and Methodologic Features of Studies Evaluating Tai Chi for Low BMD

Features	Qin et al[70]	Gong et al[72]	Chan et al[68]	Zhou[69]	Xu et al[71]	Qin et al[73]
Randomization employed	–	–	√	√	–	–
Randomization methods	NA	NA	√	–	NA	NA
Clear inclusion/exclusion criteria	√	√	√	–	–	√
Outcome assessors blinded	–	–	–	–	–	–
Withdrawal and dropouts reported	√	–	√	–	–	–
Sample size justified/estimated	–	–	√	–	–	–
Appropriate data analysis	√	√	√	√	–	√
Tai Chi intervention described	–	–	√	√	√	–
Qualifications of Tai Chi instructors	–	–	–	–	–	–

Abbreviation: NA, not applicable.
Legend: √, design and methodology feature adequately reported; –, design and methodology feature not adequately reported.

sion criteria; blinding of outcomes assessors; description of withdrawal and dropouts; sample size estimates and justification; use of appropriate statistical analyses; details of Tai Chi intervention (eg, style, training schedule); and experience of Tai Chi instructors (table 1).

Our database searches of Medline, Science Citation Index, and Cochrane identified a total of 191 citations. Titles and abstracts of these citations were manually reviewed and considered eligible only if they described a prospective or cross-sectional study that employed Tai Chi as an intervention, and had at least 1 outcome related to measurement of BMD. A total of 9 citations met these criteria. Six of these 9 citations were limited to abstracts of proceedings from scientific meetings and were thus excluded; the remaining 3 were included in this review. Two additional eligible citations were identified using the China Biological Medicine Database for Chinese-language randomized trials, and 1 was identified in the personal library of an author of this review.

The 6 eligible studies identified by our search are summarized in table 2. Two were RCTs,[68,69] 2 were nonrandomized prospective parallel cohort studies,[70,71] and 2 were static cross-sectional comparisons.[72,73] Tai Chi practitioners were compared with age-matched sedentary controls in 5 studies[68-70,72]; 1 compared Tai Chi with rope skipping and vigorous martial arts,[69] and 1 compared Tai Chi with acupuncture and Chinese herbal medicine.[71] The duration of the Tai Chi intervention in the 3 prospective studies with naive practitioners ranged from 8 to 12 months. Five of the 6 studies were conducted in China and included only Asian women.

The methodologic quality of most studies was poor, as summarized in table 1. Of the 2 RCTs, only 1 provided adequate details of randomization methods, inclusion and exclusion criteria, dropout rates, and justification for sample sizes. None of the 6 studies indicated that outcome assessors were blinded, none included any information on the experience of Tai Chi instructors, and for all the non-RCT studies, dropout rates, sample size justifications, and characteristics of the Tai Chi intervention were poorly described.

Results across the 6 studies summarized in table 2 suggest the following: First, long-term postmenopausal Tai Chi practitioners have higher BMD than age-matched sedentary controls, and have slower rates of bone loss. In 1 cross-sectional study of postmenopausal women, Qin et al[73] used dual-energy x-ray absorptiometry (DXA) to compare BMD of 48 long-term Tai Chi practitioners with 51 age-matched sedentary controls. Subjects in the Tai Chi group had significantly higher BMD in the lumbar spine (7.1%), the greater trochanter (7.2%), and Ward's area (7.1%) of the proximal femur ($P<.05$). Similar magnitudes of BMD differences between Tai Chi and age-matched sedentary controls were observed in an earlier study conducted by the same research group in a similar population.[70] This earlier study also tracked changes in BMD over a 12-month period and found that rates of both trabecular and cortical BMD loss in the distal tibia (assessed using peripheral quantitative computerized tomography [pQCT]) were approximately 50% lower in the Tai Chi group ($P=.044$, $P=.031$). The Tai Chi group also exhibited a nonsignificant trend toward lower BMD loss in the femur (measured with DXA). Another cross-sectional study also reported greater spine and femur BMD among long-term female Tai Chi practitioners (n=18) when compared with age- and sex-matched controls (n=22) ($P=.01$).[72]

