RESEARCH ARTICLE

The Effect of Tai Chi Training on Cardiorespiratory Fitness in Healthy Adults: A Systematic Review and Meta-Analysis

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Abstract

Background
Tai Chi may be efficient for healthy adults to improve the cardiorespiratory fitness, but there is no systematic evaluation for its effectiveness.

Objective
To systematically assess the effectiveness of Tai Chi on cardiorespiratory fitness in healthy adults.

Methods
Seven electronic databases were searched from their inception to October 2013. The controlled trials including randomized controlled trial (RCT), non-randomized controlled trial (NRCT), self-controlled trial (SCT), and cohort study (CS) testing Tai Chi exercise against non-intervention control conditions in healthy adults that assessed any type cardiorespiratory fitness outcome measures were considered. Two reviewers independently performed the selection of the studies according to predefined criteria. The risk of bias was assessed using Cochrane criteria. RevMan 5.2 software was applied for data analysis.

Results
Twenty studies (2 RCTs, 8 NRCTs, 3 SCTs, and 7 CSs) with 1868 participants were included, but most of them belonged to low methodological quality. The results of systematic review showed that Tai Chi exercise had positive effect on majority outcomes of cardio function (Blood pressure: n = 536, SPB SMD = -0.93, 95% CI -1.30 to -0.56, P < 0.00001; DBP SMD = -0.54, 95% CI -0.90 to -0.18, P < 0.00001; heart rate at quiet condition: n = 986, SMD = -0.72, 95% CI -1.27 to -0.18, P = 0.010; stroke volume: n = 583, SMD = 0.44, 95% CI 0.28 to 0.61, P < 0.00001; cardio output: n = 583, MD = 0.32 L/min, 95% CI 0.08 to 0.56, P = 0.009), lung capacity (FVC at quiet condition: n = 1272, MD = 359.16 mL, 95% CI 19.57 to 698.75, P = 0.04 for less than one year intervention, and MD = 442.46 mL, 95% CI 271.24 to
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613.68, \( P < 0.0001 \) for more than one year intervention; \( V \cdot O_2 \text{peak} \): \( n = 246, \text{SMD} = 1.33, 95\% \text{ CI} 0.97 \text{ to } 1.70, \text{P} < 0.00001 \), and cardiorespiratory endurance (\( O_2 \) pulse at quiet condition: \( n = 146, \text{SMD} = 1.04, 95\% \text{ CI} 0.69 \text{ to } 1.39, \text{P} < 0.00001 \); stair test index at quiet condition: \( n = 679, \text{SMD} = 1.34, 95\% \text{ CI} 0.27 \text{ to } 2.40, \text{P} = 0.01 \). No adverse events were reported.

Conclusions

The results are encouraging and suggest that Tai Chi may be effective in improving cardiorespiratory fitness in healthy adults. However, concerning the low methodological quality in the included studies, more larger-scale well-designed trials are needed till the specific and accurate conclusions can be perorated.

Introduction

Cardiorespiratory fitness (CRF) is a measure of the capacity of the cardiovascular system to transport oxygen and the ability of the muscles to use it. Furthermore CRF indicates the ability of the circulatory, respiratory, and muscular systems to supply oxygen to skeletal muscles during sustained physical activity [1]. It therefore is strongly associated with various health outcomes. Substantial data have demonstrated that CRF is associated with morbidity and mortality in general population independently of other risk factors [2–4]. Compared with the individuals with the low level CRF, those with high level CRF had 53% lower risk for all-cause mortality for women and 43% for men [5]. Moreover, the efficient CRF has benefit to reduce the risk of heart disease, lung cancer, type 2 diabetes, stroke, and other chronic diseases [6–7]. However, with increasing of age in the general population, cardiorespiratory system generates certain changes in shape and functionality, which shows the angiosclerosis of arterial vascular walls, the decline of blood vessel compliance, enlargement of peripheral resistance, increase of blood pressure, decline of respiratory muscle function and low-efficiency work of breathing [8]. Thus low CRF is an important risk factor for the development of cardiovascular disease. CRF also is an independent predictor of mortality, and provides significantly more accurate prognostic information [9].

Although CRF has a genetic contribution, physical activity habits are its primary determinant in adults, and changes in physical activity levels result in changes in CRF [10–12]. Furthermore intensity and duration of physical activity may emerge as the best independent predictor of CRF [13–14]. A number of published studies have demonstrated that regular physical activity can significantly increase aerobic capacity as well as lung capacity and decreased heart rate [15–17]. Previous studies also testified that physical activity and exercise training resulted in significant cardiorespiratory fitness improvements not only in healthy populations [18] but also in patients of traumatic brain injury [19].

Tai Chi (TC), also known as Tai Chi Chuan, developed originally as a martial art from the 17th century, and has been practiced for centuries in China as a no-contact, low-impact, soft body and mindfulness exercise for health promotion in general population [20–21]. The basic action of TC is “a series of individual movements linked together a continuous manner that flow smoothly from one movement to another” [22]. The practitioners were required to keep deep diaphragmatic and rhythmic breathing, and integrate into body motions to harmonize the body balance and mental concentration when TC is practiced [23]. It’s also principled upon breathing and neuromuscular active relaxation with slow and gentle movement meanwhile maintaining stable postures [24]. Studies have been performed to examine the effect of TC exercise on the physical condition of a wide age range [25–26] particularly in the elder people [27–28]. Beneficial
improvement has been reported on blood pressure, immune capacity, mental control, flexibility, and balance control [29–30]. Currently, the increasing data from clinical trials and exercise intervention studies found that TC exercise associated with the improvement of CRF in both healthy people and patients with chronic diseases. For example, some studies indicated that TC training with low to moderate intensity is of great positive importance on outcomes of CRF including the oxygen uptake (\(V\text{O}_2\)), O\(_2\) pulse [31], ventilatory efficiency [32], lung function [33–35], blood pressure [36], aerobic endurance [37] and exercise capacity [38]. The results from a meta-analysis and its update suggested that Tai Chi might be effective in improving the aerobic capacity of CRF outcomes among sedentary adults with over 55 years old [39–40], whereas another previous systematic review found no significant differences [41]. Furthermore those previous review or meta-analysis did not involve in other outcomes of CRF. Therefore the convincing evidence of Tai Chi on improving CRF in the general healthy population or patients with chronic diseases was yet unclear. To our knowledge, no systematic reviews have evaluated the effect of Tai Chi exercise on the outcomes of CRF in healthy adults. We therefore designed this systematic review to investigate the effectiveness and safety of Tai Chi exercise on the outcomes of CRF in healthy adults.

