REVIEW ARTICLE

Can Tai Chi Improve Vestibulopathic Postural Control?

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ABSTRACT. Wayne PM, Krebs DE, Wolf SL, Gill-Body KM, Scarborough DM, McGibbon CA, Kaptchuk TJ, Parker SW. Can Tai Chi improve vestibulopathic postural control? Arch Phys Med Rehabil 2004;85:142-52.

Objectives: To evaluate the rationale and scientific support for Tai Chi as an intervention for vestibulopathy and to offer recommendations for future studies.

Data Sources: A computer-aided search, including MEDLINE and Science Citation Index, to identify original Tai Chi studies published in English; relevant references cited in the retrieved articles were also included.

Study Selection: A preliminary screening selected all randomized controlled trials (RCTs), non-RCTs, case-control studies, and case series that included Tai Chi as an intervention and had at least 1 outcome variable relevant to postural stability.

Data Extraction: Authors critically reviewed studies and summarized study designs and outcomes in a summary table.

Data Synthesis: Twenty-four Tai Chi studies met screening criteria. No studies specifically studying Tai Chi for vestibulopathy were found. Collectively, the 24 studies provide sometimes contradictory but generally supportive evidence that Tai Chi may have beneficial effects for balance and postural impairments, especially those associated with aging. Ten RCTs were found, of which 8 provide support that Tai Chi practiced alone, or in combination with other therapies, can reduce risk of falls, and/or impact factors associated with postural control, including improved balance and dynamic stability, increased musculoskeletal strength and flexibility, improved performance of activities of daily living (ADLs), reduced fear of falling, and general improvement in psychologic well-being. Studies using other designs support the results observed in RCTs.

Conclusions: At present, few data exist to support the contention that Tai Chi specifically targets the impairments, functional limitations, disability, and quality of life associated with peripheral vestibulopathy. There are, however, compelling reasons to further investigate Tai Chi for vestibulopathy, in part because Tai Chi appears useful for a variety of nonvestibulopathy etiologic balance disorders, and is safe. Especially needed are studies that integrate measures of balance relevant to ADLs with other psychologic and cognitive measures; these might help identify specific mechanisms whereby Tai Chi can remedy balance disorders.

Key Words: Balance; Posture; Rehabilitation; Tai Chi.

VESTIBULOPATHY, OR INNER EAR disease causes whole body dynamic postural control impairments, functional limitations in locomotor activities, disability in typical role activities, and decreased quality of life[1-3] (QOL). Patients with vestibulopathy experience a constellation of problems for which they are often referred to rehabilitation, including unsteady standing and gait and difficulty stabilizing the visual environment during head movement.[4,5] Findings from research on vestibular rehabilitation provide an understanding about the benefits and limitations of vestibular rehabilitation for this patient population.[6] Tai Chi, which purports to improve overall body control, mind-body focus, and psychologic well-being, may offer an alternative or complementary approach to treating vestibulopathy-induced balance dysfunction, but, to date, little such evidence exists to support Tai Chi as an effective intervention for this population.

Tai Chi, also referred to as Tai Chi Chuan and Taijiquan, has its roots in the martial arts; yet, for centuries millions of Chinese have practiced Tai Chi's flowing, meditative movements to cultivate and maintain health and well-being. Numerous anecdotal reports of past and present practitioners claim that Tai Chi exercise has helped cure a diversity of health disorders.[7,8] Considered a treasure of Chinese medicine, Tai Chi is based on the same core principles that underlie acupuncture and Chinese herbal therapies.[9-11] Although acupuncture relies on needle insertion and herbal medicine on phytochemical pharmacology, Tai Chi uses detailed regimens of physical movement, breathing techniques, and cognitive tools (both visualization and focused internal awareness) to strengthen the body, to relax the mind, and to "balance the flow of chi" (life force).[12-14]

Falls and unsteady gait are critical problems in older adults.[15] Tai Chi has been used extensively among older adults, but the benefits of Tai Chi for vestibulopathy are largely unknown. Tai Chi's reputed health benefits, apparent safety, low cost, and growing recognition have resulted in this exercise becoming more prominent as a preventive and rehabilitative therapeutic tool by the Western, allopathic medical community. Recent studies have begun to address the safety and efficacy of Tai Chi as a therapeutic intervention for various health concerns, including postmyocardial infraction,[16] coronary artery bypass surgery cardiac rehabilitation,[17] hypertension,[18] general cardiorespiratory function,[19-23] multiple sclerosis,[24] rheumatoid arthritis,[25] osteoarthritis,[26] microcirculation and endothelial function,[27,28] immune function,[29] dementia,[30] and general stress management.[31-33] These and other Tai Chi uses have been

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reviewed in recent articles by Wolf et al,[34] Sandlund and Norlander,[35] Li et al,[36] Lan et al,[37] and Wu.[38]

The purpose of this review was to evaluate the rationale and scientific support for Tai Chi as an intervention for vestibulopathy. We begin by characterizing the functional and psychologic impairments associated with vestibulopathy and its current management. We then present a rationale for why Tai Chi could be a useful intervention to address vestibulopathy impairments, functional limitations, and disability. Last, we review the evidence that Tai Chi improves postural control and balance in various populations.

Vestibulopathy and Vestibular Rehabilitation

The healthy vestibular system is responsible for stabilizing gaze during head movement, particularly during rapid head movement. Other eye and body stabilizing mechanisms, such as visual and proprioceptive inputs, are available during preplanned or slow movements, but only the vestibulo-ocular reflex (VOR) is typically able to control gaze during rapid ($>100°$/s) head movement. Vestibulopathy symptoms may include oscillopsia during locomotion and head movements, dizziness, and unsteadiness during gait and other functional activities.[39] As with many chronic diseases, vestibulopathy-induced changes in life style and QOL can impact psychologic well-being, which may further limit functional abilities.[40]

Persons with chronic, stable vestibulopathy have either unilateral (UVH) or bilateral vestibular hypofunction (BVH). Individuals with UVH have damage only on 1 side. The chief visual function symptom of people with UVH is decreased gaze stability during ipsilesional head turning. People with UVH sometimes compensate rather well with the remaining intact contralesional vestibular apparatus, while those with BVH function with an overall reduced amount of vestibular information. People with BVH have damage on both sides, although the loss may be asymmetric. The primary visual function symptoms among persons with BVH include decreased gaze stability with all head movements including oscillopsia. Typically, caloric responses and VOR gains (ratio of eye to head movement) are decreased bilaterally in persons with BVH. Among healthy adults, this VOR gain is close to 1.0, that is, eye movements compensate for head movement. People with BVH may have near 0 gains, signifying a near-complete decoupling of eye movement from head displacements. This VOR gain is quite plastic, being suppressed temporarily in spinning dancers and ice skaters, and increased or decreased in subjects wearing Frenzel lenses. Thus, state-of-the-art vestibular rehabilitation programs have taken advantage of this plasticity by attempting to increase VOR gain among people with UVH and BVH. The extent to which improved VOR results in improved gaze stability during functional activities or contributes to balance improvements remains unclear.[41,42]

