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Review Article

Tai Chi Research: A Narrative Review

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Abstract

This paper is a narrative review of empirical studies, systematic reviews and meta-analyses on tai chi published during the last few years (2016-2019). The review includes safety data as well as the use of tai chi for pediatric problems, cognitive function, psychiatric, medical and immune conditions. Tai chi research continues to be predominantly focused on aging problems, most especially falling and facilitating balance. Recent research has also explored potential underlying mechanisms including increased heart rate variability, functional connectivity of different areas of the brain and gray matter volume. Brief summaries are given of the methods and results of studies along with their limitations and suggestions for future research. In most studies, tai chi has been more effective than treatment as usual and waitlist control conditions, although tai chi has not always been more effective than other forms of exercise. More randomized controlled trials are needed in which tai chi styles are compared as well as shorter sessions for greater compliance. And, potential underlying mechanisms need to be further explored. Nonetheless, the studies reviewed here continue to highlight the therapeutic effects of tai chi.

This paper is a narrative review of empirical studies, systematic reviews and meta-analyses on tai chi that have been published over the last few years (2016-2019) since our last review [1]. The term tai chi was entered into PubMed and the selection criteria were peer-reviewed empirical studies (single arm or randomized controlled studies) in which standard treatment, waitlist and other exercise groups were compared with the different style tai chi groups. Systematic reviews and meta-analyses are also included. Exclusion criteria were case studies, qualitative studies, small sample pilot studies and research in which the assessors were not blind.

Brief summaries of papers are given on the safety of tai chi as well as several conditions that have been alleviated by tai chi. These include student anxiety and cognitive function; psychological conditions including sleep problems, depression, PTSD and schizophrenia; pain syndromes including low back pain, neck pain, knee osteoarthritis and fibromyalgia; cardiovascular and cardiorespiratory conditions including hypertension, stroke and COPD; metabolic conditions including metabolic syndrome and type II diabetes; immune conditions including breast, prostate and lung cancer; and aging problems including fear of falling, balance, osteoporosis and Parkinson's. Most of the recent tai chi research has focused on improving balance, lower limb strength and gait problems in the elderly. Potential underlying mechanism studies have also appeared in this recent literature including heart rate variability as well as brain connectivity and brain matter studies. Other methods of tai chi delivery include wheelchair tai chi, water tai chi (Ai chi), video and online tai chi. The methods and results of these studies are briefly summarized along with their limitations and suggestions for future research.

Keywords: Tai chi; Pain syndrome; Schizophrenia; Hypertension; Parkinson's disease

Survey Data on Tai Chi Safety

Tai chi involves a series of slow and rhythmic circular

motions that are performed without physical contact with another person but typically in a group in parks and large spaces. Although five different styles are practiced, the Yang and Sun forms have been the most popular in the U.S. and in the research that is summarized here. Tai chi movements as compared to walking

involve large vertical and mediolateral displacements of the body [2]. For example, the movements called “repulse monkey” and “wave hand in cloud” involve the knees being flexed, and, as compared to walking, there is greater abduction and adduction of the knees. The series of movements called “the form” require concentration and memorization, making it a cognitive as well as a physical exercise.

Tai chi is considered a low to moderate intensity exercise based on oxygen consumption and heart rate data and it is considered a safe form of exercise [3]. When safety data were evaluated in a systematic review, only 33% of 153 Randomized Controlled Trials (RCTs) reported on adverse events and of those, only 12% overall noted a monitoring protocol for adverse events [4]. Only minor adverse events were reported including musculoskeletal aches and pains typically in the knee and back. In a more recent meta-analysis on 24 randomized controlled trials, the frequency of non-serious, serious and intervention-related adverse events did not differ for tai chi, inactive and active control groups [5]. When data for heart failure participants in this meta-analysis were analyzed, more serious adverse events were reported for inactive controls versus tai chi groups. When kinematic and kinetic data have been compared for walking, jogging and typical brush knee/twist step tai chi movement, greater range of motion was noted for the tai chi movement [6]. In addition, lower contact peak stresses were recorded on the cartilage and meniscus, suggesting that there is less risk of knee joint injury during tai chi than during walking and jogging. These results are tentative inasmuch as the reporting on adverse events has been limited and inconsistent.

In contrast, the health outcome data have been generally consistent. In a systematic review of systematic reviews, for example, the “evidence map” suggested that tai chi was effective for hypertension, fall prevention, cognitive performance, osteoarthritis, depression, chronic obstructive pulmonary disease, pain, balance confidence and muscle strength [7]. Consistent with this, a survey of systematic reviews and meta-analyses by a different group suggested that tai chi was effective for balance training, for fall prevention, cancer, chronic obstructive pulmonary disease, Parkinson’s disease and cardiac and cardiovascular disorders [8]. In another review of systematic reviews, tai chi was rated for its benefits [9]. Excellent evidence was noted for preventing falls, osteoarthritis, Parkinson’s disease, chronic obstructive pulmonary disease and cognitive capacity in older adults. Good evidence was reported for depression, cardiac and stroke rehabilitation and fair evidence was noted for cancer, fibromyalgia, hypertension and osteoporosis. Systematic reviews of fitness benefits showed evidence for improving balance and aerobic capacity. No studies found that tai chi worsened a condition and no serious adverse events were reported.

Pediatric Tai Chi

Surprisingly little research has appeared in the literature on pediatric tai chi given that it could become an early lifestyle that may be preventive of many of the conditions that are later treated by tai chi. In addition, many of the conditions that are treated in adults, for example, pain syndromes are now prevalent in youth. Those pediatric conditions that appear in the recent literature include autism spectrum disorder, intellectual disability, sensorineural hearing loss and asthma (Table 1).

Condition	Effect	First Author
Autism	increased balance; increased motor coordination	[10]
Intellectual disability	increased balance; increased limb coordination	[11]
Asthma	increased pulmonary function	[12]

Table 1: Pediatric conditions, tai chi effects and first author.

In the study on children with autism spectrum disorder, the tai chi program consisted of 18 one-hour sessions across six weeks [10]. The data suggested that the tai chi versus the control group showed significant improvement in balance and motor coordination. Similarly, in a sample of children and adolescents with intellectual disability, a 12-week tai chi group as compared to a group that received arts and crafts activities showed significant increases in vertical jumping, lower limb coordination and upper limb coordination as well as balance [11]. However, when tai chi was compared with a conventional exercise group with children who have congenital sensorineural hearing loss, the groups were equivalent on balance and functional mobility after 10 weeks of one-hour sessions [12].