Second, Tai Chi-naive women who undergo Tai Chi training exhibit reduced rates of postmenopausal BMD decline. One methodologically sound RCT of postmenopausal women observed that those randomized to 12 months of regular Tai Chi training (n=67) exhibited 3.6-fold (trabecular) to 2.3-fold (cortical) reductions in rates of BMD decline in the distal tibia as measured with pQCT ($P<.005$), as compared with a no-exercise control group (n=65). No significant differences between groups were reported for BMD of the spine or femur as measured with DXA.[68] A second, less methodologically sound RCT[69] observed that DXA measures of BMD at the lumbar spine significantly increased (1.81%) after 10 months of Tai Chi whereas sedentary controls decreased (1.83%). Another intervention arm in this study—Tai Chi pushing hands (a 2-person interactive exercise that involves a continuous issuing and receiving of gentle pushes)—exhibited even greater increases in lumbar BMD (3.4%). This study also reported significant BMD increases of the same magnitude in the distal ulna and radius. Finally, another methodologically weak, nonrandomized study reported that 4 months of Tai Chi training resulted in a 7.3% increase in bone density (skeletal location not indicated) as measured with broadband ultrasound attenuation (BUA).[71] This study also reported that serum osteocalcin, a biomarker for bone formation, increased significantly in the Tai Chi group. No BMD or osteocalcin data for the control group were provided.

Third, 1 nonrandomized cross-over study[71] provided qualitative data suggesting that Tai Chi improves perimenopausal symptoms including hot flashes and abdominal distention.

Finally, Tai Chi appears to be safe for peri- and postmenopausal women. No significant adverse effects were reported in any of the 6 studies evaluated.

Table 2: Summary of Studies Evaluating Impact of Tai Chi on BMD in Peri- and Postmenopausal Women

Study	Study Design (Duration)	Study Location (Language)	Study Population (Age)	Interventions and Sample Size	Outcomes Measured	Results
Qin et al[70]	Prospective cohort (12mo)	Hong Kong (English)	Postmenopausal community-dwelling women (54±3.4y)	• Long-term Tai Chi practitioners (min 4y experience) (n=17) • Age- and sex-matched sedentary controls (n=17)	BMD of lumbar spine and proximal femur (w/DXA), and distal tibia (w/pQCT)	Significantly greater BMD in lumbar spine, proximal femur, and tibia in Tai Chi vs control. Reduced rates of BMD loss in Tai Chi, but trend significant only w/pQCT
Gong et al[72]	Cross-sectional	Shanghai, PRC (Chinese)	Community-dwelling men and women (67.0±1.3y)	• Long-term Tai Chi practitioners (min 5y experience) (n=28) • Age-matched sedentary controls (n=32)	BMD of lumbar spine and proximal femur (w/DXA)	BMD significantly greater in L1 through L4 and femur for Tai Chi vs control. 5–10y experience not different from 10+
Chan et al[68]	RCT (12mo)	Hong Kong (English)	Postmenopausal community-dwelling women (54.0±3.5y)	• Tai Chi: 5 sessions/wk, 45min (n=67) • Sedentary control (n=65)	BMD of lumbar spine and proximal femur (w/DXA), and of distal tibia using (w/pQCT)	Reduced rate of tibial bone loss in Tai Chi group (pQCT); nonsignificant trends in reduced rates of bone loss w/DXA
Zhou[69]	RCT (10mo)	Shanxi, PRC (Chinese)	Postmenopausal school teachers (55.9±2.8y)	• 5 groups: • Rope skipping (n=12) • Mulan boxing (n=12) • Tai Chi solo form (n=12) • Tai Chi push hands (n=12) • Sedentary control (n=12)	BMD of L2-4, distal radius and ulna (w/ DXA)	BMD decreased in nonexercise control and increased in all exercise groups Tai Chi pushing hands significantly higher increases in BMD
Xu et al[71]	Paired crossover design (8mo)	Melbourne Australia (English)	Menopausal women (49.3y)	• Tai Chi (n=12) • Acupuncture (n=14) • Chinese herbs (n=14) Half of each cohort initially allocated to sedentary control; then crossed over at 16wk	Broadband ultrasound attenuation; bone formation marker (osteocalcin) Bone resorption markers (pyridinoline, deoxypyridinoline) TCM diagnoses	Tai Chi reduced rate of decline in broadband ultrasound attenuation; Tai Chi increased rate of bone formation (osteocalcin), but no effect on resorption; Tai Chi improved a number of menopausal symptoms according to TCM theory
Qin et al[73]	Cross-sectional	Hong Kong (English)	Postmenopausal community-dwelling women (55.5±3.1y)	• Long-term Tai Chi practitioners (min 3y experience) (n=48) • Age-matched sedentary controls (n=51)	BMD of lumbar spine and proximal femur (by DXA), quadriceps strength, flexibility, balance	Significantly greater BMD in lumbar spine and some regions of femur (greater trochanter, Ward's area) in Tai Chi vs control. Greater quad strength and balance in Tai Chi vs control