Vestibular rehabilitation is an exercise program intended to remediate the problems of dizziness, gaze instability, and balance disturbances caused by damage to the vestibular system. Although common elements of vestibular rehabilitation include (1) eye-head coordination exercises to reduce gaze instability and dizziness and (2) balance retraining exercises to reduce balance impairments, various forms of vestibular rehabilitation are in use today.[4,5,43-48] One approach was originally described by Cawthorne[45] and Cooksey[46] in the 1940s for patients with persistent vestibulopathy symptoms. This Cawthorne–Cooksey vestibular rehabilitation approach includes general eye-and-head exercises, total body movements, and balance activities that are performed repeatedly by the person on a daily basis. These exercises are not tailored to an individual's symptoms. A second vestibular rehabilitation approach more recently described by Herdman,[49] Shumway-Cook and Horak,[50,51] and Krebs et al,[3,4] is focused on individualized balance retraining and on improving the gain, phase, and symmetry of the VOR. This approach attempts to achieve central nervous system (CNS) compensation with exercises that enhance VOR adaptation (when some remaining vestibular function exists) and vestibulospinal reflexes. This vestibular rehabilitation program is individually tailored for each individual based on the person's signs, symptoms, functional limitations, and amount of remaining peripheral vestibular function. The VOR-focused vestibular rehabilitation program has 2 important specific features. First, it includes exercises that promote gaze stability during both quiet standing and dynamic functional activities. One typical exercise is having a patient focus on reading a short printed word on a piece of paper held at arm's distance while moving the head side to side several times and then up and down several times. This activity is repeated at different speeds and with various-sized fonts. This and other gaze stability exercises are performed with progressing levels of difficulty; that is, the sitting position followed by standing with a narrow base of support followed by marching in place and walking. The second feature is balance retraining that incorporates the use of various sensory cues for postural control. An example of this feature is the practice of maintaining balance during standing or walking with eyes open (which requires enhanced use of somatosensory and vestibular inputs for postural control) or on a foam surface (which requires enhanced use of visual and vestibular inputs). Presently, evidence supports the usefulness of vestibular rehabilitation for persons with vestibulopathy, but limited evidence supports the long-term effects of vestibular rehabilitation on function.[5,41,43,47-52]

In the current health care environment, vestibular rehabilitation typically ends because patients either show a plateau in improvement or health insurance coverage limits the number of vestibular rehabilitation visits provided. Although there are reports of improved function after vestibular rehabilitation,[3,4] often the optimization of functional recovery is not observed or documented. Current health care restrictions have led many patients whose vestibular rehabilitation is stopped to seek help from other sources, such as fitness centers and alternative medicine therapies. Recent studies addressing the potential benefits of Tai Chi for older people's balance and overall health suggest that Tai Chi is worth exploring as a complement or alternative way to help patients with vestibulopathy reach their full functional potential.

Tai Chi for Whole Body Postural Control and Balance Impairment

The concept of balance is at the heart of the yin-yang, or tai chi symbol ☯. Phrases from historical Tai Chi classics such as—"suspend the spine like a string of pearls from heaven" and "stand like a balance and move like a cartwheel"[53]—reflect inherent, sophisticated insight into human biomechanics. The movements of Tai Chi are practiced at a slow, gentle, and continuous pace. A primary goal of Tai Chi is relaxation of the body and the mind. Even the eyes are relaxed, using a nonfocused gaze with the "eyelids half closed like curtains."[54] Levandoski and Leyshon,[55] Tse and Bailey,[56] Wolf et al,[34] and Li et al[36] identified a number of characteristics of Tai Chi practice that might make it an effective therapy for postural control and balance. These intended characteristics, and their purported effects, include (1) a continuous, slow, even tempo facilitates sensory awareness of the speed, force, trajectory, and execution of movements, as well as awareness of the external environment; (2) an emphasis on maintaining a vertical posture with an extended head and trunk position promotes a less flexed posture; (3) a constant shifting of weight from 1 leg to the other facilitates improved dynamic standing balance and lower-extremity strength; (4) the use of different parts of the body taking turns playing the role of stabilizer and mover enables movements to be executed smoothly without compromising balance and stability; (5) the symmetrical and diagonal arm movements of Tai Chi promote arm swing in gait and increase trunk rotation around the waist; (6) moderate knee flexion lowers the body's center of gravity; and (7) flowing circular and spiraling movements promote joint flexibility. Because so many of the fundamental principles of Tai Chi directly relate to issues of postural control, and because cost-effective therapies for balance training are needed, especially for older adults[57] and those with balance impairment, researchers have begun to address scientifically the extent to which Tai Chi improves postural balance and function, and are also studying biomechanic, physiologic, and psychologic mechanisms underlying balance improvements.[38,58]

METHODS

We performed a literature search with the use of MEDLINE and Science Citation Index using the key words *Tai Chi* and *Taijiquan*. The searches were restricted to the English language, and covered the period January 1966 through June 2002. A manual search through the bibliographies of retrieved research and review articles was also conducted. Only empirical studies that included at least 1 outcome relevant to postural control were included. This search revealed 10 randomized controlled trials (RCTs) and an additional 14 non-RCTs or uncontrolled prospective or cross-sectional Tai Chi studies. These 24 studies are summarized in table 1; the RCTs are discussed in more detail below. In the literature review section that follows, all results discussed are statistically significant ($P \leq .05$) unless noted otherwise.

Literature Review Results

RCTs with outcomes relevant to postural control. Wolf et al[59] conducted a large sample ($N=200$) RCT evaluating the efficacy of Tai Chi in balance training and fall prevention. The study, which focused on community-dwelling older adults, compared the efficacy of 15 weeks of Tai Chi instruction with computerized balance training and education. The Tai Chi intervention included 10 movements from the traditional Yang style. Tai Chi instruction was administered in weekly, 45-minute group classes. Balance training was done with a computerized balance system that had force transducers and a visual cursor that prompted the subject to move his/her center of mass without foot displacement. Over the course of the intervention, sway and floor movement were progressively increased to the limits of postural stability. The education groups were instructed not to change their exercise regimens and met weekly to discuss gerontologic and health-related issues. Balance-related outcome measures included occurrence of falls (monitored for a minimum of 7mo and a maximum of 20mo), fear of falling, strength (knee, hip, ankle, handgrip), and lower-extremity flexibility. Results indicated that, after adjusting for fall risk factors, compared with balance training and education, Tai Chi delayed the onset of first or multiple falls by 47.5%. Fear of falling measures were also reduced to a greater extent in the Tai Chi versus education group. No significant changes in lower-extremity strength or flexibility were observed. In a companion study, Wolf et al[60] explored elements of postural stability associated with decreased fall probabilities in a subset of the original study sample. Platform balance measures revealed greater static stability after training for balance training, but not Tai Chi or education. They concluded that Tai Chi does not improve static postural stability, and Tai Chi may gain its success in preventing falls by means other than reductions in sway-based measures. The results and experience from these studies have been used to design a phase III, 2-arm RCT comparing the efficacy of intense Tai Chi training (48wk) versus a wellness education program for reducing falls in older adults.[61]

Jacobson et al[62] conducted a 12-week RCT comparing a Tai Chi intervention with a nonexercise control group. Participants were healthy, young, Tai Chi–naive volunteers. The Tai Chi intervention included 3 classes weekly (1.0–1.5h), during which subjects were taught the entire 108-movement, Yang-style form. Control group participants agreed to not engage in resistance training and activities dependent on balance. Outcomes measured at baseline and at 12 weeks included lateral body stability (stability platform test), isometric muscular strength of dominant knee at 90°, and kinesthetic sense of the glenohumeral joint at 30°, 45°, and 60°. Improvements between pre- versus posttests in lateral stability and balance were greater in the Tai Chi group versus control group, as were improvements in knee strength. Improvements in the kinesthetic sense of the glenohumeral joint at 60° (but not at 45° or 30°) were also greater for the Tai Chi versus control group. The investigators argued that lack of improvement in kinesthetic sense at the more acute angles was justified because the Tai Chi form did not regularly include these angles of rotations.