**Methods**

**Eligibility Criteria**

Available human clinical or community studies with a randomized controlled, non-randomized controlled, self-control trials and cohort design published in English or Chinese were included in this review. The participants were defined to healthy adults. The included studies should focus on the effect of TC exercise for CRF comparing with non-intervention, which those comparing TC with other exercise intervention were excluded. Outcomes measures for CRF assessment should cover at least one of essential outcomes such as heart rate, stroke volume, cardiac output, myocardial oxygen consumption, left heart energy effective utilization, left ventricular effective pump power, gas exchange rate, forced vital capacity, forced vital capacity in the first second, maximal minute ventilation, peak oxygen uptake, myocardial oxygen consumption, oxygen pulse, expansion coefficient of elasticity of blood vessels.

**Data Sources and Searches**

The original research articles were searched from 7 electronic English and Chinese databases which covered PubMed, Science Citation Index (SCI), EMBASE, Cochrane library, Chinese Scientific Journal Database (VIP), China National Knowledge Information database (CNKI) and Wan Fang from their inception to October 2013. We used the following search strategy ((Taiji OR Tai Chi OR Chi, Tai OR Tai Ji Quan OR Ji Quan, Tai OR Quan, Tai Ji OR Tai-ji OR Taijiquan OR T'ai Chi OR Tai Chi Chuan) AND (cardiorespiratory function OR maximal oxygen OR FVC OR Forced Vital Capacity OR gas exchange rate OR stroke volume OR VE OR minute ventilation OR minute respiratory volume OR EWK OR myocardial oxygen consumption OR HOV OR MOCI OR HOI OR maximal oxygen consumption OR FEK OR expansion co-efficient of elasticity of blood vessels OR heart rate OR blood pressure OR oxygen pulse) AND (control OR comparison OR controlled trial)) in the English databases and (Taiji AND cardiorespiratory function AND comparison) in the Chinese databases. The detail of search strategies can be found in [S1 File](#). The reference lists of identified articles were also searched.

**Study Identification and Quality Assessment**

Two reviewers (LSZ and HMM) independently screened the title and abstract of the searched studies. Full text of the studies that potentially met the eligibility criteria were obtained, and the
potentially relevant references were retrieved according to predefined eligibility criteria. Data was extracted by one reviewer (LSZ) using the prepared forms and checked for accuracy by the second (HMM). The extracted details from eligible literatures included the language of publication, age of participants, methodological information, demographics of participants, sample size, experimental and control interventions, duration, frequency and style of TC exercise, outcomes, and adverse effects. Disagreements were resolved through discussion, and the original author was contacted with if the results could not come to an agreement.

Quality of studies was assessed independently by two reviewers (LSZ and LFW) using the Cochrane Collaboration’s tool for assessing the risk of bias [42]. The following recommended domains were considered: selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting) and other bias, each of which was rated according to the level of bias and categorized into either low, high, or unclear.

**Data Analysis**

Statistical heterogeneity among studies was assessed using a Chi-square test, or by calculating Higgins $I^2$ values [43]. The results were pooled using a fixed effect model when the $I^2$ value was less than 40%. Otherwise, a random effect model was applied. However if the $I^2$ value among studies was more than 75%, the heterogeneity was considered substantive and the overall meta-analysis was not appropriate to conducted but subgroup analysis was considered to measure the pooled effect. Sensitivity analysis was used to explore the source of heterogeneity. The mean difference (MD) or standard mean difference (SMD) with corresponding 95% confidence interval (CI) was calculated for the continuous outcomes. Review Manager 5.2 software of The Cochrane Collaboration was applied for data analysis and all $P$ values were two sided [44].

**Results**

**Description of Studies**

The detail screening flow about the generating of eligible articles was presented in the Fig. 1. A total of 532 records were identified through database searches. After removing duplicates, 395 remained to be screened for eligibility, and 23 were selected for a full-text evaluation. Of these, 3 studies were excluded, and reasons included: duplicate publication (n = 1) [45]; unqualified control intervention (n = 1) [46], and incomplete statistical results (n = 1) [47] (S2 File). Consequently, 20 literatures met with the inclusion criteria and 19 studies were included into meta-analysis. Table 1 illustrated the characteristics of the sample, intervention and outcomes. This review involved a total of 1783 healthy community-dwellers (age from 45 to 75 years old). And the design type of those included studies covered 2 randomized controlled trials (RCTs) [48–49], 8 non-randomized controlled trials (NRCTs) [50–57], 7 Cohort studies (CSs) [58–64] and 3 Self-controlled trials (SCTs) [65–67]. Few studies [49, 54, 56, 57, 63, 64] definitely described the type of Tai Chi used in their studies. Apart from the 3 Self-controlled trials, the remaining 17 trials compared TC with non-intervention. Moreover, all the measurement of outcomes utilized acknowledged apparatus and method. Additionally, TC has not been reported to be associated with adverse events during the intervention.