Abbreviation: TCM, traditional Chinese medicine.

DISCUSSION

Limitations of Reviewed Studies Evaluating Tai Chi's Impact on BMD

Although the 6 studies summarized in table 2 suggest Tai Chi may improve BMD of postmenopausal women, these results should be considered inconclusive and interpreted with caution for the following reasons.

First, the majority of these studies have design and methodologic limitations. Only 2 of the 6 studies were randomized trials. Although cross-sectional studies enable investigations of long-term effects of Tai Chi, absence of randomization and longitudinal monitoring introduces great potential for bias. Sample sizes across all studies were small, with an average of 31 participants in Tai Chi and control groups. Additionally, information on Tai Chi interventions, eligibility criteria, blinding methods, and qualification of instructors were not available or poorly described (see table 1). Finally, because of both the diversity of approaches used to characterize BMD (ie, DXA, pQCT, BUA) and the diversity of skeletal sites at which BMD was assessed, comparisons and synthesis across studies is difficult. Moreover, some of the specific methods used to characterize BMD, such as BUA, are known to have very low precision; the 1 study employing BUA that reported a 7.3% increase in bone density after only 4 months of Tai Chi most likely reflects a measurement artifact.

Second, the studies in table 2 include women with a range of baseline BMD scores, ranging from normative to severely osteoporotic. Results of conventional exercise studies suggest that the responsiveness of BMD to exercise may vary with developmental stage and degree of BMD loss severity.[74,75] This makes it difficult to evaluate the potential benefits of Tai Chi for women that differ in their magnitude of fracture risk (eg, normative BMD vs osteopenic vs osteoporotic).

Third, all but 1 of the 6 studies in table 2 were conducted in China and included only Asian women. It is well established that the prevalence of osteopenia and osteoporosis, and patterns of postmenopausal BMD loss vary in a predictable manner with respect to race and ethnicity—for example, African Americans have the lowest, Hispanics intermediate, and whites and Asians the highest prevalence of osteoporosis.[1] Consequently, results of these studies are of only limited use in predicting the responses of racially diverse populations of women.

The Impact of Tai Chi Versus Conventional Exercise on BMD in Postmenopausal Women

The results of the most methodologically credible RCT we reviewed suggests that 12 months of Tai Chi training for Tai Chi-naive practitioners resulted in a clinically and statistically significant reduction in the magnitude of tibial BMD loss of approximately 1.0%, as measured with QCT. The magnitude of this retardation in bone loss is similar to that reported in a meta-analysis characterizing the effects of walking exercise on reductions in rate of BMD loss in postmenopausal women's BMD (1.31% and 0.92% retardation in bone loss for hip and spine, respectively, assessed using DXA).[76] This comparison, however, must be made cautiously, because BMD estimates were made at different anatomic sites and using different instrumentation. Moreover, it is difficult to measure "exercise dosage" across varied types of exercise and studies. Because no studies have directly compared Tai Chi with walking, there is no exact comparability in terms of exercise, intensity, and compliance across these studies.