Hartman et al[26] investigated the benefits of Tai Chi for older adults with osteoarthritis. The benefits of a Yang-style (9-form) Tai Chi intervention, including two 1-hour classes for a 12-week period, was compared with a control group that met socially on 3 occasions and were regularly contacted by telephone to discuss osteoarthritis issues. Balance-related outcomes included 1-leg stand time, 50-ft (15-m) walking speed, and time to rise from a chair. Results indicated that Tai Chi, but not control, participants exhibited moderate improvements for these 3 outcomes; differences between groups were not statistically significant. Li et al[63] conducted an RCT with older individuals comparing the benefits of a 6-month Tai Chi intervention (Yang-style 24-step) with a wait-list control group. Results of a 6-item self-reported physical functioning scale, a subset of the Medical Outcomes Study 20-Item Short-Form Health Survey, suggested that the Tai Chi group improved significantly more than the control group across a range of functional activities, including walking, lifting, and activities of daily living (ADLs), such as eating, dressing, and bathing. Finally, Sun et al[64] reported that subjects in a 10-week Tai Chi intervention, but not in a control group, improved shoulder and knee, but not trunk, flexibility among older Hmong Americans.

Four additional RCTs have evaluated the value of adding Tai Chi to other therapies. Judge et al[65] conducted a 6-month, 2-arm RCT with older women to test the hypothesis that a vigorous exercise program that was performed frequently and included resistance training, brisk walking, and flexibility, and postural control exercises (combined training) would be superior to a program that was performed once a week and included only flexibility and postural control exercises (flexibility training). Simplified Tai Chi movements constituted 1 component of the flexibility exercises for each arm. Outcome measurement included double- and single-standing tests performed on a force platform. The mean displacement of the center of pressure in single-limb standing improved 18% in the combined training group but did not change in the flexibility-only training group. Differences in trends between groups were not statistically significant when analyzed with a repeated-measure analysis of

Table 1: Summary of Tai Chi Studies That Include Outcomes Related to Postural Stability

Study	Design	Interventions	Sample Size and Age	Subject Health	Balance-Related Outcome Measures	Results
Wolf et al[59]	RCT	• Tai Chi, YS, 10 movements (TC) • Computerized balance training (BT) • Education, nonexercise control (ED) All IN 1h/wk for 15wk	TC: n=72 BT: n=64 ED: n=64 Avg age=76.2y	Healthy	• Occurrence of falls (monitored a minimum of 7mo, maximum of 20mo) • Strength (knee, hip, ankle, grip) • Flexibility (lower-extremity ROM) • 12-min walk • Fear of falling • Instrumental ADLs (IADLs)	• TC (vs BT and ED) delayed onset of first or multiple falls by 47.5% • TC (vs ED) reduced fear of falling • Grip strength declined slower in TC (vs BT and ED) • Trend toward greater IADL improvement in TC (vs ED) (*P*=.058)
Wolf et al[60]	RCT	• Tai Chi, YS, 10 movements (TC) • Computerized balance training (BT) • Education, nonexercise control (ED) All IN 1h/wk for 15wk	TC: n=24 BT: n=24 ED: n=24 Avg age=76.8y Note. Subjects were a subset of Wolf[59]	Healthy	• Platform balance measures of COB in 4 conditions: (1) quiet standing EO; (2) quiet standing EC; (3) angular perturbation EO; (4) angular perturbation EC.	• BT (vs TC and ED) reduced dispersion index during conditions 3 and 1; and COB in ML axis during condition 3 and in AP axis during condition 1.
Jacobson et al[62]	RCT	• Tai Chi, YS, 108 movements (TC) (three 1/2-h sessions/wk for 12 wk) • Nonexercise control (C)	TC: n=12 C: n=12 Avg age=30.4y	Healthy	• Lateral stability (stability platform test) • Isometric strength of dominant knee at 90° • KS of glenohumeral joint at 30°, 45°, and 60°	• TC (vs C) increased lateral stability and balance • TC (vs C) improved knee strength • TC (vs C) improved KS in glenohumeral joint at 60°
Hartman et al[26]	RCT	• Tai Chi, YS, 9 movements (TC) (two 1-h sessions/wk for 12wk) • Nonexercise control (C) (social gatherings+education)	TC: n=18 C: n=15 Avg age=30.4y	Osteoarthritis	• 1 leg standing time • 50-ft walking speed • Time to rise from chair	• Trends toward greater improvement in TC vs C in standing time (*P*=.054), walking speed (*P*=.086), and chair rise time (*P*=.084)
Li et al[63]	RCT	• Tai Chi, YS, 24 movements (2 times/wk for 24wk) • Control (not described) (C)	TC: n=49 C: n=45 Avg age=72.8y	Healthy	• Physical functioning scale (subset of SF-20)	• TC functional status improved more than control at 12wk and 24wk
Sun et al[64]	RCT	• Tai Chi* (ten 2-h sessions, 1 times/wk +education) • Wait list control (C)	TC: n=10 C: n=10 Avg age=66.75y	Healthy	• TC Program Inventory Instrument including knowledge and expectations of TC, perceived stress, heart rate, BP, skin temperature, and goniometry	• TC (vs C) increased flexibility in knee and shoulder; trend in increased flexibility in trunk (*P*=.0767) • TC (vs C) reduced self-perceived stress, skin temperature assessment of stress, resting systolic BP and diastolic BP
Judge et al[65]	RCT†	• Combined strength training+brisk walking+flexibility (including TC-like movements*) (COMB) (3 sessions/wk for 6mo) • Flexibility (including TC-like movements*) (FL) (3 sessions/wk 3mo)	COMB: n=12 FL: n=9 Avg age=72.8y	Healthy	• Variety of double- and single-stance tests of center of force (sway) on a force platform with EO and EC	• COMB improved in single-stance tests, but trend not significantly different than FL

Table 1 (Cont'd): Summary of Tai Chi Studies That Include Outcomes Related to Postural Stability

Study	Design	Interventions	Sample Size and Age	Subject Health	Balance-Related Outcome Measures	Results
Van Deusen and Harlowe[66]	RCT	• Tai Chi–like dance program* (TC) (90 min/wk for 8wk) • Wait-list control (with reading) (C)	TC: n=17 C: n=16 Avg age=56y	Rheumatoid arthritis	• ROM of upper and lower extremities • 5-point rating scale on enjoyment of exercise and rest	• TC (vs C) greater increases in shoulder flexion, shoulder rotation, elbow and wrist flexion, ankle plantarflexion, and hip, knee, and ankle dorsiflexion • TC greater enjoyment during exercise and rest
Nowalk et al[67]	RCT	• Fit NB Free (FNBF) (individual strength+ conditioning) • LL/TC (group fear behavior modification+TC* • Basic Enhanced Program (C) (education control) FNBF and TC sessions 3 times/wk for 13–28mo	FNBF: n=38 TC: n=37 C: n=35 Avg age=76.8y	Healthy	• Time to first fall • Incidence of falls • Time to death • Number of days hospitalized • Chair rise stand time • Walk time (20ft) • Grip strength • IADL	• LL/TC rate of fall 17% lower than C, but trend NS • All other outcomes NS between groups
Wolfson et al[68]	RCT†	• Strength training (ST) • Balance training (BT) • Balance+strength training (BS) • Education control (C) • Tai Chi administered for maintenance beginning at 3mo for 6mo (YS, 37 movements, 1h, 1/wk)	ST: n=28 BT: n=28 BS: n=27 C: n=27 Avg age=79.8y	Healthy	• Loss of balance during SOT • Functional base of support • Single-stance time • Lower-extremity isokinetic strength • Gait velocity	• Pre- vs post-TC maintenance phase measures suggest balance gains in SOT remained stable across groups, but gains in function, base of support, and stance times declined
Yan[75]	PNRCT†	• Tai Chi: YS, 24 movements (TC) • Locomotor activity (C) All IN 45min, 3 times/wk for 8wk	TC: n=28 C: n=10 Avg age=79.0y	Healthy	• Stability platform balance measures (no details given) • Arm movement variability	• TC improved time on balance more than C • TC increased arm control more than C
Yan[76]	PNRCT	• Tai Chi: YS, 24 movements (TC) • Locomotor activity (C) All IN 45min, 3 times/wk for 8wk	TC: n=12 C: n=8 Avg age=79.4y	Healthy	• Arm movement force output during linear and curvilinear tasks	• TC reduced variability in curvilinear arm movement force
Lan et al[23]	PNRCT	• Tai Chi: YS, 108 movements (TC) (daily practice, 12mo) • Age- and health-matched control group (C)	TC: n=20 C: n=18 Avg age=65.5y	Healthy	• Knee extensor and flexor strength • Thoracolumbar flexibility	• TC increased knee extensor strength and flexor strength more than control • TC increased thoracolumbar flexibility more than control
Schaller[70]	PNRCT	• Tai Chi Chih, 20 form (TC) (1h/wk for 10wk) • Control: maintain usual level of activity (C)	TC: n=24 C: n=22 Avg age=70.0y	Healthy	• Single-leg stance time, EO, and EC • Modified sit-and-reach test	• TC (vs C) improved balance time with EO • TC (vs C) sit-and-reach test (NS)
Lan et al[77]	PNCT	• Tai Chi: YS, 108 movements (TC) (daily practice, 6mo)	TC: N=20 Avg age=61.1y	Healthy	• Knee strength: concentric extensor peak torque, eccentric peak torque, and endurance ratio	• TC increased knee concentric peak torque, eccentric peak torque, and endurance ratio