**Methodological Quality**

Of 2 included RCT, one trial described the random sequence generation by using the coin, and another utilized the blinding of outcome assessment. The remaining 18 trials were designed as non-
randomized control, Self-control trial and cohort study. 3 studies indicated no dropouts. 4 studies reported dropouts as well as withdraw, and described their numbers and reason in detail. In all, all included studies were considered high risk of bias. The detail of risk of bias was illustrated in Table 2.

**Measures of Effect**

**The effect of cardiovascular efficiency.** 12 studies involving in 753 participants reported the systolic and diastolic blood pressures which were measured at quiet condition and at immediately as well as 5 and 10 minute after exercise. Meta-analyses including 9 studies with 536 subjects revealed that SPB (SMD = -0.93; 95% CI-1.30 to-0.56; \( P < 0.00001 \); Fig. 2) and DBP (SMD = -0.54, 95% CI-0.90 to-0.18, \( P < 0.00001 \); Fig. 3) in TC exercise group significantly decreased at quiet condition comparing with non-intervention group. But significant changes on SBP or DBP between groups were not observed at immediately, 5 and 10 minutes after exercise except for the SBP at 10 minute. Moreover, one non-randomized study reported that the blood
| Author, year | Study design | Place of study | No. of participants (T/C) | Age (year) | Intervention | Frequency and Duration of Tai Chi exercise | Outcomes |
|-------------|--------------|----------------|--------------------------|------------|--------------|------------------------------------------|-----------|
| Nguyen et al. 2012 (48) | RCT | Vinh, Vietnam | 96(48/48) | 69.23±5.3 | Tai Chi | Non-intervention | 60 minutes per time and twice per week for 6 months | HR,SBP,DBP |
| Lu et al.2012 (49) | RCT | Taiwan, China | 50(25/25) | 50–67 | Yang’s Tai Chi Chung | Non-intervention | 40 minutes per time and 7 times per week for 3 months | FVC,FEV₁,SBP, DBP |
| Tu HL 2005 (50) | NRCT | Hubei, China | 32(16/16) | 61.64±4.21 | Taijiquan | Non-intervention | 12 minutes per time and 3 times per week for 10 weeks | SV,CO,VPE, EWK,HOV, SBP,DBP |
| Xu and Wen 1997 (51) | NRCT | Sichuan, China | 34(18/16) | 47–59 | Yang’s Tai Chi Chung | Non-intervention | 60 minutes per time and 4 times per week for 8 weeks. | HR,SBP,SBP,MMVFVC |
| Lu et al.2012 (52) | NRCT | Gansu, China | 60(30/30) | 50–70 | Yang’s Tai Chi Chung | Non-intervention | 35 minutes per time and more than 4 times per week for 1 year. | SBP,SBP,HR, FVC, Step test index |
| Chang et al.2013 (53) | NRCT | Taiwan, China | 39(21/18) | 60.05±4.48 | Yang’s Tai Chi Chung | Non-intervention | 1 hour and 4.6 ± 1.3 times per week for 11.2 ± 1.4 months. | HR,VO₂peak,O₂ pulse, MMV |
| Thornton et al. 2004 (54) | NRCT | UK | 40(20/20) | 47.2±4.07 | Yang’s Tai Chi Chung | Non-intervention | three times per week for 12 weeks. | SBP,SBP |
| Lu et al.2003 (55) | NRCT | Taiwan, China | 40(20/20) | 52.8±7.5 | Yang’s Tai Chi Chung | Non-intervention | 40 minutes per time and 3 times per week for an average of 1.9±1.0 years. | SBP,SBP |
| Rong et al.2009 (56) | CS | Beijing, China | 421(212/209) | Over 45 | Taijiquan | Non-intervention | More than 30 minutes per time and more than 4 times per week for more than 5 years. | FVC, Step test index |
| Yan Y 2013 (57) | CS | Liaoning, China | 98(48/50) | Over 45 | Taijiquan | Non-intervention | More than 30 minutes per time and more than 3 times per week for 1 year. | FVC, Step test index |
| Li XH 2008 (58) | CS | Liaoning, China | 60(30/30) | 65.3±4.8 | Taijiquan | Non-intervention | From 40 to 60 minutes per time and more than 4 times per week for 1 years. | FVC,HR,SV,CO |
| Peng CZ 2000 (59) | CS | Zhejiang, China | 380(180/200) | 61.94±3.64 | Taijiquan | Non-intervention | More than 30 minutes per time and 3 times per week for 5 years | FVC,HR,SV, CO,MMV |
| Liang YW 2001(60) | CS | Guangdong, China | 33(15/18) | 66.7±7.4 | Taijiquan | Non-intervention | No description | FVC,HR,SV, CO,MMV,SBP, DBP |
| Lai et al.1995 (61) | CS | Taiwan, China | 84(45/39) | 62.6±6.1 | Yang’s Tai Chi Chung | Non-intervention | 54 minutes per time and 5 times per week for 2 years. | HR,VO₂peak,O₂ pulse, MMV |

(Continued)
pressure had a significant decrease regardless of systolic or diastolic blood pressure after 12 weeks TC training, whereas no obvious change was found in the control group [68].

11 studies with 986 participants reported heart rate outcome which was measured at quiet condition in 6 studies and immediately after exercise in other 5 studies. Of 6 studies with HR measured at quiet condition, the pooled result of meta-analysis showed a significant decline (SMD = -0.72; 95% CI -1.27, -0.18; P = 0.010; Fig. 4). But heterogeneity among studies was substantive with $I^2 = 89\%$, and not obviously changed after sensitivity analysis by removing any one of those studies. No study but one (Wang 2010) was found a significant effect on heart rate at immediately measured after exercise. But pooled analysis showed a significant increase (SMD = 3.10; 95% CI 0.91 to 5.29) with a substantive heterogeneity ($I^2 = 98\%$, $P = 0.005$). The pooled result was changed as SMD being 0.13 (95% CI 0.08 to 0.56; $P < 0.00001$; Fig. 5) after sensitivity analysis was conducted by removing Wang 2010.