In a study on elementary school students with asthma, the children showed significant improvement on several pulmonary measures after weekly one-hour sessions for 12 weeks [12]. These included peak expiratory flow rate and forced expiratory volume in one second (both important clinical measures of pulmonary function).

In a systematic review of the health benefits of tai chi for 9263 students in higher education, both primary and secondary health outcomes were noted [13]. The primary benefits were increased flexibility, reduced depression, anxiety, and improved interpersonal sensitivity. The secondary outcomes included improved lung capacity, balance, 800/1000 meter run time and sleep quality. Symptoms of compulsion, somatization, phobia

and hostility were also reduced. In a randomized controlled trial on nursing students, those in the tai chi group showed significant reductions in cognitive and somatic anxiety along with an increase in self-efficacy and improved performance [14].

Cognitive Function

Several cognitive functions have improved following tai chi including attention level, performance on cognitive tests, and executive and non-executive function (Table 2). In at least two studies, improved cognitive function has been associated with biomarkers including increased brain derived neurotrophic factor (a nerve growth factor for both the peripheral and central nervous system) and increased amplitude of low-frequency fluctuations in the dorsolateral prefrontal cortex. In the attention level study, tai chi practitioners were compared to non-practitioners on attention levels, stress levels and heart rate [15]. The results suggested that the tai chi group had a greater increase in attention level, a greater decrease in perceived stress and a greater increase in heart rate. In a study that included the cognitive tests of logical memory, block design, digit span and trail making, the tai chi group had better performance on these tasks after combined center and home-based training three times per week for 15 weeks [16]. Tai chi has been more effective even than brisk walking on reaction time in both the Stroop naming and executive conditions and were more accurate in the inhibition condition [17].

Effect	First Author
Increased attention	[15]
Decreased heart rate	
Increased memory	[16]
Increased executive function	[17]
Increased brain derived neurotrophic factor	[18]
Increased memory	
Increased memory	[19]
Increased amplitude dorsolateral prefrontal cortex	

Table 2: Cognitive effects and first authors.

In a study that assayed plasma Brain Derived Neurotrophic Factor (BDNF), the tai chi participants practiced at home for 50-minute sessions three times a week for six months [18]. At the end of the study, the tai chi group showed better performance on the Logical Memory and Trail Making Test and also showed a significant increase in plasma BDNF. In a group that received 12 weeks of tai chi training for one hour per day five days per week, the tai chi group showed significant improvement in memory function and increased amplitude of low-frequency fluctuations in

the dorsolateral prefrontal cortex [19].

Psychological Conditions

Several psychological conditions have benefited from tai chi including anxiety and sleep quality, depression, PTSD and schizophrenia (Table 3). In a systematic review and meta-analysis, 14 studies yielded moderate to large effects on the negative emotions of anxiety and depression [20]. Interestingly, although negative emotions were reduced in both young adults and older adults, the older adults benefited more from tai chi than the young adults. This may relate to their having had more experience with tai chi than the young adults both by virtue of their age and available time for practicing tai chi.

Effect	First Author
Decreased depression	[20]
Decreased anxiety	
Decreased state & trait anxiety	[21]
Decreased anxiety	[22]
Increased sleep quality	[23-26]
Decreased depression	[27-29]
Decreased PTSD	[30]
Decreased cortisol in schizophrenia	[31]
Decreased negative symptoms	[32,33]

Table 3: Psychological effects and first authors.

At least two other studies reported a decrease in anxiety following tai chi. In one study, the participants who were healthy but stressed people were randomly assigned to tai chi, exercise or waitlist groups for a 12-week practice [21]. Although both the tai chi and the exercise groups showed significant decreases in both state and trait anxiety, the authors suggested that tai chi provided a safer and less physically vigorous alternative to exercise. In another study, young adults were randomly assigned to 10 weeks of tai chi sessions twice per week, to 10 weeks of tai chi with a DVD of the curriculum and a control group receiving handouts on anxiety management [22]. Inasmuch as the two tai chi groups did not differ, their data were combined. The tai chi groups showed a significant reduction in anxiety as well as improved sleep quality, at least for those who attended 80% of the classes.

Sleep quality has improved following tai chi in at least three other studies. In one study, tai chi training consisted of two 60-minute sessions each week for two months [23]. In this sample, the results from the Pittsburgh Sleep Quality Index suggested a better global score, and greater sleep duration and sleep efficiency for the tai chi versus the control group. In another study, the participants

who were depressed received one-hour tai chi training sessions two times per week for 10 weeks [24]. In this study, the Pittsburgh Sleep Quality Index scores significantly improved. In addition, analyses of EKG recordings showed decreased sleep onset latency, increased stable sleep and decreased unstable sleep. Significant correlations were noted between the changes in the subjective self-report measures and the more objective EKG measures. In contrast, in another study in which tai chi was compared with cognitive behavioral therapy, both groups receiving 3 months of therapy had improved scores on the Pittsburgh Sleep Quality Index as well as sleep diary measures and related symptoms, but no improvement on the EKG sleep measures, unlike the results of the previous study [25]. In a meta-analysis of 10 trials, tai chi not only improved sleep but led to less fatigue and depression [26].

At least three research groups have reported a reduction in depression. Major depressive disorder is one of the most prevalent mental illnesses and the typical treatments for depression are unsatisfactory given the side effects and the high relapse rates [27]. In a randomized clinical trial, participants were assigned to either combined music or tai chi for three months or to a control group that involved routine health education [28]. At the end of the three months, the tai chi group had significantly lower depression scores. It is not clear the degree to which music had an additive effect, although it's unusual that these two mediums were combined given that tai chi is usually practiced without music.

In another randomized controlled trial, depressed individuals were randomized to a tai chi, an education or waitlist group for a three-month period [29]. The response rates were 25%, 21%, and 56% and the remission rates were 10%, 21% and 50% for the waitlist, education and tai chi groups respectively. Thus, the tai chi group showed significantly greater response rates and greater remission rates than the other two groups. In a review of the literature, tai chi has been an effective treatment in a large number of clinical trials [11]. The authors suggested that this has become a promising exercise because of the availability of instructional videos and the development of more simplified and less structured tai chi forms as a low-intensity mind-body exercise. The mechanisms that the authors explored were that tai chi alleviates depressive symptoms by the modulation of activity and connectivity of key brain regions that are involved in mood regulation, that reduce inflammation, that modulate the autonomic nervous system and regulate hippocampal neurogenesis. The authors further suggested that tai chi needs to be compared with other forms of exercise such as yoga.