Table 1 (Cont'd): Summary of Tai Chi Studies That Include Outcomes Related to Postural Stability

Study	Design	Interventions	Sample Size and Age	Subject Health	Balance-Related Outcome Measures	Results
Shih[78]	PNCT	• Tai Chi: YS, 24 movements (TC) (3 times/wk for 16wk)	N=11 Avg age=30.8y	Healthy	• Force platform measure of sway velocity during static and dynamic tests	• TC reduced avg sway velocities in AP direction during dynamic, but not static balance tests
Forrest[79]	PNCT	• Tai Chi (TC) (16wk; no information on frequency)	N=8 Avg age=36.5y	Healthy	• Balance platform measures of APA and COP	• TC reduced APA of certain muscles and decreased COP movement during load dropping in both AP and ML planes
Hain et al[73]	PNCT	• Tai Chi: Combination of Yang, Wu, and Pa Kua styles • 1 time/wk for 8wk	Total N=22 Age range, 20–60y (n=6) Age range, 61–75y (n=7) Age >75y (n=9)	Mild balance disorder	• Balance platform tests (SOT) • Romberg tests • Reach test • DHI • SF-36	• TC improved posturography during SOT • TC improved tandem Romberg scores • TC improved DHI scores • TC improved SF-36 scores
Husted et al[24]	PNCT	• Tai Chi* (TC) 8wk (no information on frequency)	N=19	Multiple sclerosis	• Walking speed (25ft) • Hamstring flexibility • SF-36	• 21% increase in walking speed • 28% increase in hamstring flexibility (no statistical analyses)
Ross et al[71]	PNCT	• Tai Chi* (TC) 8wk (no information on frequency)	N=11	Healthy	• Goniometry (elbow, shoulder, knee, hip) • Single-leg stance time • Heel-to-toe walking	• All participants showed some improvement in all measures, but no trends were statistically significant
Hong et al[81]	CSS	• Tai Chi: YS 108 movements (TC) • Age-matched sedentary control (C) Avg 13.2y TC experience	TC: n=28 C: n=30 Avg age=66.7y	Healthy	• Single-leg stance times, EC • Sit-and-reach test • Total body rotation	• TC (vs C) greater single-stance times with EC, but not EO • TC (vs C) greater sit and reach • TC (vs C) greater body rotation
Tse and Bailey[56]	CSS	• Tai Chi* (TC) • Age-matched sedentary control (C) Range of 1–20y TC experience	TC: n=9 C: n=9 Age range, 68–86y	Healthy	• Single-leg stance times, EO, and EC • Heel-to-toe walking	• TC greater single-stance time with EO • TC greater heel-toe distance
Lan et al[22]	CSS	• Tai Chi: YS (TC) • Age-matched sedentary control (C) Avg 11.8y TC experience	TC: n=41 C: n=35 Age=68.5y	Healthy	• Thoracolumbar flexibility	• TC greater thoracolumbar flexibility
Wong et al[80]	CSS	• Tai Chi* (TC) • Age-matched sedentary control (C) Avg 15.6y TC experience	TC: n=25 C: n=14 Age=68.9y	Healthy	• Platform balance SOT	• TC greater maximal stability • TC better avg velocity of COG

NOTE. All results are statistically significant ($P \leq .05$) unless noted otherwise. Marginally significant results are followed by *P* values.
Abbreviations: AP, anteroposterior; APA, anticipatory postural adjustment; Avg, average; BP, blood pressure; COB, center of balance; COG, center of gravity; COP, center of pressure; CSS, cross-sectional study; DHI, Dizziness Handicap Inventory; EC, eyes closed; EO, eyes open; FNBF, Fit NB Free; IN, intervention; KS, kinesthetic sense; LL/TC, Living and Learning/Tai Chi; ML, mediolateral; NS, nonsignificant ($P > .05$); PNCT, prospective, noncontrolled trial; PNRCT, prospective, non-RCT; SF-20/SF-36, Medical Outcomes Study 20-Item/36-Item Short-Form Health Survey; SOT, Sensory Organization Test; TC, Tai Chi; YS, Yang style.
*No information given on TC intervention.
†TC intervention included in all groups.

variance. Van Deusen and Harlowe[66] conducted an RCT in which participants with rheumatoid arthritis were included in a therapeutic dance program that combined elements of Tai Chi with occupational therapy; they compared this intervention with wait-listed participants. The Tai Chi–like intervention included dancing, with an emphasis of flowing, relaxed movement, postural awareness, breathing, and visualization. Instruction was provided in a group format over an 8-week period (90min/wk). Participants were given an audiotape and illustrated instructions for home practice and were encouraged to practice daily. Outcome measures, which included joint range of motion (ROM) and a 5-point exercise rating scale that assessed functional benefits and enjoyment of exercise and rest, were made before, immediately after, and 4 months after the intervention. At 4 months, 3 of 4 ROM measures in the upper extremities were significantly better in the active intervention as compared with control subjects. Lower-extremity ROM was also significantly greater in the active intervention group at week 8, but not at 4 months. Compared with the control group, the dance group also expressed significantly greater enjoyment during exercise and rest.

Nowalk et al[67] conducted a 3-arm RCT to test whether exercise programs would reduce falls and fall sequelae among residents of long-term care facilities. Older individuals were randomized into 1 of 2 exercise programs or a control group. The Fit NB Free (FNBF) group received individualized, progressive strength training combined with conditioning (treadmill, bicycling) 3 times weekly. The Living and Learning/Tai Chi (LL/TC) group included 2 components. The LL module focused on modulating fear of falling by using behavioral and psychotherapeutic methods and met once per month. The Tai Chi intervention met 3 times weekly. A program called the Basic Enhanced Program, served as a control; subjects in this group participated in 3 educational and therapeutic programs and were not allowed to participate in study-related exercise programs. Enrollment took place over 15 months, and all interventions were offered for 28 months. Consequently, subjects could participate in the intervention for 13 to 28 months, depending on enrollment date. Rates of falls were 72%, 58%, and 75% in the FNBF, LL/TC, and control groups, respectively. The 17% lower fall rate in the LL/TC group versus control group was not statistically significant. Time to first fall, time to death, and number of days hospitalized also did not differ significantly between groups nor among any other physical or cognitive outcomes. Finally, Wolfson et al[68] conducted a 4-arm RCT that compared the efficacy of balance training, strength training, balance plus strength training, and an educational control for balance in older adults. After each of these interventions, subjects also participated in a 6-month Tai Chi maintenance program. Comparisons of measurements made before and after the Tai Chi maintenance phase suggest that many, but not all, of the gains in postural stability resulting from balance and strength training were maintained during the Tai Chi maintenance intervention.