Stroke volume (SV) and cardio output (CO) were evaluated at quiet condition in 5 studies involving 583 participants, and were immediately evaluated after exercise in one study with 33 participants. Comparing to non-intervention, results of meta-analyses revealed that SV and CO in participants with TC exercise at quiet condition had a significant improvement with the pooled SMD of SV being 0.44 (95% CI 0.28 to 0.61; $P < 0.00001$; Fig. 5) and pooled MD of CO being 0.32 L/min (95% CI 0.08 to 0.56; $P = 0.009$; Fig. 6), respectively. One study reported a significant improvement in SV other than CO at immediately evaluated after exercise.

2 studies involving 110 participants measured outcomes about Myocardial oxygen consumption (HOV), Left heart energy effective utilization (EWK) and Left ventricular effective pump power (VPE) at quiet condition. Comparing to controls, the significant reduction on the HOV (MD = -4.11 mL/min; 95% CI -7.31 to -0.91; $P = 0.01$; Fig. 7) and increase on the EWK (MD = 0.02%; 95% CI 0.00 to 0.04; $P = 0.03$; Fig. 8) in participants with TC exercise were observed. But the significant changes was not found in the VPE outcome (MD = -0.03 Kg/n; 95% CI -0.14 to 0.07; $P = 0.55$; Fig. 9).

The effect of respiratory efficiency. Forced vital capacity (FVC) was measured at quiet condition in 9 studies (involving in 1272 participants), and measured immediately after exercise in

| Author, year | Study design | Place of study | No. of participants (T/C) | Age (year) | Intervention | Frequency and Duration of Tai Chi exercise | Outcomes |
|-------------|-------------|---------------|--------------------------|------------|--------------|------------------------------------------|----------|
| Lan et al. 2004 (64) | CS | Taiwan, China | 24(12/12) | 58.8 ±7.9 | 59.9 ±5.2 | Yang's Tai Chi Chuan | Non-intervention | 54 minutes per time and 3 times per week for 4.7 ±3.3 years. | HR, VO2peak, O2 pulse, MMV |
| Lei et al. 2001 (65) | SCT | Fujian, China | 39 | 61.87 ±4.4 | | Taijiquan. | | 30 minutes per time and 7 to 14 times per week for 1 year. | SV, CO, VPE, EWK, HOV, SBP, DBP |
| Han YZ 2010 (66) | SCT | Jilin, China | 50 | 61.1 ±6.14 | | Taijiquan | | No less than 1 hour per time and mean 4 times per week for 6 months | HR, SBP, DBP, FVC |
| Wang GJ 2010 (67) | SCT | Jilin, China | 50 | 63.5 ±2.8 | | Taijiquan | | No description | SBP, DBP, HR, FVC, VO2peak, Step test index |

Abbreviations: RCT, randomized controlled trial; NRCT, non-randomized controlled trial; CS, Cohort study; SCT, Self-control trial; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; SV, stroke volume; CO, cardiac output; HOV, myocardial oxygen consumption; EWK, left heart energy effective utilization; VPE, left ventricular effective pump power; FVC, forced vital capacity; FEV1, forced vital capacity in the first second; MMV, maximal minute ventilation; VO2peak, peak oxygen uptake; O2 pulse, oxygen pulse.
Table 2. The risk of bias about included studies.

| Author, year | Random sequence generation (selection bias) | Allocation concealment (selection bias) | Blinding of participants and personnel (performance bias) | Blinding of outcome assessment (detection bias) | Incomplete outcome data (attrition bias) | Selective reporting (reporting bias) | Other bias | Total bias |
|--------------|---------------------------------------------|------------------------------------------|----------------------------------------------------------|----------------------------------------------|------------------------------------------|-------------------------------------|-----------|-----------|
| Nguyen et al. 2012 (48) | Unclear | Unclear | High | High | Unclear | High | Unclear | High |
| Lu et al. 2012 (49) | Low | Low | High | High | Unclear | High | Unclear | High |
| Tu HL 2005 (50) | High | High | High | High | Unclear | High | Unclear | High |
| Xu and Wen 1997 (51) | High | High | High | High | Unclear | High | Unclear | High |
| Liu and Jin 2010 (52) | High | Unclear | High | Unclear | Unclear | High | Unclear | High |
| Yang and Fu 2010 (53) | High | High | High | High | Unclear | High | Unclear | High |
| Lan et al. 1998 (54) | High | High | High | Unclear | Unclear | High | High | High |
| Chang et al. 2013 (55) | High | High | High | Low | High | Unclear | Unclear | High |
| Thornton et al. 2004 (56) | High | High | High | Low | Unclear | Low | Unclear | High |
| Lu et al. 2003 (57) | High | High | High | High | Unclear | High | Unclear | High |
| Rong et al. 2009 (58) | High | High | High | High | Unclear | Low | Unclear | High |
| Yan Y 2013 (59) | High | High | High | High | Unclear | High | Unclear | High |
| Li XH 2008 (60) | High | High | High | High | Unclear | Unsure | Unclear | High |
| Peng CZ 2006 (61) | High | High | High | High | Unclear | High | Unclear | High |
| Liang YW 2001 (62) | High | High | High | High | Unclear | High | Unclear | High |
| Lai et al. 1995 (63) | High | High | High | Unclear | Unclear | High | Unclear | High |
| Lan et al. 2004 (64) | High | High | Unclear | Unclear | High | Unclear | High | High |
| Lei et al. 2001 (65) | High | High | High | High | Unclear | High | Unclear | High |
| Han YZ 2010 (66) | High | High | High | High | Unclear | Unclear | Unclear | High |
| Wang GJ 2010 (67) | High | High | High | High | Unclear | High | Unclear | High |