Surprisingly, only one study appeared in the recent literature on the use of tai chi with posttraumatic stress disorder [30]. The veterans who participated in this study reported that tai chi was effective for managing their distressing symptoms including intrusive thoughts, concentration difficulties and physiological arousal.

At least three papers were found on tai chi for patients with chronic schizophrenia. The authors of each of these papers suggested that tai chi may be an alternative treatment for psychotic symptoms inasmuch as the anti-psychotic medication often has severe side effects and lacks adherence. In a three-arm randomized controlled trial, chronic schizophrenic patients were recruited from a mental health rehab program and randomized to tai chi, exercise or waitlist control groups [31]. Both of the intervention groups received 12 weeks plus their standard medication. As compared to the controls, the tai chi group showed significant decreases in motor deficits and cortisol levels and increases in backward digit span. However, the two exercise groups did not differ on these tasks except that fewer symptoms were noted in the exercise group.

In a randomized controlled trial by another group, the sample was randomized to medication treatment alone or to tai chi plus medication [32]. The tai chi group had lower scores on the Positive and Negative Symptoms Scale and fewer negative symptoms as well as a lower risk for aggressive behavior and greater adherence to medication. Unfortunately, here too, the tai chi effects were confounded by also including social skills training. In a systematic review and meta-analysis, six randomized controlled trials including 483 participants involved comparisons between tai chi and control groups for tai chi effects on schizophrenia [33]. Although there were no significant differences regarding improvement on positive symptoms assessed by the Positive and Negative Symptoms Scale, the tai chi groups did show improvement on negative symptoms assessed by the same scale.

Pain

As might be expected, many of the recent tai chi studies have focused on pain. These can be categorized as musculoskeletal pain including neck pain, knee pain and low back pain or disease-related pain which has been limited to fibromyalgia pain (Table 4).

Syndrome	First author
Decreased musculoskeletal pain	[34-37]
Decreased neck pain	[38,39]
Decreased low back pain	[40-44]
Decreased knee pain	[45]
Decreased fibromyalgia pain	[47,48]

Table 4: Pain syndromes and first authors.

Musculoskeletal Pain

At least two studies have focused on musculoskeletal pain in general (multisite pain). In a randomized controlled trial, the participants were randomly assigned to either a tai chi or light physical exercise program that was offered twice per week for

three months [34]. Although the dropout rate was higher and the attendance rate lower for tai chi as compared to light physical exercise, tai chi lowered pain severity and pain interference as well as fear of falling and improved single-task and dual-task gait measures. Surprisingly, light physical exercise did not affect these measures. In a pre-post study on a three-month tai chi program to reduce musculoskeletal pain, pain intensity was reduced and performance also improved on a six-minute walk test [35].

In a systematic review and meta-analysis on 18 randomized controlled trials for chronic pain conditions, immediate relief was noted for chronic pain from osteoarthritis, low back pain and osteoporosis [36]. In another systematic review and meta-analysis on musculoskeletal pain conditions, 15 studies were identified on tai chi for osteoarthritis (80%), back pain (13%) and headache (7%) [37]. Tai chi was more effective than usual care for reducing pain and disability. The evidence for other outcomes was low quality and there was very little information regarding long-term effects. The authors concluded that although the number of studies on this topic has increased, the rigor has not. They commented that the studies were conducted on small samples and that they were further limited by the lack of long-term assessments.

Neck Pain

Two papers were found in the recent literature on tai chi for neck pain. In a randomized controlled trial, participants with chronic nonspecific neck pain were randomly assigned to three months of tai chi or conventional neck exercises (with weekly sessions of 75 to 90 minutes) or a waitlist control group [38]. Although tai chi was more effective at reducing pain relative to the waitlist control group, the tai chi and exercise group were equivalent on pain reduction. In a secondary analysis of these data by the same group, a linear forward stepwise regression was conducted to determine predictor variables for the reduction in neck pain intensity [39]. This analysis revealed that reductions in pain intensity from baseline to three months were predicted by greater pain intensity at baseline, a decrease in anxiety and an increase in postural awareness.

Low Back Pain

As might be expected because of the high incidence of low back pain, several randomized controlled trials and a systematic review and meta-analysis of randomized controlled trials have appeared in the recent literature on tai chi. In one of the randomized controlled trials, participants were assigned to a tai chi, a core stability training program or a control group [40]. After this 12-week program of three one-hour sessions per week, both the tai chi and the core stability training groups experienced less nonspecific chronic low back pain. In a systematic review and meta-analysis of randomized controlled trials addressing the effects of tai chi on pain and disability in patients with low back pain, several effects

were noted [41]. These included decreased pain, pain intensity and sleep problems and improvements in lifting, walking, standing and traveling.

Some potential mediators for the effects of tai chi on low back pain have been explored including pain-catastrophizing, lumbar vertebrae degeneration and beta endorphin levels. In the study on pain-catastrophizing as a potential mediator of the effects of tai chi on low back pain, a secondary analysis was conducted on a randomized controlled trial [42]. After a 10-week tai chi intervention, the results suggested that a reduction in catastrophizing explained approximately one third of the effect of tai chi on pain intensity and two thirds of the effect of tai chi on disability. Another likely mediator is the degeneration of lumbar vertebrae. In a study on magnetic resonance images of lumbar vertebrae, the tai chi practitioners with more than four years of regular tai chi exercise had significantly fewer degenerated lumbar vertebrae and lumbar discs than the control group [43]. The most severely affected lumbar vertebrae and discs were L5 and L4 respectively. Another possible mechanism is the effect of tai chi on beta endorphin levels. For example, in a study on older adults, those who completed 70% or more of the tai chi classes had significantly lower levels of beta endorphin as opposed to a light physical exercise group [44].