Psychologic Responses to Tai Chi

A few studies have provided some information regarding the relationship between Tai Chi, psychologic well-being, and postural control. Wolf et al[59] reported that Tai Chi training significantly reduced fear of falling. A multivariate model suggested that fear of falling was a strong predictor of subsequent falls. This study also reported near-significant trends on an intrusiveness instrument, suggesting that Tai Chi increased subject's sense of being able to do all the activities that they would like to. A subset of participants in this trial also participated in a qualitative exit interview to assess perceived benefits of participation in the study.[69] Both Tai Chi and balance training participants reported increased confidence in balance and movement, but only Tai Chi participants reported that their daily activities and overall lives had been affected. Approximately 50% of these participants subsequently enrolled in Tai Chi classes. Kutner et al[69] concluded that when mental and physical control are perceived to be enhanced, with a generalized sense of improvement in overall well-being, older persons' motivations to continue exercising might also increase. In another RCT evaluating the effect of exercise and exercise plus cognitive strategies on psychologic health, Brown et al[33] found that women (but not men) in a 16-week Tai Chi–type program experienced significant reductions in tension, depression, anger, confusion, and total mood disturbance and significant improvement in general mood. In contrast, Schaller[70] found no improvement in mood after 10 weeks of Tai Chi. Ross et al[71] also reported that Tai Chi significantly improved composite scores on the Multiple Affect Adjective Check List. Jin[32] measured hormonal levels indexing stress and mood states before, during, and after participating in a Tai Chi session for experienced Tai Chi practitioners. Relative to measures taken beforehand, Tai Chi raised heart rate, increased noradrenaline excretions in urine, and decreased salivary cortisol concentration. Participants also reported less tension, depression, anger, fatigue, confusion, and state anxiety. Sun et al[64] reported that Tai Chi reduced self-preceived stress scores (self-designed Tai Chi Program Inventory) and stress assessed by skin temperature. In the RCT by Van Deusen and Harlows[66] the Tai Chi–dance group expressed significantly greater enjoyment during exercise and rest, compared with control group. Finally, in a companion study to Li et al,[63] the effects of Tai Chi on perceptions of personal efficacy and exercise behavior were evaluated.[72] Self-efficacy outcomes included 2 components. A barriers scale characterized subjects' self-perception of ability to do Tai Chi, and a time-based performance-efficacy scale assessed their confidence to perform certain qualities of movements continuously for various lengths of time. Participants in the Tai Chi group experienced significant improvements in self-efficacy over the course of the intervention, and changes in efficacy were associated with higher levels of program attendance. Li concluded that self-efficacy can be enhanced through Tai Chi and that the changes in self-efficacy are likely to improve exercise adherence.

DISCUSSION

Our review of the literature suggests that few reports specific to the application of Tai Chi for patients with vestibulopathy exist. There is limited, sometimes contradictory but generally supportive, evidence that Tai Chi may have beneficial effects on balance and postural impairments associated with aging. Of the 24 studies we reviewed, 20 (83%) reported significant beneficial effects (ie, at least 1 significant outcome) of Tai Chi on reducing falls or in improving parameters associated with falls, such as balance, strength, or flexibility (see table 1). Analysis of the results of prospective RCTs in particular supports the conclusion that Tai Chi may have beneficial effects on postural control. Of the 10 RCTs reviewed, 8 provide support that Tai Chi practiced alone, or in combination with other therapies, can reduce risk of falls,[59,60] and/or positively impact factors associated with postural control, including fear of falling,[59,60] static and/or dynamic balance,[62,65,68] strength,[59,62,65,68] flexibility,[64,66,68] and performance of ADLs.[63,64,66,68] Of the remaining 2 RCTs, one reported near significant trends (*P* range, .056–.84) on static single-leg balance, walking speed, and chair-rise speed.[26] Only 1 RCT, conducted by Nowalk et al,[67] reported clear, statistically nonsignificant negative results for all outcomes. These negative outcomes may result from a number of factors specific to their study. First, their participants were older than in any of the other studies we reviewed (average age, 84.7y). Second, the mean score of participants on the Mini-Mental State Examination during enrollment was 25.3, reflecting a relatively low level of cognitive function. Nowalk acknowledged that reduced cognitive function might have made concentrating, and thus learning and remembering Tai Chi techniques, more challenging. Third, overall adherence in the Nowalk study was low (mean, 40%), and was particularly low in the Tai Chi intervention (≈25%), yet this variability in adherence was not accounted for in analyses. With these limitations in mind, a 17% reduction in fall risk among the Tai Chi group is noteworthy.

Collectively, the results of the studies reviewed suggest that Tai Chi may improve balance, especially in the elderly. Their relevance to vestibulopathy, however, and to postural control in general must be interpreted cautiously for a number of reasons discussed below.

Relevance of Tai Chi Studies to Date for Patients With Vestibulopathy

The vast majority of balance-related Tai Chi studies we have cited focused on older and/or frail adults without a specific diagnosis of vestibular disease. Only 4 studies[59,60,67,73] specifically mention fall history or balance problems among the recruited participants. Only 1 study[73] included younger subjects with balance impairments, and it did not report specific causes of impairments. Some proportion of the older adults whose balance improved from participation in Tai Chi studies we reviewed may have had undiagnosed vestibular dysfunction. However, the evidence suggesting that older adults have decreased vestibular function is limited and contradictory. Although the number of cochleovestibular axons or cell bodies may indeed decrease with age, aging patients are rarely diagnosed with frank vestibulopathy. Perhaps this is because of the plasticity of the CNS, but it could as well signify the extremely small impact the vestibular system has on the slow, deliberate movements typical of older persons. Only from the results of future Tai Chi trials that explicitly enroll older patients with and without vestibulopathy will we be able to evaluate the benefits of Tai Chi for vestibulopathy versus general, presbyopic balance, and postural impairments.

Design Limitations of Studies to Date and Considerations for Future Tai Chi–Vestibulopathy Studies

Both the types of, and the great variability in, outcome measures across studies published to date limit our ability to evaluate the efficacy of Tai Chi for vestibulopathy, and for balance impairment in general. Of the studies summarized in table 1, 2 directly monitored fall frequency, 6 assessed static balance tests (eg, single-leg standing time), 12 dynamic stability, 4 gait speed, 9 flexibility, 6 strength, 2 fear of falling, and 7 impacts on ADLs and QOL. This heterogeneity of outcome measures makes it very difficult to make comparisons between studies or to draw broader generalizations across all studies. Further, few studies have made the coordinated measurements of multiple outcome variables that enable one to analyze relationships between outcomes. An exception is the work done by Wolf et al.[59,60,69] These studies included concomitant measures of dynamic stability, strength, flexibility, fear of falling, QOL, and ADLs. This broader, multivariate approach allowed for modeling that revealed the somewhat unexpected result that Tai Chi reduced the probability of falling through means other than reductions in sway velocity, including modulating fear of falling. In a recent review, Wu[38] also noted the marked variability in outcome measures used in Tai Chi studies, and its impact on limiting generalizations. Paralleling a trend of poor experimental designs in complementary and alternative medicine research in general,[74] many of the studies we reviewed relied on designs that significantly limit inference. Of the 24 studies included in this review, only 10 were prospective RCTs. Ten additional prospective studies either did not involve randomization[23,70,75,76] or simply did not include a control group.[24,71,73,77-79] The remaining trials were cross-sectional studies.[22,56,80,81] Additionally, sample sizes in the RCTs were relatively small, ranging from 20 to 200 (mean, 71.7; median, 52.5), and were even smaller in non-RCT studies (mean, 30.1; median, 21.0).