The use of QCT to assess BMD in Tai Chi studies is noteworthy.[68,70] In contrast to DXA, QCT has the advantage of being able to quantify true volumetric density as well as partition the 2 types of bone, trabecular and cortical, which may respond differently to exercise. Moreover, it has the potential to have higher precision.[77] In the study by Chan et al,[68] the magnitude of both cortical and trabecular BMD loss in the tibia decreased by approximately 1% in response to Tai Chi. In contrast, a recent conventional exercise study that employed QCT to monitor BMD dynamics observed that a 2-year intervention combining high- and low-impact training exhibited markedly greater impact on cortical versus trabecular BMD of the spine (≈3 % vs 1%, respectively).[78] Again, direct comparison between studies is limited by the different locations that BMD was assessed. Nevertheless, because cortical and trabecular BMD are known to contribute differently to the mechanical strength of bone, future Tai Chi studies should consider using QCT to better understand the impact of this weight-bearing exercise on bone morphology and quality, and the relationship between BMD compartmentalization and fracture risk. Even though cost is greater and radiation dosage is higher with QCT (radiation dosage is comparable to the background radiation dose obtained over the course of a year), it is justifiable to use this technology when testing new therapies because it is essential to understand how potential improvements in the skeleton are manifest.

Tai Chi May Also Impact Other Risk Factors Associated With Low BMD

Independent of changes in BMD, Tai Chi may be of benefit to women with low bone density because of its positive effect on postural balance and fall risk. Systematic reviews,[3,38,79] which include numerous randomized trials, suggest that Tai Chi practice can directly reduce risk of falls,[4,5] and/or positively impact factors associated with postural control including fear of falling,[4,5] static and/or dynamic balance,[6,80,81] musculoskeletal strength[4,6,80,81] flexibility,[13-15] and performance of activities of daily living.[82-85] Drawing on these data, a cost-benefit analysis concluded that Tai Chi could significantly reduce costs associated with fall-related hip fractures.[86] Noteworthy across these studies is that the majority have focused on older people, including frail[3] and deconditioned[87] adults, and as in the trials reviewed above, few adverse effects have been reported. This suggests that the findings are relevant to postmenopausal women, and that Tai Chi can be safely practiced well into later stages of life.

Only 1 of the studies included in this systematic review reported data on fracture rates. During their 12-month prospective RCT, Chan[68] observed 1 fracture in the Tai Chi group compared with 3 in the control group. Because this study was not designed and powered to compare fracture rates, and because so few fractures were observed, this data should not be overinterpreted. Surprisingly, none of the cross-sectional Tai Chi studies we reviewed included information on prevalence of falls or fractures. Future long-term prospective and cross-sectional studies evaluating Tai Chi for bone health should also include data on prevalence of fractures.

CONCLUSIONS

Conclusions on the efficacy of Tai Chi for reducing rates of BMD loss in postmenopausal women are limited by the small number and generally low quality of studies to date. Acknowledging these limitations, the totality of the available evidence suggests Tai Chi may be an effective, safe, and practical intervention for maintaining BMD is postmenopausal women. One methodologically sound prospective RCT suggests Tai Chi reduces rates of tibial BMD loss, 2 sound cross-sectional

studies suggest long-term Tai Chi practitioners have higher lumbar and femur BMD than age-matched sedentary controls. Other sound research summarized above indicates that Tai Chi can be of benefit to women with low BMD by improving balance, reducing fall frequency, and increasing musculoskeletal strength. Finally, Tai Chi has been shown to be very safe in aging, frail, and deconditioned populations,[3,23,87] does not require equipment, and is relatively inexpensive to administer.[86] As such, Tai Chi may be a logical and practical response to the Surgeon General's recent call for novel exercise programs for women with low bone density.[1]

Further research is warranted to better characterize the potential of Tai Chi, both as a therapy for women with low BMD and as a preventive intervention for women at risk for osteoporosis. This research should include appropriately powered randomized trials that include women representing a variety of races and ethnicities. This research should also explore the use of alternatives to DXA for the measure of BMD, including QCT, as has been suggested by the Surgeon General.[1] Long-term prospective studies and cross-sectional studies should also include data on incidence of fractures. Combining the use of sensitive markers of BMD dynamics with objective measures of Tai Chi's impact on biomechanic (eg, mechanical load at specific skeletal sites), physiologic, and psychosocial outcomes could provide important insight into the mechanisms by which Tai Chi impacts bone health. Finally, because low BMD is not a condition limited to women,[88] future trials specifically evaluating the impact of Tai Chi on BMD in osteopenic and osteoporotic men may also be warranted.