Knee Pain

Typically, knee pain has been researched on samples of patients with knee osteoarthritis. In a randomized controlled trial, tai chi (two times per week for 12 weeks) was compared to physical therapy (two times per week for six weeks followed by six weeks of monitored home exercise) [45]. The tai chi group notably had significantly greater improvements on measures of pain and depression. In a secondary analysis of that database by the same research group, both groups had a greater than 20% improvement in pain and function if they attended for two weeks and a greater than 50% improvement if attendance was 4-5 weeks. Systematic reviews and meta-analyses have not appeared for knee osteoarthritis in the recent literature probably because of the difficulty grouping the studies due to their highly variable protocols in terms of frequency and duration of treatment [46].

Fibromyalgia

Fibromyalgia involves chronic widespread pain and a heightened painful response to pressure. In a randomized trial, participants were randomly assigned to either supervised aerobic exercise (24 weeks twice weekly) or one of four classic Yang style tai chi sessions (12 or 24 weeks, once or twice weekly) [47]. Tai chi as compared with aerobic exercise had greater benefit based on the Fibromyalgia Impact Questionnaire. And, surprisingly, greater improvements were noted for those who received it for the shorter time period (12 vs. 24 weeks). It was also surprising that there was

no additional benefit for those who received tai chi twice versus once weekly.

In a meta-analysis on six randomized controlled trials on tai chi for fibromyalgia, the Fibromyalgia Impact Questionnaire scores were improved following tai chi as were pain scores, sleep quality, fatigue and depression [48]. These greater improvements were noted when tai chi was compared to standard care. The authors suggested, however, that more large-scale, high-quality and multicenter trials are required to provide stronger evidence for the effectiveness of tai chi as an alternative to aerobic or conventional exercise.

Cardiovascular Conditions

Tai chi research has also been effective for cardiovascular conditions. These include hypertension, coronary heart disease and stroke (Table 5).

Condition	Effect	First author
Hypertension	decreased blood pressure	[50-52]
Stroke	increased vital capacity	[53]
	increased balance	[55]
	increased dual task	[57,58]
Coronary heart disease	decreased pro-inflammatory cytokines	[59]
	decreased heartrate	[60,61]
	decreased left ventricular ejection fraction	
	increased aerobic endurance	[62]
	increased cardiorespiratory fitness	[63]
COPD	increased distance in 6 minutes	[64,65]
	decreased respiratory rate	[66]
	increased pulmonary function	[67]
	increased distance in 6 minutes	[68]
	increased pulmonary function	

Table 5: Cardiovascular conditions, effects and first authors.

Hypertension

In a six-week tai chi training (60 minutes per session, five sessions per week) a simplified Yang style was used including 10 minutes of warm-up exercises, 45 minutes of a tai chi form and five minutes of cool down exercises [49]. After the six

week intervention, blood pressure was significantly decreased. In a randomized controlled trial, older adults with hypertension received a six-month tai chi training and were compared to a usual care group [50]. Blood pressure again decreased. In another sample of hypertensive adults, tai chi was compared to walking following a single 30 minute session [51]. In both the tai chi and walking groups, systolic blood pressure decreased following the session. In a systematic review and meta-analysis, significant benefits were noted for tai chi over no intervention for hypertension including significant decreases in systolic blood pressure and diastolic blood pressure [52].

Stroke

Tai chi has been used in an effort to prevent stroke in individuals at risk for stroke. In a tai chi training that involved five 60-minute sessions per week for 12 weeks, echocardiograms were used to measure cardiac structure and cardiac function at the end of the 12-week intervention [53]. Only three of the measures improved in the tai chi group including right ventricular diameter, main pulmonary artery diameter and vital capacity maximum. The authors suggested that a longer duration intervention may be necessary to improve the other measures of cardiac function. However, the same group of investigators published another paper on the same sample and protocol that suggested a significant increase in blood flow velocity, pulse utility index and resistance as well as decreased triglyceride, fasting blood glucose and homocysteine levels [54].

Most of the research on tai chi for stroke has involved stroke survivors. The effects have included reduced fear of falling and improved balance. For example, in a randomized controlled trial, a 12-week tai chi training resulted in less fear of falling and improved balance [55]. In a pre-post repeated measures design, stroke survivors experienced a twice weekly twelve month tai chi training [56]. At the end of the program, balance improved as well as flexibility.

Two studies by the same group used a dual-task situation to assess the effects of a 12 month tai chi training. Given that tai chi involves focus/concentration, participants might improve on dual tasking. In this paradigm, participants are asked to step down or turn around while completing a cognitive task which requires simultaneous attention to a physical and a cognitive task. In the first of the two studies using this paradigm, the stroke survivors were asked to step down while performing a Stroop auditory task which involves focusing on the high or low pitch of a voice while a contradictory word “high” or “low” is presented or focusing on the word high or low while a contradictory pitch is presented [57]. Following a 12-week tai chi training versus 12 weeks of conventional exercise, the tai chi participants showed improvement on this dual task. In a subsequent publication by the same authors, the dual-tasking condition involved a turning-while-walking plus

the auditory Stroop task [58]. Once again, the tai chi versus the conventional exercise group showed superior performance on this dual task.

Coronary Heart Disease

In a randomized controlled trial using a waitlist control, the effects of tai chi on adults at risk for coronary heart disease were assessed at the end of an eight week intervention and two months later [59]. Surprisingly, at the two-month follow-up assessment, significant decreases were noted in pro-inflammatory cytokines that are associated with underlying cardiovascular risk including interferon gamma, tumor necrosis factor, IL-4 and IL-8.

A few systematic reviews and meta-analyses have been conducted on tai chi for patients with chronic heart failure or coronary heart disease and their results have been consistent. In one of these, 11 trials with 656 patients were available for analysis [60]. The results of this meta-analysis suggested that tai chi was associated with improved six minute walk distance, reduced heart rate and reduced left ventricular ejection fraction and B-type natriuretic peptide. The exact same findings were reported by an entirely different group of investigators based on a meta-analysis of 13 randomized controlled trials [61]. Both research groups recommended that larger, well-designed randomized controlled trials are needed to exclude the risk of bias. These meta-analyses combined suggests that tai chi is an effective cardiac rehabilitation for patients with chronic heart failure. In still another meta-analysis on tai chi for coronary heart disease, 13 studies met inclusion criteria [62]. In this case, tai chi groups showed a large and significant improvement in aerobic endurance compared with both active and non-active control groups. Not surprisingly, they also had a lower level of anxiety and depression and reported having significantly better quality of life. In a meta-analysis on cardiorespiratory fitness of adults with coronary heart disease, five studies showed significantly improved cardiorespiratory fitness (VO₂max measure) following tai chi compared to no exercise or other types of exercise with low-to-moderate intensity [63].