The duration of the Tai Chi interventions varied considerably across studies. Prospective studies ranged from 8 weeks to 1 year, and cross-sectional studies included participants with experience ranging from 1 to 35 years. There is no consensus in the Tai Chi literature as to how long or intensively one needs to practice to benefit from Tai Chi. Wu[38] noted that, across both prospective and cross-sectional studies, some balance-related outcomes such as single-leg stance time with eyes closed were greater in studies that involved participants with longer durations of Tai Chi training. We also found significant variability in the content of Tai Chi interventions. Studies relied on grossly different styles of Tai Chi (eg, Yang vs Wu vs Tai Chi Chih), and within a style also differed in the particular forms they have used. For example, studies that relied on the Yang style variously employed 108, 37, 24, and 9 movement forms, or they extracted subsets of movements from these systems to be practiced in novel sequences. Eight studies did not provide information on the style of Tai Chi practiced,[24,56,63,64,71,79,80] and 4 studies simply stated that they included Tai Chi–like movements, giving little or no detail of the specific content included in the intervention.[33,65-67] Moreover, a number of studies mentioned the inclusion of ancillary exercises that preceded (warm-up) and/or followed (cool-down) practice of Tai Chi forms, with little or no description of these exercises. Given that little research is available to evaluate the potential advantages and disadvantages of different Tai Chi styles and forms, and of the additive or synergistic value of ancillary exercises, direct comparisons between studies, and generalization across studies should be made cautiously. Future Tai Chi–vestibulopathy studies should be explicit about the content of ancillary exercises and their relevance to the therapeutic intervention.

Finally, few studies provide any detailed information on the experience or qualifications of Tai Chi instructors, and only 1 study[63] of the 10 RCTs reported using more than 1 Tai Chi instructor. Because Tai Chi interventions can include many qualitative components, including imagery, philosophy, encouragement, and even the apparent embodiment of Tai Chi principles, it is likely that individual personalities play a key role in the success or failure of an intervention. A sample size of only 1 instructor essentially creates the problem of pseudoreplication—the effects of the instructor cannot be separated from the effects of the intervention. Future studies should include multiple instructors in both Tai Chi and control groups to account for, and possibly characterize the relationship between, instructor traits such as experience and personality, and the success of an intervention.

Elements of Tai Chi That May Improve Vestibulopathy Patients

Despite the lack of empirical evidence from Tai Chi studies conducted with vestibulopathy patients, it is useful to speculate on the mechanisms by which Tai Chi might improve function in vestibulopathy patients, because this speculation may help design future studies. A key component of vestibular rehabilitation is improving VOR in persons who have gaze instability. In VOR training, relatively rapid eye movement exercises are emphasized. In contrast, Tai Chi emphasizes maintaining a relaxed, nonfocused gaze during practice of many styles of Tai Chi. Thus, improvements in dynamic postural stability related to Tai Chi are not likely to be facilitated by improved VOR–mediated gaze stability. However, only future Tai Chi–vestibulopathy trials that monitor eye-head stability during Tai Chi practice and characterize VOR function before and after Tai Chi interventions will be able to test this hypothesis.

In contrast, the Tai Chi–related improvements reported in musculoskeletal strength,[22,23,59,62,77] flexibility,[23,62,64,66,77] limb control and kinesthetic sense,[62,75,76] and single-stance times[56,65,70,73,75,81] may provide mechanisms that bypass the rapid, demand-oriented, typical function of the VOR, emphasizing proprioceptive and CNS adaptations. Improved strength, flexibility, and single-stance times, for example, have been correlated with improved dynamic postural stability and reduced falls.

Interestingly, in studies where dynamic measures of balance were directly assessed, results have been contradictory. For example, some studies suggest Tai Chi reduces measures of sway,[78,80] whereas others suggest that postural stability during dynamic testing is not improved.[60,79] Wolf et al[60] suggested that Tai Chi might gain its success by preventing falls by training older trainees to sway with the perturbation rather than to resist it by limiting sway. Forrest[79] hypothesized that Tai Chi leads to greater use of elasticity of the peripheral structures, suggesting that Tai Chi may be affecting biomechanics and neuromuscular control in fundamentally different ways than other vestibular rehabilitation interventions.

Tai Chi's emphasis on mental concentration may provide another mechanism by which it can improve postural control. Tai Chi encourages practitioners to be very focused and concentrate when practicing, and by doing so they exclude other distractions and stressors, and improve their awareness of their body and its movements.[35,55,60] A growing body of evidence suggests that attentional control may be an important factor in posture and gait.[82] For example, older adults challenged with cognitive demands take longer to recover from postural perturbations than those without simultaneous cognitive demands.[82] Moreover, these effects are greatest for older persons with balance impairments.[83] One possible mechanism by which Tai Chi could improve vestibulopathy is through focused attention. This notion could be tested in a Tai Chi–vestibulopathy study that included a dual-task paradigm.

Another mechanism by which Tai Chi may improve vestibulopathy patients' postural control is through improved overall mood, optimism, and expectancy. Long-term chronic health problems and limited ADLs, such as those associated with vestibulopathy, may lead to poor psychologic profile, with further negative feedback on function.[40] Among transitionally frail older adults, Kressing et al[84] found an association between fear of falling and depression. Results from many studies suggest that physical exercise promotes emotional health and psychologic well-being.[85-88] In this review, we summarized 8 studies that reported positive psychologic responses to participating in a Tai Chi intervention; 6 of the 8 studies also characterized outcomes related to postural control. Only 1 study reported fear of falling[59,60] and one the Dizziness Handicap Inventory,[73] which includes some psychologic and ADL questions related to balance; in both cases, Tai Chi improved survey scores. Only 1 of the 8 studies[60] showed quantitative relationships between psychologic behavior and balance-related measures.

The rapidly expanding field of mind-body medicine has clearly shown that the mind and the health of the physical body are integrally interconnected.[89-91] Our thoughts and beliefs may influence a broad range of health-related phenomena including immune function,[92] cardiovascular disease,[93] pain management, and life expectancy with cancer.[94] There is evidence suggesting that some of the positive emotional gains resulting from exercise may not result directly from an increase in physical fitness, but may be because of the psychologic gains from the expectancy or experience of trying to get fit, or believing that one is fit.[88,95-97] In 2 studies by Jin,[31,32] in which Tai Chi was found to reduce anxiety and improve various components of mood, improved psychologic well-being was thought to be partially accounted for by subject's high expectations about gains from Tai Chi. More broadly, Kaptchuck[98] has proposed that therapies involving complementary and alternative medicine rituals, beliefs, imagery, and alternative conceptions of meanings of self and health may provide "enhanced" placebo effects, beyond the magnitude of placebo effects normally associated with mainstream therapies. This may especially apply to Tai Chi, which incorporates unique metaphors of vital energy, nature's restorative power, and the potency of mind-body interaction. Such constructs have the potential to modify significantly a subject's beliefs and expectations, which, in turn, may contribute to a robust nonspecific effect and healing in general.

Although the Tai Chi studies we reviewed suggest that Tai Chi may improve psychologic well-being, and that these outcomes occur concurrently with improved postural control, the data are limited and provide little evidence of what the causal links are between psychologic well-being and improved balance, and whether these relationships would also be true for vestibulopathy subjects. Nevertheless, the "mind" component of this mind-body exercise may play an important role in postural control of vestibulopathy patients, and exploring this possibility poses an exciting area for future research.