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2 studies with 67 participants (Fig. 10). Comparing to non-intervention, Subgroup analyses showed TC exercise had a mean of 359.16 mL improvement (95% CI 19.57 to 698.75, \( P = 0.04 \)) for less than one year intervention, and a mean of 442.46 mL improvement (95% CI 271.24 to 613.68, \( P < 0.0001 \)) for more than one year intervention. But heterogeneity among studies was substantive, and \( I^2 \) value were 92%, 82% respectively. The heterogeneity in subgroup with intervention period less than one year was not obviously changed after sensitivity analysis was performed by removing one of any studies. But in subgroup with intervention period more than one year, the heterogeneity among studies took an obvious change from \( I^2 = 82\% \) to 0% when sensitivity analysis was conducted by removing Yang and Fu 2010. Additionally, when measured immediately after exercise, the pooled result from 2 studies showed TC training significantly enlarged the FVC efficiently (MD = 670.00 mL; 95% CI 344.70 to 995.30; \( P < 0.0001 \)).

5 studies measured the maximal minute ventilation (MMV) at the quiet condition. Comparing to non-intervention, the subgroup analyses on the basis of the different intervention period showed TC exercise had significant improvement to MMV regardless of intervention period for less than 2 years (MD = 2.09 L/min; 95% CI 0.90 to 3.28; \( P = 0.0006 \)) or more than 2 years (MD = 7.02 L/min; 95% CI 5.96 to 8.09; \( P < 0.00001 \)). 3 studies immediately evaluated this outcome after exercise, and the pooled result showed a obvious improvement of MMV (MD = 1.84 L/min; 95% CI 0.40 to 3.27; \( P = 0.01 \)) in participants with TC exercise comparing with those with non-intervention (Fig. 11).

2 studies involving 70 participants reported the forced vital capacity in the first second (FEV\(_1\)) measured at quiet condition (Fig. 12). Result of meta-analyses showed no significant changes between TC exercise and control groups (SMD = -0.07; 95% CI-0.92 to 1.07; \( P = 0.89 \)).
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Figure 3 Tai Chi versus Non-intervention: Diastolic Blood Pressure.

Fig 3. Tai Chi versus Non-intervention: Diastolic Blood Pressure.
doi:10.1371/journal.pone.0117360.g003

Figure 4 Tai Chi versus Non-intervention: Heart Rate.

Fig 4. Tai Chi versus Non-intervention: Heart Rate.
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The peak oxygen uptake \((V\cdot O_2)_{\text{peak}}\) at quiet condition was evaluated in 4 studies with 246 participants (Fig. 13), and the pooled result showed a significant increase in TC exercise group (SMD = 1.33; 95% CI 0.97 to 1.70; \(P < 0.00001\)) with no heterogeneity.

The effect of cardiorespiratory endurance. 3 studies (involving 146 participants, Fig. 14) reported the oxygen pulse (O\(_2\) pulse) at quiet condition. Comparing to non-intervention, the result of meta-analyses showed a significant improvement (SMD = 1.04; 95% CI 0.69 to 1.39; \(P < 0.00001\)) in participants with TC exercise.
4 studies with 679 participants reported stair test index at quiet condition. The pooled result revealed a significant SMD for the effect of TC exercise on stair test index at quiet condition (SMD = 1.34; 95% CI 0.27 to 2.40; \( P = 0.01 \); Fig. 15). But heterogeneity among studies was substantive (\( I^2 = 96\% \), \( P < 0.00001 \)), and no obvious changes in heterogeneity by sensitivity analysis through removing any one of those studies.

Adverse events
No included study reported the adverse events.

Discussion

Summary of Main Results
In this systematic review, 20 studies with 1783 healthy adults comparing TC exercise with non-intervention were included. The measured outcomes on CRF involved in cardiovascular efficiency, respiratory efficiency, and cardiorespiratory endurance. The review indicated that TC
exercise might have a significant impact in improving cardiovascular efficiency by reducing resting blood pressure (SBP: SMD = -0.93; DBP: SMD = -0.94) and resting heart rate (SMD = -0.72), as well as enhancing stroke volume (MD = 0.44 mL/n) and cardiac output (MD = 0.32 L/min) at quiet condition, and HOV, EWK and VPE. There was substantial unexplained statistical heterogeneity observed in the resting blood pressure and resting heart rate, and small included studies in the HOV, EWK and VPE analysis, which suggested that the need for caution in interpreting these results. In addition, the present review also found significant improvement of TC exercise on respiratory function expressed by FVC, MMV, EFV1, VO2peak, and on cardiorespiratory endurance by measured stair test index and oxygen pulse. This review found no significant effect of Tai Chi exercise on VPE and EFV1. Nevertheless, these findings suggest that TC manifests promise as an optional exercise modality for the healthy adults to enhance CRF.