Acknowledgments: We thank Weidong Lu for his assistance reviewing the Chinese language literature, and Monica Shields and Ellen Connors for administrative support.

The contents of this review are solely the responsibility of the authors and do not necessarily represent the official views of the Center for Complementary and Alternative Medicine or the National Institutes of Health.

References

1. U.S. Department of Health and Human Services. Bone health and osteoporosis: a report of the Surgeon General. Rockville U.S. Department of Health and Human Services, Office of the Surgeon General; 2004.
2. National Osteoporosis Foundation. America's bone health: the state of osteoporosis and low bone mass in our nation. Washington (DC): NOF; 2002.
3. Wolf S, Sattin R, Kutner M, O'Grady M, Greenspan A, Gregor R. Intense Tai Chi exercise training and fall occurrences in older, transitionally frail adults: a randomized controlled trial. J Am Geriatr Soc 2003;51:1693-701.
4. Wolf S, Barnhart H, Kutner N, McNeely E, Coogler C, Xu T. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. J Am Geriatr Soc 1996; 44:489-97.
5. Wolf S, Barnhart H, Ellison G, Coogler C. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques. Phys Ther 1997;77: 371-81.
6. Jacobson B, Chen H, Cashel C. The effect of T'ai Chi Chuan training on balance, kinesthetic sense, and strength. Percept Mot Skills 1997;84:27-33.
7. Hain T, Fuller L, Weil L, Kotsias J. Effects of T'ai Chi on balance. Arch Otol Head Neck Surg 1999;125:1191-5.
8. Wong A, Lin Y, Chou S, Tang F, Wong P. Coordination exercise and postural stability in elderly people: effect of Tai Chi Chuan. Arch Phys Med Rehabil 2001;82:608-12.
9. McGibbon C, Krebs D, Wolf S, Wayne P, Scarborough D, Parker S. Tai Chi and vestibular rehabilitation effects on gaze and whole-body stability. J Vestib Res 2004;14:467-78.
10. McGibbon C, Krebs D, Parker S, Scarborough D, Wayne P, Wolf S. Tai Chi and vestibular rehabilitation improve vestibulopathic gait via different neuromuscular mechanisms: preliminary report. BMC Neurol 2005;5:3.
11. Wayne P, Scarborough D, Krebs D, et al. Tai Chi for vestibulopathic balance dysfunction: a case study. Altern Ther Health Med 2005;11(2):60-6.
12. Lan C, Lai J, Chen S, Wong M. Tai Chi Chuan to improve muscular strength and endurance in elderly individuals: a pilot study. Arch Phys Med Rehabil 2000;81:601-7.
13. Lan C, Lai J, Wong M. Cardiorespiratory function, flexibility, and body composition among geriatric Tai Chi Chuan practitioners. Arch Phys Med Rehabil 1996;77:612-6.
14. Lan C, Lai J, Wong M. 12-month Tai Chi training in the elderly: its effect on health fitness. Med Sci Sports Exerc 1998;30:345-51.
15. Wu G. Evaluation of the effectiveness of Tai Chi for improving balance and preventing falls in the older population—a review. J Am Geriatr Soc 2002;50:746-54.
16. Channer K, Barrow D, Barrow R, Osborne M, Ives G. Changes in haemodynamic parameters following Tai Chi Chuan and aerobic exercise in patients recovering from acute myocardial infarction. Postgrad Med J 1996;72:349-51.
17. Lan C, Chen S, Lai J, Wong M. The effect of Tai Chi on cardiorespiratory function in patients with coronary artery bypass surgery. Med Sci Sports Exerc 1999;31:634-8.
18. Young D, Appel L, Lee S. The effects of aerobic exercise and T'ai Chi on blood pressure in older people: results of a randomized trial. J Am Geriatr Soc 1999;47:277-84.
19. Lai J, Lan C, Wong M, Tenh S. Two-year trends in cardiorespiratory function among older Tai Chi Chuan practitioners and sedentary subjects. J Am Geriatr Soc 1995;43:1222-7.
20. Lai J, Wong M, Lan C. Cardiorespiratory responses of Tai Chi Chuan practitioners and sedentary subjects during cycle ergometry. J Formos Med Assoc 1993;92:894-9.
21. Schneider D, Leung R. Metabolic and cardiorespiratory responses to the performance of Wing Chun and T'ai Chi Chuan exercise. Int J Sports Med 1991;12:319-23.
22. Husted C, Pham L, Hekking A, Niederman R. Improving quality of life for people with chronic conditions: the example of T'ai Chi and multiple sclerosis. Altern Ther Health Med 1999;5:70-4.
23. Kirsteins A, Dietz F, Hwang S. Evaluating the safety and potential use of a weight-bearing exercise, Tai-Chi Chuan, for rheumatoid arthritis patients. Am J Phys Med Rehabil 1991;70:136-41.
24. Hartman C, Manos T, Winter C, Hartman D, Li B, Smith J. Effects of T'ai Chi training on function and quality of life indicators in older adults with osteoarthritis. J Am Geriatr Soc 2000;48:1553-9.
25. Wang J, Lan C, Chen S. Tai Chi Chuan training is associated with enhanced endothelin-dependent dilation in skin vasculature of healthy older men. J Am Geriatr Soc 2002;50:1024-30.
26. Wang J, Lan C, Wong M. Tai Chi Chuan training to enhance microcirculatory function in healthy elderly men. Arch Phys Med Rehabil 2001;82:1176-80.
27. Sun X, Xu Y, Xia Y. Determination of E-rosette-forming lymphocytes in aged subjects with Taichiquan exercise. Int J Sports Med 1989;10:217-9.
28. Irwin M, Pike J, Cole J, Oxman M. Effects of a behavioral intervention, Tai Chi Chih, on Varicella-Zoster Virus specific immunity and health functioning in older adults. Psychosom Med 2003;65:824-30.
29. Gibb H, Morris C, Gleisberg J. A therapeutic programme for people with dementia. Int J Nurs Pract 1997;3:191-9.
30. Jin P. Changes in heart rate, noradrenaline, cortisol and mood during Tai Chi. J Psychosom Res 1989;33:197-206.