CONCLUSION

At present, few data support the contention that Tai Chi specifically targets the impairments, functional limitations, disability, and QOL associated with peripheral vestibulopathy. There are, however, compelling reasons to further investigate Tai Chi for vestibulopathy, in part because Tai Chi appears to be useful for various nonvestibulopathy etiologic balance disorders. Especially needed are studies that integrate measures of balance relevant to ADLs with other psychologic and cognitive measures; these might help identify specific mechanisms whereby Tai Chi can remedy balance disorders. Certainly, Tai Chi is safe and has few side effects: Tai Chi provides a moderate aerobic, low impact dynamic postural control challenge, so even the least fit individuals can participate. Indeed, few adverse effects have been reported despite Tai Chi applications across numerous and diverse settings, patient diagnoses, and comorbidities. More rigorous research is required, including RCTs comparing Tai Chi and vestibular rehabilitation among people with vestibulopathy, before a firm, defensible answer is in hand.

References

1. Shumway-Cook A, Woollacott MH. Motor control: theory and practical applications. Baltimore: Williams & Wilkins; 1995.
2. Woollacott MH, Tang PF. Balance control during walking in the older adult: research and its implications. Phys Ther 1997;77: 646-60.
3. Krebs DE, Gill-Body KM, Riley PO, Parker SW. Double-blind, placebo-controlled trial of rehabilitation for bilateral vestibular hypofunction: preliminary report. Otolaryngol Head Neck Surg 1993;109:735-41.
4. Gill-Body KM, Krebs DE, Parker SW, Riley PO. Physical therapy management of peripheral vestibular dysfunction: two clinical case reports. Phys Ther 1994;74:129-42.
5. Herdman SJ, Clendaniel RA, Mattox DE, Holliday MJ, Niparko JK. Vestibular adaptation exercises and recovery: acute stage after acoustic neuroma resection. Otolaryngol Head Neck Surg 1995;113:77-87.
6. Krebs DE, Gill-Body KM, Parker SW, Ramirez JV, Wernick-Robinson M. Vestibular rehabilitation: useful but not universally so. Otolaryngol Head Neck Surg 2003;128:240-50.
7. Cheng MC. Master Cheng's thirteen chapters on Tai Chi Chuan. New York: Sweet Chi Pr; 1982.
8. Lee M, Lee E, Johnstone JA. Ride the tiger to the mountain: Tai Chi for health. Reading: Addison-Wesley; 1989.
9. Plummer JP. 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.
10. Kaptchuk TJ. The web that has no weaver: understanding Chinese medicine. 2nd ed. Chicago: McGraw-Hill/Contemporary; 2000.
11. Helm B. Gateways to health: Taijiquan and traditional Chinese medicine. Taijiquan J 2000;3:8-12.
12. Yang JM. Yang style Tai Chi Chuan: I. Advanced Tai Chi theory and Tai Chi Jing. Boston: Yangs Martial Arts Academy; 1985.
13. Chia M, Li J. The inner structure of Tai Chi. New York: Healing Tao Books; 1996.
14. Frantzis BK. The power of internal martial arts: combat secrets of Ba Gua, Tai Chi, and Hsing-I. Berkeley: North Atlantic Books; 1998.
15. Parker SW. Dizziness in the elderly. In: Albert ML, Knoefel JE, editors. Clinical neurology of aging. 2nd ed. Oxford: Oxford Univ Pr; 1994. p 569-79.
16. Channer KS, 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 SY, Lai JS, Wong MK. 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 DR, Appel LJ, Jee S, Miller ER. The effects of Tai Chi on blood pressure in older people: results of a randomized trial. J Am Geriatr Soc 1999;47:277-84.
19. Schneider D, Leung R. Metabolic and cardiorespiratory responses to the performance of Wing Chun and Tai Chi Chuan exercise. Int J Sports Med 1991;12:319-23.
20. Lai JS, Wong MK, Lan C, Chong CK, Lien IN. Cardiorespiratory responses of Tai Chi Chuan practitioners and sedentary subjects during cycle ergometry. J Formos Med Assoc 1993;92: 894-99.
21. Lai JS, Lan C, Wong MK, Teng SH. Two-year trends in cardiorespiratory function among older Tai Chi Chuan practitioners and sedentary subjects. J Am Geriatr Soc 1995;43:1222-7.
22. Lan C, Lai JS, Wong MK, Yu ML. Cardiorespiratory function, flexibility, and body composition among geriatric Tai Chi Chuan practitioners. Arch Phys Med Rehabil 1996;77:612-6.
23. Lan C, Lai JS, Chen SY, Wong MK. 12-month Tai Chi training in the elderly: its effect on health fitness. Med Sci Sports Exerc 1998;30:345-51.
24. 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.
25. Kirsteins AE, Dietz F, Hwang SM. 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.
26. Hartman CA, Manos TM, Winter C, Hartman DM, Li B, Smith JC. Effects of Tai Chi training on function and quality of life indicators in older adults with osteoarthritis. J Am Geriatr Soc 2000;48:1553-9.
27. Wang JS, Lan C, Wong MK. Tai Chi Chuan training to enhance microcirculatory function in healthy elderly men. Arch Phys Med Rehabil 2001;82:1176-80.
28. Wang JS, Lan C, Chen SY, Wong MK. Tai Chi Chuan training is associated with enhanced endothelium-dependent dilation in skin vasculature of healthy older men. J Am Geriatr Soc 2002; 50:1024-30.
29. Sun XS, Xu Y, Xia Y. Determination of E-rosette-forming lymphocytes in aged subjects with taichiquan exercise. Int J Sports Med 1989;10:217-9.
30. Gibb H, Morris CT, Gleisberg J. A therapeutic programme for people with dementia. Int J Nurs Pract 1997;3:191-9.
31. Jin P. Changes in heart rate, noradrenaline, cortisol and mood during Tai Chi. J Psychosom Res 1989;33:197-206.
32. Jin P. Efficacy of Tai Chi, brisk walking, meditation, and reading in reducing mental and emotional stress. J Psychosom Res 1992; 36:361-70.
33. Brown DR, Wang Y, Ward A, et al. Chronic psychological effects of exercise and exercise plus cognitive strategies. Med Sci Sports Exerc 1995;27:765-75.
34. Wolf SL, Coogler C, Xu T. Exploring the basis for Tai Chi Chuan as a therapeutic exercise approach. Arch Phys Med Rehabil 1997;78:886-92.
35. Sandlund ES, 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.
36. Li JX, Hong Y, Chan KM. Tai chi: physiological characteristics and beneficial effects on health. Br J Sports Med 2001;35:148-56.
37. Lan C, Lai JS, Chen SY. Tai Chi Chuan: an ancient wisdom on exercise and health promotion. Sports Med 2002;32:217-24.
38. 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.
39. Brandt T. Bilateral vestibulopathy revisited. Eur J Med Res 1996;1:361-8.
40. Martin HC, Sethi J, Lang D, Neil-Dwyer G, Lutman ME, Yardley L. Patient-assessed outcomes after excision of acoustic neuroma: postoperative symptoms and quality of life. J Neurosurg 2001;94:211-6.
41. Parker SW, Oas JG, McCarthy-Jacobson A, Krebs DE, Gill-Body KM. Recovery of vestibular function after gentamicin ototoxicity [abstract]. Neurology 1999;48:A134.
42. Parker SW. Vestibular evaluation—electronystagmography, rotational testing, and posturography. Clin Electroencephalogr 1993;24:151-9.
43. Norre ME, Beckers A. Vestibular habituation training: exercise treatment for vertigo based upon the habituation effect. Otolaryngol Head Neck Surg 1989;101:14-9.
44. Brandt T, Daroff RB. Physical therapy for benign paroxysmal positional vertigo. Arch Otolaryngol 1980;106:484-5.
45. Cawthorne T. The physiological basis for head exercises. J Chartered Soc Physiother 1944;30:106-7.
46. Cooksey FS. Rehabilitation in vestibular injuries. Proc Royal Soc Med 1946;39:273-8.
47. Gill-Body KM, Popat RA, Parker SW, Krebs DE. Rehabilitation of balance in two patients with cerebellar dysfunction. Phys Ther 1997;77:534-52.
48. Herdman SJ. Role of vestibular adaptation in vestibular rehabilitation. Otolaryngol Head Neck Surg 1998;119:49-54.
49. Herdman SJ. Exercise strategies for vestibular disorders. Ear Nose Throat J 1989;68:961-4.
50. Shumway-Cook A, Horak FB. Vestibular rehabilitation: an exercise approach to managing symptoms of vestibular dysfunction. Semin Hearing 1989;10:194-207.