Chronic Obstructive Pulmonary Disease

A few studies and a few systematic reviews and meta-analyses were found in the recent literature on tai chi with patients who have Chronic Obstructive Pulmonary Disease (COPD). Typically, the six-minute walk distance and pulmonary function have been assessed following tai chi. In a randomized controlled trial, patients with COPD were randomly assigned to a tai chi group or a control group [64]. The tai chi group practiced three times weekly for three months and at the end of that time the tai chi group had significantly increased the distance in six minutes and had a reduced score on the COPD assessment. In another randomized controlled trial, the tai chi group met five times weekly for 12 weeks and they too had better scores on the respiratory questionnaire as well as a greater

distance in the six minute walk [65]. In a study that compared tai chi with treadmill exercise, the respiratory rate during tai chi was significantly lower than that during treadmill exercise, although the oxygen uptake during the two forms of exercise did not differ [66].

In a systematic review of research on tai chi for COPD, 12 randomized controlled trials comparing tai chi alone or tai chi to another intervention and a control group were included [67]. When tai chi was compared with usual care, the tai chi groups demonstrated a longer six minute walk distance and better pulmonary function (i.e. forced expiratory volume in one second). Comparisons between tai chi and other exercises showed no superiority and no additional effects on symptom improvement or on physical outcomes for the tai chi groups. A problem for this systematic review was once again the number of different forms in the different studies, making it difficult to combine those for comparisons, and tai chi forms have rarely been compared.

In another systematic review and meta-analysis, 15 randomized controlled trials involving 1354 participants were included [68]. Once again, tai chi was more effective in improving exercise capacity on six-minute walking distance as well as pulmonary functions including forced expiratory volume in the first second and forced vital capacity. There was, however, no decrease in dyspnea (shortness of breath).

Metabolic Conditions

Tai Chi has also been effective with weight control and other problems related to metabolic syndrome and diabetes. The measures have typically included body mass index, oxidative stress glucose and glycosylated hemoglobin (Table 6). In a large sample study, participants practicing tai chi had lower energy metabolism than a walking group but similar health benefits in terms of aerobic fitness, resting energy expenditure, body composition and self-perceived physical health [69]. As compared to the control group, the tai chi group had lower body mass index and skinfold thickness. As compared to a walking group, tai chi had a greater effect on resting energy kilocalorie expenditure. In a systematic review and meta-analysis of randomized controlled trials on body composition, (24 studies with 1621 participants), significant improvements in body mass index were noted in 42% of the studies [70].

Effect	First author
Decreased energy metabolism	[69]
Decreased body mass index	[70]
Increased DHEAS & decreased body fat	[71]
Decreased glycosylated haemoglobin	[72]

Decreased oxidative stress markers	[73]
Decreased blood pressure	
Decreased blood glucose	
Increased high density lipoprotein	[74]
Decreased blood triglycerides & cholesterol	[75]
Decreased glucose, BMI, blood pressure	[76]
Decreased glucose, glycosylated haemoglobin	[77]
Increased nerve conduction velocity	[78]
Increased balance	

Table 6: Metabolic effects and first authors.

In a study on the difference between tai chi practitioners and sedentary individuals, no differences were noted in body composition, leg strength, blood lipid components and testosterone, but tai chi practitioners had higher levels of DHEAS (which has the potential to increase bone density, decrease body fat and improve sexual function) [71]. In addition, the tai chi practitioners had lower levels of cortisol and a higher ratio of DHEAS to cortisol, suggesting less stress and improved health-related quality of life.

In a study on the hypoglycemic and antioxidant effects of tai chi on adults with metabolic syndrome, a tai chi training program was performed for fifteen minutes, five days a week for six months [72]. The tai chi group as compared to a control group showed a decrease in glycosylated hemoglobin and a decrease in oxidative stress markers. In another randomized controlled trial on adults with metabolic syndrome, the tai chi group attended a one hour class twice a week for 12 weeks plus 30 minutes home practice three times per week [73]. As compared to the controls, the tai chi group had significantly lower systolic blood pressure and diastolic blood pressure. In a study on secondary metabolic disorders for people with intellectual disabilities, the Sun style tai chi exercise (five minute warm-up, 45 minute exercise and 10 minute meditation) was conducted twice a week for a total of 40 sessions over five months [74]. At the end of the treatment period, fasting blood glucose was lower and high density lipoprotein was higher than those values for the control group.

Diabetes has been the focus of extensive tai chi research. At least three meta-analyses were found in the recent literature on tai chi for diabetes. These were primarily focused on blood lipid values. In the first of these, six studies met criteria involving 445 participants [75]. In this analysis, the practicing groups as compared to the control groups had lower blood triglycerides and cholesterol, although they did not differ on low density lipoprotein or high-density lipoprotein. In another more recent meta-analysis, a total of 23 studies involving 1235 patients were included [76].

For this meta-analysis, not only was cholesterol lower in the tai chi groups but they also had lower fasting plasma glucose, decreased body mass index and lower systolic and diastolic blood pressure. However, no impact was noted on fasting insulin. In the third meta-analysis, 70 trials were included [77]. In this meta-analysis, tai chi led to reduced fasting blood glucose and reduced glycosylated hemoglobin after three months except for the Yang style. This finding highlighted the importance of exploring the different training durations and the different tai chi styles for their variable effectiveness.

Diabetes also leads to damage of the peripheral nerves which can cause balance and stability problems. To address these problems, balance and nerve conduction velocity were measured in patients with type II diabetes [78]. The series of Yang style tai chi classes (one hour, two sessions per week for eight weeks) led to improvement on nerve conduction velocity, balance and walking stability.

Immune Conditions

Surprisingly few studies were found on tai chi and immune function. These included a literature review on immune function and inflammation of the gut, a couple systematic reviews on multiple sclerosis and systematic reviews and meta-analyses on several types of cancer including lung, breast and prostate cancer (Table 7).