31. Jin P. Efficacy of Tai Chi, brisk walking, meditation, and reading in reducing mental and emotional stress. J Psychosom Res 1992; 36:361-70.
32. Brown D, Wang Y, Ward A, et al. Chronic psychological effects of exercise and exercise plus cognitive strategies. Med Sci Sports Exerc 1995;27:765-75.
33. Wolf S, Coogler C, Xu T. Exploring the basis for Tai Chi Chuan as a therapeutic exercise approach. Arch Phys Med Rehabil 1997; 78:886-92.
34. Sandlund E, Norlander T. The effects of Tai Chi Chuan relaxation and exercise on stress responses and well-being: an overview of research. Int J Stress Manage 2000;7:139-49.
35. Lan C, Lai J, Chen S. Tai Chi Chuan: an ancient wisdom on exercise and health promotion. Sports Med 2002;32:217-24.
36. Li J, Hong Y, Chan K. Tai Chi: physiological characteristics and beneficial effects on health. Br J Sports Med 2001;35:118-56.
37. Wolf S, O'Grady M, Xu T. Tai Chi Chuan. In: Wainapel S, Fast A, editors. Alternative medicine and rehabilitation: a guide for practitioner. New York: Demos Pr; 2002. p 99-139.
38. Wayne P, Krebs D, Wolf S, et al. Can Tai Chi improve vestibulopathic postural control? Arch Phys Med Rehabil 2004;85: 142-52.
39. Taylor-Pilae R, Froelicher E. The effectiveness of Tai Chi exercise in improving aerobic capacity, a meta-analysis. J Cardiovasc Nurs 2004;19:48-57.
40. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Report of a WHO Study Group. World Health Organ Tech Rep Ser 1994;843:1-129.
41. Cummings S, Black D, Nevitt M, et al. Bone density at various sites for prediction of hip fractures. The Study of Osteoporotic Fractures Research Group. Lancet 1993;341:72-5.
42. Kanis J, Melton L III, Christiansen C, Johnston C, Khaltaev N. Perspective: the diagnosis of osteoporosis. J Bone Miner Res 1994;9:1137-41.
43. Cummings S, Melton L. Epidemiology and outcomes of osteoporotic fractures. Lancet 2002;359:1761-7.
44. Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. BMJ 1996;312:1254-9.
45. Siris E, Miller P, Barrett-Connor E, et al. Identification and fracture outcomes of undiagnosed low bone mineral density in postmenopausal women: results from the National Osteoporosis Risk Assessment. JAMA 2001;286:2815-22.
46. Greendale G, Barrett-Connor E, Ingles S, Haile R. Late physical and functional effects of osteoporotic fracture in women: the Rancho Bernardo study. J Am Geriatr Soc 1995;43:955-61.
47. Melton L III. Adverse outcomes of osteoporotic fractures in the general population. J Bone Miner Res 2003;18:1139-41.
48. Ensrud K, Thompson D, Cauley J, et al. Prevalent vertebral deformities predict mortality and hospitalization in older women with low bone mass. Fracture Intervention Trial Research Group. J Am Geriatr Soc 2000;48:241-9.
49. Leibson C, Tosteson A, Gabriel S, Ransom J, Melton L. Mortality, disability, and nursing home use for persons with and without hip fracture: a population-based study. J Am Geriatr Soc 2002;50: 1644-50.
50. Cooper C, Atkinson E, Jacobsen S, O'Fallon W, Melton L III. Population-based study of survival after osteoporotic fractures. Am J Epidemiol 1993;137:1001-5.
51. Johnell O, Kanis J, Oden A, et al. Mortality after osteoporotic fractures. Osteoporosis Int 2004;15:38-42.
52. Kanis J, Johansson H, Oden A, et al. A meta-analysis of prior corticosteroid use and fracture risk. J Bone Miner Res 2004;19: 893-9.