**Fig 9. Tai Chi versus Non-intervention: Left Ventricular Effective Pump Power.**

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**Fig 10. Tai Chi versus Non-intervention: Forced Vital Capacity.**

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Tai Chi is a Chinese traditional mind-body exercise with a low to moderate exercise intensity [69]. The exercise intensity of TC mainly depends on its training style, posture and duration, and variation in training style and duration will result in substantial differences in exercise intensity [70]. In the present review, Yang style Tai Chi was used in six included studies, and other 14 studies did not report the definite style of TC practiced (only Taiji or Taijiquan). Furthermore, their training duration of TC varied greatly; the length of time ranged from 8 weeks to several years and frequency from 2 times to 7 times per week with 12 to 60 minute per time. These discrepancies may prevent to elucidate the potential applications for TC. Previous systematic reviews indicated that TC might be safe and effective in reducing blood pressure, improving aerobic capacity and exercise tolerance for patients with cardiovascular conditions and risk factors [71–72]. However, no previous review systematically assessed TC exercise for cardiorespiratory function regardless of healthy population or patients. A narrative review [73] demonstrated TC exercise had beneficial effects on outcomes of cardiorespiratory function including resting blood pressure, oxygen uptake (VO2), oxygen pulse, step index, and peak work rate in healthy older or patients with chronic disease. Another narrative review also suggested...
that Tai Chi exercise might have benefits to cardiovascular risk factors, such as hypertension, diabetes, dyslipidemia, poor exercise capacity, and endothelial dysfunction in patients with CVD, and indicated that Tai Chi exercise might promote cardiovascular health for patients with CVD [74]. However, these results are difficult to confirm the effect of TC for cardiorespiratory function owing to the unclear controls for evaluating the comparisons and unknown methodological quality in included studies.

Limitations and Suggestions for Future Research

This review and meta-analysis included 20 studies and covered randomized controlled, non-randomized controlled, self-controlled trial and cohort study. And the conclusion can be, to a great extent, certified more comprehensively and accurately owing to the diversity of experiments design. Even though the meta-analysis has confirmed some promising conclusions, there is also a great deal of limitation. The review extracted a large amount of non-random controlled trails and cohort study as well as 3 self-control trails which had inherent imperfection with poor quality of methodology and high risk of bias. The trails were filled with multifarious interference factor, and the results of meta-analysis were triggered to reach high heterogeneity and low reliability. Furthermore, another primary and extremely important limitation of this review is the subgroup analysis. Some of subgroups with certain outcomes only included one study or two due to the limitation of eligible trails. Until more trails are available with identical outcomes, we didn’t evaluate accurately and broadly the effect of TC to CRF.

The increasing number of healthy community-dwellers was inclined to selecting TC as their fitness programs thanks to the free of limitation of field, instrument and gender. TC is regarded as

| Study or Subgroup   | Tai Chi Mean | SD  | Control Mean | SD | Total | Weight | Std. Mean Difference IV, Fixed, 95% CI |
|---------------------|--------------|-----|--------------|----|--------|--------|--------------------------------------|
| Lai et al.1995      | 9.25         | 2.4 | 8.5          | 1.83 | 45     | 39     | 56.6%                                |
| Lan et al.1998      | 8.55         | 1.83| 7.3          | 1.46 | 20     | 18     | 27.9%                                |
| Lan et al.2004      | 11.7         | 2   | 9.5          | 1.4  | 12     | 12     | 15.5%                                |
| Total               |              |     |              |    | 77     | 69     | 100.0%                               |
| Heterogeneity: Ch² = 1.15, df = 2 (P = 0.65); I² = 0% Test for overall effect Z = 5.83 (P = 0.00001) |

Figure 13 Tai Chi versus Non-intervention: Peak Oxygen Uptake.

Fig 13. Tai Chi versus Non-intervention: Peak Oxygen Uptake.
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| Study or Subgroup   | Tai Chi Mean | SD  | Control Mean | SD | Total | Weight | Std. Mean Difference IV, Fixed, 95% CI |
|---------------------|--------------|-----|--------------|----|--------|--------|--------------------------------------|
| Lai et al.1995      | 9.25         | 2.4 | 8.5          | 1.83| 45     | 39     | 56.6%                                |
| Lan et al.1998      | 8.55         | 1.83| 7.3          | 1.46| 20     | 18     | 27.9%                                |
| Lan et al.2004      | 11.7         | 2   | 9.5          | 1.4  | 12     | 12     | 15.5%                                |
| Total               |              |     |              |    | 77     | 69     | 100.0%                               |
| Heterogeneity: Ch² = 1.15, df = 2 (P = 0.65); I² = 0% Test for overall effect Z = 5.83 (P = 0.00001) |

Figure 14 Tai Chi versus Non-intervention: Oxygen Pulse.

Fig 14. Tai Chi versus Non-intervention: Oxygen Pulse.
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a kind of historic civilization treasure in China, adhering to the simple dialectical ideology which harmonizes Yin-Yang, dynamic-static state and facilitate homeostasis body and spirit. Especially, TC is a moderate form of exercise which requires control of balance and weight [75], and coordination of movements [76]. In addition to those, TC also need muscles relaxed whilst concentrating on the specific mental attention and mix deep breathing regulation and meditation together [77–78]. And just because of those, TC might be the preliminarily recommended as a fitness program for the adults especially for the elderly. TC has been shown to be a kind of effective program to improve CRF [21] and health fitness [54]. However, the research for TC is not lucubrated and comprehensive so far. We have searched more than ten thousands of studies in Chinese and over one thousand in English up to October 2013. Most of studies about TC cover balance, hypertension, autonomic nerve, cardiovascular, lung disease and so on. There are several trials about the influence of TC on the CRF for the elderly. However, no one study with low risk has described all the indicators about the CRF. And more random, single-blind paralleled trails are need conducted randomization and allocation concealment with more standardized outcomes.

Conclusion

The results of this review suggest that TC exercise is helpful for the healthy adults on improving the most outcomes of CRF, mainly on blood pressure, stroke volume, FVC, MMV, and VO2peak. However, concerning the low methodological quality, and the discrepancies of study design and TC training protocols in the included studies, the accurate conclusion can’t be drawn so far and these findings need to be interpreted cautiously. More larger-scale well-designed trails using standardized training protocols are needed till the specific and accurate conclusions can be perorated.