Condition	Effect	First author
	decreased gut inflammation	[79]
Multiple sclerosis	increased balance & gait	[80,81]
Lung cancer	decreased fatigue	[82,85]
Breast cancer	increased sleep, decreased cortisol	[83,84]

Table 7: Immune conditions, effects and first authors.

In a review on 14 studies regarding the association between tai chi and gut microbiota, tai chi was noted to improve immune function and reduce inflammation of the gut [79]. The authors suggested that tai chi may affect gut microbiota through vagal modulation and hypothalamic pituitary adrenal axis modulation.

In a systematic review on tai chi for multiple sclerosis, ten studies met the inclusion criteria [80]. Tai chi was noted to improve functional balance, flexibility, leg strength, and gait. Also, pain and fatigue were reduced. The authors, however, highlighted the methodological flaws including small sample size, lack of specific-disease instruments, unclear description of the tai chi protocols and insufficient follow-up data in the existing literature. In a second systematic review of eight studies (three randomized controlled trials and five quasi-experimental studies) involving

193 participants with multiple sclerosis, the tai chi interventions averaged 27 sessions over 11 weeks [81]. Although mixed results were reported, overall the tai chi practitioners had better balance, gait and flexibility, less fatigue and depression and better quality of life.

In a study on tai chi for cancer-related fatigue in patients with lung cancer undergoing chemotherapy, one-hour tai chi sessions were held every other day for 12 weeks [82]. Although general fatigue and physical fatigue were decreased and vigor was increased, no changes were noted on the emotional and mental scores on the Multidimensional Fatigue Symptom Inventory. In a systematic review and meta-analysis on breast cancer survivors, 22 randomized controlled trials were included [83]. The results suggested improved limb/muscular function, better sleep and reduced cortisol levels. In a systematic review and meta-analysis of 22 studies including 15 randomized controlled trials that evaluated 1283 participants, tai chi was given for adults with various cancers including breast and prostate cancer and lymphoma [84]. Tai chi led to a significant decrease in fatigue, sleep difficulty and depression. In another meta-analysis of six randomized controlled trials involving 373 patients, tai chi had a positive effect on short-term cancer-related fatigue among patients with breast and lung cancer but not prostate cancer [85]. And, the impact on long-term effects was unclear. The effects for tai chi were superior to physical exercise and psychological support controls and a longer intervention time (8-12 weeks) led to more benefits than the shorter term interventions.

Aging Conditions

Tai chi research has most frequently focused on aging conditions as if it is a signature exercise for the elderly. Most of the research that has assessed tai chi effects on older adults has related to fear of falling, falling and improving balance (Table 8). Those are the predominant topics in the recent literature on tai chi. Other aging conditions that are reviewed here include osteoporosis, Parkinson's and dementia.

Condition	Effect	First author
Fear of falling	increased balance	[86,87]
Risk of falling	decreased falls	[88-91]
	increased balance	[90,93,94]
	decreased postural sway	[96-98]
	increased proprioception of lower limbs	[100,101]
	increased lower limb strength	[102-105]
Osteoporosis	increased balance	[107]

	increased bone mineral density	[99,108-110]
Parkinson's Disease	increased cognitive function	[111]
	increased balance	[112-115]

Table 8: Aging conditions, tai chi effects and first authors.

Fear/Risk of Falling and Balance Training

In a rare U.S. tai chi study on a sample of mostly female participants who were on average 73 years old, as many as 18% reported being afraid of falling or very afraid of falling and 18% had fallen in the past six months [86]. At the end of that 12-week tai chi program, significant improvement was noted on the most common assessments of the tai chi building-balance literature including Timed Up and Go, Functional Reach and Activities-Specific Balance Scale scores. In a randomized controlled trial that assessed both fear of falling and risk of falling, tai chi was compared to a daily activities control group [87]. The tai chi program featured three sessions per week for 10 weeks. Fear of falling decreased by the fourth week and the risk of falling was reduced by the eighth week.

Several recent systematic reviews and meta-analyses have been published on tai chi effects on the risk of falling. In the first of these on 13 randomized controlled trials, tai chi prevented the risk of falling [88]. In another literature search on tai chi for preventing falls by the same research group, only 10 of 891 potentially eligible studies met inclusion criteria [89]. The findings suggested that tai chi reduced the rate of falls and injury-related falls over the short term (less than 12 months) by approximately 43% and 50% respectively. In another systematic review and meta-analysis on 18 trials with 3824 participants, the analysis suggested that the preventive effect of tai chi was greater with increasing frequency of tai chi and that the Yang style tai chi was more effective than the Sun style [90].

When tai chi has been compared to active control groups versus inactive control groups, the data are mixed. For example, in a randomized controlled trial, six months of tai chi was compared to lower extremity training in adults who had a history of falling [91]. The tai chi group was significantly less likely to experience falling and these effects, surprisingly, remained significant after 12 months of follow-up, suggesting that many of the participants continued tai chi practice on their own. To that point, those who practiced independently seven times per week or more were even less likely to experience falls. However, in another systematic review and meta-analysis performed on the data from 10 studies involving 720 participants, tai chi significantly reduced falls as compared to no treatment groups of adults with Parkinson's disease and stroke, but when tai chi was compared to active control groups, there was no difference between tai chi and the other exercise groups [92].

Most of the tai chi interventions for fear of falling and for falling have focused on balance training. In a systematic review on 27 randomized controlled trials on tai chi for balance, tai chi was performed for an average of 57 minutes per session for three sessions per week for 20 weeks [93]. In another systematic review on 4 studies, the data suggested that balance was improved as measured by postural stability [55]. This has typically been shown by stability while ascending or descending stairways, by postural control during a distracting cognitive task and by resisting perturbation to the upper limbs. In a study on descending stairs, a tai chi group was compared to a brisk walking group [94]. Greater body stability was noted in the tai chi participants as evidenced by decreased horizontal velocity and center of mass sway as well as increased foot clearance. These effects were more evident during low illumination than high illumination, suggesting that the tai chi participants compensated to stabilize their bodies to a greater degree during low illumination. The same group of investigators reported that the tai chi participants when ascending stairs increased their body stability under low illumination by increasing their foot clearance, head inclination angle and center of mass sway [95].