53. Ray N, Chan J, Thamer M, Melton L. Medical expenditures for the treatment of osteoporotic fractures in the United States in 1995: report from the National Osteoporosis Foundation. J Bone Miner Res 1997;12:24-35.
54. Jackson RD, LaCroix AZ, Gass M, et al. Women's Health Initiative Investigators. Calcium plus vitamin D supplementation and the risk of fractures [published erratum in: N Engl J Med 2006; 354:1102]. N Engl J Med 2006;354:669-83.
55. Schousboe JT, Nyman JA, Kane RL, Ensrud KE. Cost-effectiveness of alendronate therapy for osteopenic postmenopausal women. Ann Intern Med 2005;142:734-41.
56. Mayoux-Benhamou M, Roux C, Perraud A, Fermanian J, Rahali-Kachlouf H, Revel M. Predictors of compliance with a home-based exercise program added to usual medical care in preventing postmenopausal osteoporosis: an 18-month prospective study. Osteoporosis Int 2005;16:325-31.
57. Wallace B, Cummings R. Systematic review of randomized trials of the effect of exercise on bone mass in pre- and postmenopausal women. Calcif Tissue Int 2000;67:10-8.
58. Cheng M. Master Cheng's thirteen chapters on Tai Chi Chuan. Trans D Wile. New York: Sweet Chi Pr; 1982.
59. Plummer J. Acupuncture and Tai Chi chuan (Chinese shadow boxing): body-mind therapies affecting homeostasis. In: Lau Y, editor. The scientific basis of traditional Chinese medicine. Hong Kong: Univ Hong Kong; 1982. p 22-36.
60. Frantzis B. The power of internal martial arts: combat secrets of Ba Gua, Tai Chi, and Hsing-I. Berkeley: North Atlantic Books; 1998.
61. Helm B. Gateways to health: Taijiquan and traditional Chinese medicine. Taijiquan J 2002:8-12.
62. Levandoski L, Leyshon G. Tai Chi exercise and the elderly. Clin Kinesiol 1990;44:39-42.
63. Tse SK, Bailey DM. T'ai chi and postural control in the well elderly. Am J Occup Ther 1991;46:295-300.
64. Forrest WR. Anticipatory postural adjustment and T'ai Chi Ch'uan. Biomed Sci Instrum 1997;33:65-70.
65. Hass C, Gregor R, Waddell D, et al. The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. Arch Phys Med Rehabil 2004;85:1593-8.
66. Wu G, Liu W, Hitt J, Millon D. Spatial, temporal and muscle action patterns of Tai Chi gate. J Electromyogr Kinesiol 2004;14: 343-54.
67. Jadad AR, Carroll D, Moore A, McQuay H. Developing a database of published reports of randomised clinical trials in pain research. Pain 1996;66:239-46.
68. Chan K, Qin L, Lau M, et al. A randomized, prospective study of the effects of Tai Chi Chun exercise on bone mineral density in postmenopausal women. Arch Phys Med Rehabil 2004;85:717-22.
69. Zhou Y. The effect of traditional sports on the bone density of menopause women. J Beijing Sport Univ 2004;27:354-60.
70. Qin L, Au S, Choy W, et al. Regular Tai Chi Chuan exercise may retard bone loss in postmenopausal women: a case-control study. Arch Phys Med Rehabil 2002;83:1355-9.
71. Xu H, Lawson D, Kras A. A study on Tai Ji exercise and traditional Chinese medical modalities in relation to bone structure, bone function and menopausal symptoms. J Chin Med 2004; 74:3-7.
72. Gong M, Zhang S, Wang B, Wang D. Effects of long-term shadowboxing exercise on bone mineral density in the aged. Chin J Clin Rehabil 2003;7:2238-9.
73. Qin L, Choy W, Leung K, et al. Beneficial effects of regular Tai Chi exercise on musculoskeletal system. J Bone Miner Metab 2005;23:186-90.
74. Bassey JE, Rothwell M, Littlewood JJ, Pye JW. Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. J Bone Miner Res 1998;13: 1805-13.