Supporting Information

S1 File. The detail of search strategy. (DOCX)

S2 File. The detail of excluded studies. (DOCX)

S1 PRISMA Checklist. (DOCX)

Author Contributions

Conceived and designed the experiments: GZ LC. Performed the experiments: SL. Analyzed the data: SL. Contributed reagents/materials/analysis tools: GZ. Wrote the paper: SL.
study and wrote several sections of the manuscript: GZ. In charge of coordination and direct implementation: JT. Helped to develop the study measures and analyses: MH FL. Contributed to drafting the manuscript and have read and approved the final manuscript: GZ SL MH FL JT LC.

References

1. Laukkanen JA, Kurl S, Salonen JT (2002) Cardiorespiratory fitness and physical activity as risk predictors of future atherosclerotic cardiovascular diseases. Curr Atheroscler Rep 4: 468–476. PMID: 12361495

2. Rentis JM, Treml TN, Vasdev N, French R, Dines G et al. (2013) Impaired cardiopulmonary reserve in an elderly population is related to postoperative morbidity and length of hospital stay after radical cystectomy. BJU Int 112: E13–19. doi: 10.1111/bju.12219 PMID: 23795790

3. Lee D-C, Artero EG, Sui X, Blair SN (2010) Mortality trends in the general population: the importance of cardiorespiratory fitness. J Psychopharmacol 24: 27–35. doi: 10.1177/1359786810382057 PMID: 20923918

4. Swift DL, Lavie CJ, Johannsen NM, Arena R, Earnest CP et al. (2013) Physical activity, cardiorespiratory fitness, and exercise training in primary and secondary coronary prevention. Circ J 77: 281–292. PMID: 23328449

5. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y et al. (2009) Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. JAMA 301: 2024–2035. doi: 10.1001/jama.2009.681 PMID: 19454641

6. Laaksonen DE, Lakkiva HM, Salonen JT, Niskanen LK, Rauramaa R et al. (2002) Low levels of leisure-time physical activity and cardiorespiratory fitness predict development of the metabolic syndrome. Diabetes Care 25: 1612–1618. PMID: 12196436

7. Barlow CE, LaMonte MJ, Fitzgerald SJ, Kamrath JB, Perrin JL et al. (2006) Cardiorespiratory fitness is an independent predictor of hypertension incidence among initially normotensive healthy women. Am J Epidemiol 163: 142–150. PMID: 16293717

8. Lang CC, Agostoni P, Mancini DM (2007) Prognostic significance and measurement of exercise-derived hemodynamic variables in patients with heart failure. Journal of Cardiac Failure 13: 672–679. PMID: 17923361

9. Snowden CP, Rentis J, Jacques B, Anderson H, Manas D et al. (2013) Cardiorespiratory fitness predicts mortality and hospital length of stay after major elective surgery in older people. Ann Surg 257: 999–1004. doi: 10.1097/SLA.0b013e31828dbac2 PMID: 23665968

10. Malagrinso PA, Sponton CH, Esposti RD, Franco-Penteado CF, Fernandes RA et al. (2013) Prevalence of dyslipidemia in middle-aged adults with NOS3 gene polymorphism and low cardiorespiratory fitness. Arq Bras Endocrinol Metabol 57: 33–43. PMID: 23440097

11. Fujie S, Iemitsu M, Murakami H, Sanada K, Kawano H et al. (2013) Higher cardiorespiratory fitness attenuates arterial stiffening associated with the Ala54Thr polymorphism in FABP2. Physiol Genomics 45: 237–242. doi: 10.1152/physiolgenomics.00089.2012 PMID: 23362142

12. Yu R, Yau F, Ho SC, Woe J (2013) Longitudinal changes in physical activity levels over 5 years and relationship to cardiorespiratory fitness in Chinese midlife women. J Sports Med Phys Fitness 53: 680–686. PMID: 24247192

13. Sloan RA, Haaland BA, Leung C, Padmanabhan U, Koh HC et al. (2013) Cross-validation of a non-exercise measure for cardiorespiratory fitness in Singaporean adults. Singapore Med J 54: 576–580. PMID: 24154583

14. Singhal N, Siddhu A (2014) Association of leisure-time physical activity with cardiorespiratory fitness in Indian men. J Phys Act Health 11: 296–302. doi: 10.1123/jpah.2012-0029 PMID: 23363544

15. Tsimaros V, Giagazoglou P, Foiladou E, Christoulas K, Angelopoulos N et al. (2003) Jog-walk training in cardiorespiratory fitness of adults with Down syndrome. Percept Mot Skills 96: 1239–1251. PMID: 12929778

16. Nakhkiwian C, Miay N, Sootmongkol A, Junprasert B, Yamamoto H et al. (2006) Effects of physical exercise on depression, neuroendocrine stress hormones and physiological fitness in adolescent females with depressive symptoms. Eur J Public Health 16: 179–184. PMID: 16126743

17. Ahmadi S, Masse-Biron J, Adam B, Choquet D, Freville M et al. (1998) Effects of interval training at the ventilatory threshold on clinical and cardiorespiratory responses in elderly humans. Eur J Appl Physiol Occup Physiol 78: 170–176. PMID: 9694317

18. Govindasamy D, Paterson DH, Poulin MJ, Cunningham DA (1992) Cardiorespiratory adaptation with short term training in older men. Eur J Appl Physiol Occup Physiol 65: 203–208. PMID: 1396647
19. Mossberg KA, Amonette WE, Masel BE (2010) Endurance training and cardiorespiratory conditioning after traumatic brain injury. J Head Trauma Rehabil 25: 173–183. doi: 10.1097/HTR.0b013e3181dc98f9 PMID: 20473091