In recent studies on dual tasking that involve movement during a distracting cognitive task, tai chi practitioners have shown good body stability. For example, in a study on moving forward and backward (single task) with and without a cognitive task (counting backwards), the tai chi practitioners versus the non-practitioners showed shorter reaction times and faster movement velocities [96]. In another dual-tasking study, women were randomly assigned to a 12-form Yang style tai chi training or a control group [97]. Their balance was assessed by total sway path and center of pressure while the women stood on a single leg after stepping down a step with and without a concurrent auditory Stroop test. The tai chi group not only showed significantly less sway path suggesting greater postural control but also made fewer errors on the Stroop test. Postural control has also been assessed during standing perturbed by upper limb movement in a couple studies. In one of these studies, three groups were compared including a tai chi, brisk walking and a sedentary group [98]. Once again, the tai chi group showed less posture sway [98]. In the other study on lateral postural perturbation, electromyography signals were collected on several leg muscles showing enhanced neuromuscular reactions in the tai chi versus jogging and sedentary control groups [99].

Kinesthesia or proprioception has also been notably greater for the lower limbs of tai chi practitioners. In one study, the data suggested that after 24 weeks of tai chi, kinesthesia of knee flexion and extension as well as ankle dorsiflexion increased [100]. After 48 weeks, those effects were even greater and plantar flexion was also improved. In a systematic review and meta-analysis, 11 trials met criteria and suggested that tai chi had significant positive effects on the proprioception of the lower limbs [101].

Further, tai chi has been noted to increase lower extremity strength, which has helped balance. For example, greater strength has been noted in several muscles including the quadriceps and hamstrings involving knee extension when long-term tai chi practitioners have been compared to non-practitioners [102,103]. And, finally, with regard to balance, gait parameters have improved including gait stride time in at least two studies on those who have experience with tai chi [104,105] and in a systematic meta-analysis on five randomized controlled trials on gait measures [106].

Osteoporosis

Osteoporosis is a particular problem in postmenopausal women and is associated with the risk of falling and fractures, bone mineral density loss and pain issues. In a study to improve balance, postmenopausal women with osteoporosis were randomly assigned to a six-month tai chi program (two times per week) or a control group [107]. At the end of the study, the tai chi group had better standing balance and less pain.

Bone mineral density has been the focus of so many studies that four systematic reviews and meta-analyses have appeared in the recent literature on tai chi for postmenopausal women. In one of these, five trials combined to suggest that tai chi reduced pain and increased bone mineral density in the spine, although it had no effect on bone mineral density in the hip [99]. A similar systematic review and meta-analysis on 11 studies also showed an increase in bone mineral density in the spine, although when tai chi was combined with calcium supplement and compared to calcium supplement alone, there were no group differences [108]. In a meta-analysis on 15 randomized controlled trials involving 857 patients, bone mineral density increased and osteoporotic pain decreased in the tai chi groups versus the no treatment groups [109]. Finally, in a systematic review on nine studies totaling 1222 participants, five studies showed statistically significant increases in bone mineral density after tai chi, while three studies showed non-significant differences [110]. Notably, those studies with non-significant results had a shorter duration tai chi practice.

Parkinson's Disease

Both physical and cognitive function have been the focus of tai chi studies for patients with Parkinson's disease including two randomized controlled trials and three systematic reviews/meta-analyses. In a study on cognitive function, group-based tai chi training was compared to individual-based training [111]. Only the group-based training patients showed significant improvement on cognitive function. However, that group also had a higher home-exercise compliance rate which could explain their greater improvement. In a study that was focused on balance in patients with Parkinson's, tai chi was exercised at the clinic two times a week and at home one time per week for 12 weeks [112]. The tai chi as compared to a control group showed significant improvements

in balance (standing on 1 foot with eyes opened). In a systematic review of 11 studies on tai chi for adults with Parkinson's, tai chi groups had better balance, although mixed results were noted [113]. As the authors suggested, future research is needed with larger samples, greater doses of tai chi and measures that assessed mechanisms as well as effects. In another meta-analysis on five randomized controlled trials that included 355 Parkinson's patients, improved balance was again reported along with decreased fall rates and increased functional mobility [114]. In still another meta-analysis on 15 randomized controlled trials including 735 participants, tai chi was associated with significant improvement on most motor measures including improved balance and reduced falling as well as decreased depression [115].

Physiological Markers

A few physiological markers of tai chi have been explored in the recent literature. These include increased heart rate variability, functional connectivity between different parts of the brain and increased gray matter volume (Table 9).

Markers	First authors
Increased heartrate variability (vagal activity)	[116-119]
Increased prefrontal cortical activity	[120,121]
Increased functional connectivity	[122-125]
Increased gray matter volume	[126,127]

Table 9: Physiological markers and first authors.

Heart Rate Variability (Vagal Activity)

Heart rate variability (vagal activity) has been considered a marker of health with low variability indicating compromised health [116]. Tai chi is a form of aerobic exercise that is associated with diaphragmatic breathing, and both aerobic exercise and diaphragmatic breathing have enhanced heart rate variability. It is therefore not surprising that heart rate variability has been increased by tai chi. In a study on heart rate variability, tai chi practitioners whose practice averaged approximately 21 years were compared with non-practitioners matched on age, sex and education [117]. The tai chi practitioners had greater vagal activity and a greater balance between parasympathetic and sympathetic activity during relaxation. In a 12-week tai chi training, women with fibromyalgia showed significant increases in parasympathetic tone (vagal activity) and this was, in turn, correlated with reduced pain and increased strength and flexibility [118]. In a randomized controlled trial on patients undergoing chemoradiotherapy, tai chi led to greater heart rate variability and less general, physical and emotional fatigue [119].

Heart rate variability has also been associated with prefrontal oxygenation during tai chi in at least two studies in which tai

chi was compared to arm ergometer cycling (a low-impact cardiovascular exercise that works both flexors and extensors in the shoulders, scapula and elbows). In the first of these studies, the two forms of exercise occurred on two separate days and the tai chi versus the cycling led to greater parasympathetic activity as well as higher prefrontal oxyhemoglobin and total hemoglobin levels [120]. In a later study by the same research group, practitioners who had practiced for at least seven years were compared to non-practitioners [121]. Tai chi was performed after watching a video of 12-form Yang style. Prefrontal cortical activity was measured using the prefrontal oxygenation level as measured by near-infrared spectroscopy. Higher levels of oxyhemoglobin and total hemoglobin were noted in the practitioner group. Although the researchers interpreted this finding as tai chi having greater cognitive effects, it is also possible that the arm ergometer cycling may have been more strenuous than the tai chi and thus had less positive effects.