75. Riggs B, Khosla S, Melton L III. Sex steroids and the construction and conservation of the adult skeleton. Endocr Rev 2002;23:279-302.
76. Bonaiuti D, Shea B, Iovine R, et al. Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database Syst Rev 2002;(3):CD000333.
77. Qin L, Au SK, Leung PC, et al. Baseline BMD and bone loss at distal radius measured by peripheral quantitative computed tomography in peri- and postmenopausal Hong Kong Chinese women. Osteoporos Int 2002;13:962-70.
78. Kemmler W, Engelke K, Weineck J, Hensen J, Kalendar W. The Erlangen fitness osteoporosis prevention study: a controlled exercise trial in early postmenopausal women with low bone density—first-year results. Arch Phys Med Rehabil 2003;84:673-82.
79. Wang C, Collet J, Lau J. The effect of Tai Chi on health outcomes in patients with chronic conditions. Arch Intern Med 2004;164:493-501.
80. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. Phys Ther 1993;73:254-62.
81. Wolfson L, Whipple R, Derby C, et al. Balance and strength training in older adults: intervention gains and Tai Chi maintenance. J Am Geriatr Soc 1996;44:498-506.
82. Li F, McAuley E, Harmer P, Duncan T, Chaumeton N. Tai Chi enhances self-efficacy and exercise behavior in older adults. J Aging Phys Act 2001;9:161-71.
83. Sun W, Dosch M, Gilmore G. Effects of a Tai Chi Chuan program on Hmong American older adults. Educ Geronotol 1996;22:161-7.
84. Van Deusen J, Harlowe D. The efficacy of the ROM Dance Program for adults with rheumatoid arthritis. Am J Occup Ther 1987;41(2):90-5.
85. Kutner N, Barnhart H, Wolf S, McNeely E, Xu T. Self-report benefits of Tai Chi practice by older adults. J Gerontol B Psychol Sci Soc Sci 1997;52:242-6.
86. Wilson C, Datta S. Tai Chi for the prevention of fractures in a nursing home population: an economic analysis. J Clin Outcomes Manage 2001;8:19-27.
87. Yeh G, Wood M, Lorell B, et al. Effects of Tai Chi mind-body movement therapy on functional status and exercise capacity in patients with chronic heart failure: a randomized controlled trial. Am J Med 2004;117:541-8.
88. Cauley J. The determinants of fracture in men. J Musculoskelet Neuronal Interact 2002;2:220-1.