51. Shumway-Cook A, Horak FB. Rehabilitation strategies for patients with vestibular deficits. Neurol Clin 1990;8:441-57.
52. Horak FB, Shumway-Cook A. Clinical implications of posture control research. In: Duncan P, editor. Balance: proceedings of the APTA forum. Nashville: APTA; 1989. p 105-11.
53. Wile D. Lost T'ai-Chi classics from the late Ch'ing dynasty. New York: State Univ New York; 1996.
54. Wile D. Cheng Man-Ching's advanced T'ai-Chi form instructions. New York: Sweet Chi Pr; 1985.
55. Levandoski LJ, Leyshon GA. Tai Chi exercise and the elderly. Clin Kinesiol 1990;44:39-42.
56. Tse SK, Bailey DM. T'ai chi and postural control in the well elderly. Am J Occup Ther 1991;46:295-300.
57. Gardner MM, Robertson MC, Campbell AJ. Exercise in preventing falls and fall related injuries in older people: a review of randomized controlled trials. Br J Sports Med 2000;34:7-17.
58. Zwick D, Rochelle A, Choksi A, Domowicz J. Evaluation and treatment of balance in the elderly: a review of the efficacy of the Berg Balance Test and Tai Chi Quan. NeuroRehabilitation 2000; 15:49-56.
59. Wolf SL, Barnhart HX, Kutner NG, McNeely E, Coogler C, Xu T. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies of Intervention Techniques. J Am Geriatr Soc 1996;44:489-97.
60. Wolf SL, Barnhart HX, Ellison GL, Coogler CE. 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.
61. Wolf SL, Sattin RW, O'Grady M, et al. A study design to investigate the effect of intense Tai Chi in reducing falls among older adults transitioning to frailty. Control Clin Trials 2001;22: 689-704.
62. Jacobson BH, Chen HC, Cashel C, Guerrero L. The effects of Tai Chi Chuan training on balance, kinesthetic sense, and strength. Percept Mot Skills 1997;84:27-33.
63. Li F, Harmer P, McAuley E, et al. An evaluation of the effects of Tai Chi exercise on physical function among older persons: a randomized controlled trial. Ann Behav Med 2001;23:139-46.
64. Sun WY, Dosch M, Gilmore GD, Pemberton W, Scarseth T. Effects of a tai chi chuan program on Hmong American older adults. Educ Gerontol 1996;22:161-7.
65. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. Phys Ther 1993;73:254-62.
66. Van Deusen J, Harlowe D. The efficacy of the ROM Dance Program for adults with rheumatoid arthritis. Am J Occup Ther 1987;41:90-5.
67. Nowalk MP, Prendergast JM, Bayles CM, D'Amico FJ, Colvin GC. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. J Am Geriatr Soc 2001;49:859-65.
68. 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.
69. Kutner NG, Barnhart H, Wolf SL, McNeely E, Xu T. Self-report benefits of Tai Chi practice by older adults. J Gerontol B Psychol Sci Soc Sci 1997;52:P242-6.
70. Schaller KJ, Tai Chi Chih: an exercise option for older adults. J Gerontol Nurs 1996;22:12-7.
71. Ross MC, Bohannon AS, Davis DC, Gurchiek L. The effects of a short-term exercise program on movement, pain, and mood in the elderly. Results of a pilot study. J Holist Nurs 1999;17:139-47.
72. Li FZ, McAuley E, Harmer P, Duncan TE, Chaumeton NR. Tai chi enhances self-efficacy and exercise behavior in older adults. J Aging Phys Act 2001;9:161-71.
73. Hain TC, Fuller L, Weil L, Kotsias J. Effects of T'ai Chi on balance. Arch Otol Head Neck Surg 1999;125:1191-5.
74. Fontanarosa PB, Lundberg GD. Alternative medicine meets science. JAMA 1998;280:1618-9.
75. Yan JH. Tai chi practice improves senior citizens' balance and arm movement control. J Aging Phys Act 1998;6:271-84.
76. Yan JH. Tai chi practice reduces movement force variability for seniors. J Gerontol A Biol Sci Med Sci 1999;54:629-34.
77. Lan C, Lai JS, Chen SY, Wong MK. Tai Chi Chuan to improve muscular strength and endurance in elderly individuals: a pilot study. Arch Phys Med Rehabil 2000;81:604-7.
78. Shih J. Basic Beijing twenty-four forms of T'ai Chi exercise and average velocity of sway. Percept Mot Skills 1997;84:287-90.
79. Forrest WR. Anticipatory postural adjustment and T'ai Chi Ch'uan. Biomed Sci Instrum 1997;33:65-70.
80. Wong AM, Lin YC, Chou SW, Tang FT, Wong PY. Coordination exercise and postural stability in elderly people: effect of Tai Chi Chuan. Arch Phys Med Rehabil 2001;82:608-12.
81. Hong Y, Li JX, Robinson PD. Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. Br J Sports Med 2000;34:29-34.
82. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002;16:1-14.
83. Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. J Gerontol A Biol Sci Med Sci 2001;56:M489-96.
84. Kressing RW, Wolf SL, Sattin RW, et al. Associations of demographic, functional and behavioral characteristics with activity-related fear of falling among older adults transitioning to frailty. J Am Geriatr Soc 2001;49:1456-62.
85. International Society of Sport Psychology. Physical activity and psychological benefits: a position statement. Sports Psychologist 1992;6:199-203.
86. Byrne A, Byrne DG. The effect of exercise on depression, anxiety and other mood states: a review. J Psychosom Res 1993;37:565-74.
87. Gauvin L, Spence JC. Psychological research on exercise and fitness: current research trends and future challenges. Sports Psychologist 1995;9:434-48.
88. Plante TG. Does exercise help in the treatment of psychiatric disorders? J Psychosoc Nurs Ment Health Serv 1996;34:38-43.
89. Benson H. The relaxation response. New York: William Morrow; 1975.
90. Goleman D, Gurin J. How to use your mind for better health. New York: Consumer Reports Books; 1993.
91. Dossey L. Healing words: the power of prayer and the practice of medicine. San Francisco: Harper; 1995.
92. Watkins A. Mind-body medicine: a clinician's guide to psychoneuroimmunology. New York: Churchill Livingstone; 1997.
93. Castillo-Richmond A, Schneider RH, Alexander CN, et al. Effect of stress reduction on carotid atherosclerosis in hypertensive African Americans. Stroke 2000;31:568-73.
94. Spiegel D, Bloom JR, Kraemer HC, Gottheil E. Effect of psychosocial treatment on survival of patients with metastatic breast cancer. Lancet 1989;2(8668):888-91.
95. Plante TG. Could the perception of fitness account for many of the mental and physical health benefits of exercise? Adv Mind Body Med 1999;15:291-5.
96. Desharnais R, Jobin J, Cote C, Levesque L, Godin G. Aerobic exercise and the placebo effect: a controlled study. Psychosom Med 1993;55:149-54.
97. Folkins CH, Sime WE. Physical fitness training and mental health. Am Psychol 1981;36:373-89.
98. Kaptchuk TJ. The placebo effect in alternative medicine: can the performance of a healing ritual have clinical significance? Ann Intern Med 2002;136:817-25.