Functional connectivity between various areas of the brain has also increased following tai chi training. For example, following a 12-week tai chi training, increased functional connectivity was noted between the medial prefrontal cortex and the right putamen/caudate based on resting-state fMRI scans [122]. In another study, experienced practitioners were compared to non-practitioners, and tai chi training improved the functional connectivity between the prefrontal cortex, the motor cortex and the occipital cortex [123]. And, in a systematic review, 11 studies based on fMRI, EEG and MRI data suggested not only increased functional connectivity but also increased cortical thickness [124]. These alterations in brain connectivity have been associated with improved motor function, cognitive function, mental health and sleep quality [125].

Gray matter volume has also increased following tai chi training. Structural changes in the brain including atrophy of gray matter are associated with aging. In a study on elders with long-term tai chi experience, those practitioners were matched with a control group on age, gender, and physical activity level [126]. The gray matter volume of the thalamus and the hippocampus were greater in the tai chi group and the gray matter volume of the thalamus was positively correlated with both meditation level and emotional stability. In a study by a different group of investigators, significantly increased gray matter volume was noted in the insula, medial temporal lobe and putamen after 12 weeks of tai chi exercise [127]. As might be expected, memory scores were correlated with the increased gray matter volume of the hippocampus.

Other Forms of Tai Chi

Other forms of tai chi including wheelchair tai chi and ai chi (water tai chi) have had positive effects. In a randomized controlled trial, seated tai chi training occurred three times a week for 26 weeks in a sample of older people using wheelchairs [128]. At the end of the treatment period, those who received tai chi versus a

group that engaged in their usual activity had fewer depression symptoms and better quality of life, general health, physical health and psychological health. In a study on seated tai chi for individuals with spinal cord disorder, the participants reported less pain and a greater physical and emotional sense of well-being [129]. Following another 12-week wheelchair tai chi training among the elderly with a disability, significant improvements were noted in systolic and diastolic blood pressure as well as shoulder external rotation and trunk rotation [130]. In a comparison between ai chi (an aquatic motor intervention) and tai chi (an identical on-land motor intervention), 14 weeks of training led to greater balance as well as better performance on the digit span forward test in the ai chi versus the tai chi group [131]. The better ai chi group performance may relate to the water resistance providing stimulation to the entire body versus the tai chi providing stimulation primarily to the upper and lower limbs.

Limitations and Future Directions

Several of the limitations of the older literature previously reviewed have remained problems for the recent tai chi studies [1]. One problem is that many different tai chi styles have been tried with different conditions. A specific type of tai chi may be more beneficial for a specific condition, suggesting that the different tai chi styles should be compared as opposed to comparing tai chi with other types of exercise. The two most popular styles, Yang and Sun styles, have been compared in at least one study in which the Yang style had more positive effects [132]. The greater effects for a chi versus tai chi sessions is another example of how different forms of tai chi yield differential effects [131].

Another problem is that tai chi combines leg and arm movements with breathing and deep concentration. Although leg and arm movements predominate most tai chi sessions, it is difficult to parse the effects of the different components. Tai chi is a low intensity exercise as it involves concentration and increased vagal activity (slowing of the nervous system) which may be the reason that it sometimes has lesser effects than an active exercise group that requires less concentration. The different components of tai chi may have additive effects, although their separate effects have not been studied. These components need to be elaborated in greater detail in order that tai chi studies can be replicated. The parameters of tai chi are also highly variable including individual versus group practice, the length of the sessions (20-90 minutes), the class frequency (daily, weekly) and the duration of the training period (weeks, months) [132-135].

The sampling for the research studies has also been highly variable, with some studies recruiting both beginners and long-term practitioners even though these two groups are different at baseline [117,136]. Long-term practitioners are often in better condition and practice tai chi on a regular basis. Although randomized controlled designs have more often appeared in this

recent literature on tai chi, several researchers are still using a pre-post within group research design. And the comparisons between tai chi and inactive control groups have typically yielded more positive effects for the tai chi group. However, when tai chi has been compared to another form of exercise, the groups typically haven't differed [137,138]. Sometimes the comparison exercise group has experienced more positive effects and sometimes it has not, likely because the exercise protocol was too rigorous. Tai chi may remain the exercise of choice for more fragile people like pregnant women and older adults because it is a less intense form of exercise and because it facilitates balance [139].

The recent literature continues to lack cross-cultural studies comparing tai chi effects in different cultural groups. Also, different age group and gender comparisons have rarely appeared. Although tai chi has been more frequently practiced by the elderly in China as well as most often studied by Chinese researchers, the tai chi practice has been rapidly growing in different cultures and in different age groups except for pediatric populations that have been rarely studied [140]. Most of the studies have continued to use self-report measures which are reputedly not as reliable as more objective observation measures. However, physical, physiological and biochemical measures have appeared more often in the recent literature including body mass index, blood pressure, cortisol, functional connectivity of regions of the brain and gray matter volume that have been enabled by more sophisticated technology including spectroscopy and fMRIs.

Future research should use randomized controlled trials in which different tai chi styles are compared. Shorter, simpler forms might help the participants more easily practice the forms. Multivariate studies are needed in which physical and physiological measures are combined with self-report protocols, and potential underlying mechanism studies are needed. Despite these methodological limitations, the recent literature has continued to highlight the therapeutic effects of tai chi.

Conclusion

This paper is a narrative review of empirical studies, systematic reviews and meta-analyses on tai chi published during the last few years (2016-2019). The review includes safety data as well as the use of tai chi for pediatric problems, cognitive function, psychiatric, medical and immune conditions. Tai chi research continues to be predominantly focused on aging problems, most especially falling and facilitating balance. Recent research has also explored potential underlying mechanisms including increased heart rate variability, functional connectivity between different areas of the brain and increased gray matter volume. Brief summaries are given of the methods and results of studies along with their limitations and suggestions for future research. In most studies, tai chi has been more effective than treatment as usual and waitlist control conditions, although tai chi has not always been

more effective than other forms of exercise. More randomized controlled trials are needed in which tai chi styles are compared to each other as well as shorter sessions for greater compliance. And, potential underlying mechanisms need to be further explored. Nonetheless, the studies reviewed here continue to highlight the therapeutic effects of tai chi.

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