20. Yan JH, Gu WJ, Sun J, Zhang WX, Li BW et al. (2013) Efficacy of Tai Chi on pain, stiffness and function in patients with osteoarthritis: a meta-analysis. PLoS One 8: e61672. doi: 10.1371/journal.pone.0061672 PMID: 23620778

21. Bu B, Haijun H, Yong L, Chaohui Z, Xiaoyuan Y et al. (2010) Effects of martial arts on health status: a randomized controlled trial. Disabil Rehabil 35: 1429–1435. doi: 10.1080/09638288.2012.737084 PMID: 23167499

22. Lee LY, Chong YL, Li NY, Li MC, Lin LN et al. (2013) Feasibility and effectiveness of a Chen-style Tai Chi programme for stress reduction in junior school students. Stress Health 29: 117–124. doi: 10.1002/smi.2435 PMID: 22674634

23._zoom out to full zoom – zoom in to full zoom

24. Cheon SM, Lan C, Chen SY, Lai JS, Wong AM (2013) Tai Chi Chuan in Medicine and Health Promotion. Evid Based Complement Altern Med 2013: 502131. doi:10.1155/2013/502131 PMID: 24159346

25. Birdee GS, Cai H, Xiang YB, Yang G, Li H et al. (2013) Tai Chi Training and Cardiorespiratory Fitness. J Altern Complement Med 19: 550–551. doi: 10.1089/acm.2012.0223 PMID: 23289529

26. Lee LY, Chong YL, Li NY, Li MC, Lin LN et al. (2013) Feasibility and effectiveness of a Chen-style Tai Chi programme for stress reduction in junior school students. Stress Health 29: 117–124. doi: 10.1002/smi.2435 PMID: 22674634

27. Tousignant M, Corriveau H, Roy PM, Desrosiers J, Dubuc N et al. (2013) Efficacy of supervised Tai Chi exercise training and falls prevention in frail older adults: a randomized controlled trial. Disabil Rehabil 35: 1429–1435. doi: 10.3109/09638288.2012.737084 PMID: 23167499

28. Li J, Hong Y, Chan K (2001) Tai Chi: physiological characteristics and beneficial effects on health. Br J Sport Med 35: 148–156. PMID: 11375872

29. Yeh GY, Wang C, Wayne PM, Phillips RS (2008) The effect of tai chi exercise on blood pressure: a systematic review. Prev Cardiol 11: 82–9. PMID: 18401235

30. Lan C, Chen SY, Lai JS, Wong MK (1999) The effect of Tai Chi on cardiorespiratory function in patients with coronary artery bypass surgery. Med Sci Sports Exerc 31: 634–6. PMID: 10331880

31. Xiong KY, He H, Ni GX (2013) Effect of skill level on cardiorespiratory and metabolic responses during Tai Chi training. Eur J Sport Sci 13: 347–352. doi:10.1080/17461391.2013.1057 PMID: 24210727

32. Chan AW, Lee A, Lee DT, Suen LK, Tam WW et al. (2013) The sustaining effects of Tai chi Qigong on physiological health for COPD patients: a randomized controlled trial. Complement Ther Med 21: 585–594. doi: 10.1016/j.ctim.2013.09.008 PMID: 24280465

33. Lo HM, Yeh CY, Chang SC, Sung HC, Smith GD (2012) A Tai Chi exercise programme improved exercise behaviour and reduced blood pressure in outpatients with hypertension. Int J Nurs Pract 18: 545–551. doi:10.1111/j.1744-9961.2011.01360.x PMID: 21383445

34. Taylor-Piliae RE, Froelicher ES (2004) Effectiveness of Tai Chi as exercise among middle-aged and elderly Chinese in urban China. J Altern Complement Med 10: 550–551. doi:10.1089/17461391.2013.1057 PMID: 24210727

35. Taylor-Piliae RE, Hoke TM, Hepworth JT, Latt LD, Najafi B et al. (2014) Effect of Tai Chi on physical function, fall rates and quality of life among older stroke survivors. Arch Phys Med Rehabil 95: 816–824. doi:10.1016/j.apmr.2014.01.001 PMID: 24440643

36. Leung RW, McKeeough ZJ, Alison JA (2013) Tai Chi as a form of exercise training in people with chronic obstructive pulmonary disease. Expert Rev Respir Med 7: 587–592. doi: 10.1586/17476384.2013.839244 PMID: 24224506

37. Taylor-Piliae RE, Hoke TM, Hepworth JT, Latt LD, Najafi B et al. (2014) Effect of Tai Chi on physical function, fall rates and quality of life among older stroke survivors. Arch Phys Med Rehabil 95: 816–824. doi:10.1016/j.apmr.2014.01.001 PMID: 24440643

38. Leung RW, McKeeough ZJ, Alison JA (2013) Tai Chi as a form of exercise training in people with chronic obstructive pulmonary disease. Expert Rev Respir Med 7: 587–592. doi: 10.1586/17476384.2013.839244 PMID: 24224506

39. See comment in PubMed Commons belowTaylor-Piliae RE, Froelicher ES (2004) Effectiveness of Tai Chi exercise in improving aerobic capacity: a meta-analysis. J Cardiovasc Nurs 19: 48–57. PMID: 14994782

40. Taylor-Piliae RE (2008) The effectiveness of Tai Chi exercise in improving aerobic capacity: an updated meta-analysis. Med Sport Sci 52:40–53. doi: 10.1159/000134283 PMID: 18487885
41. Lee MS, Lee EN, Emst E (2009) Is tai chi beneficial for improving aerobic capacity? A systematic review. Br J Sport Med 43:569–73. doi: 10.1136/bjsm.2008.053272 PMID: 19019905
42. Savović J, Weeks L, Sterne JA, Turner L, Altman DG et al. (2014) Evaluation of the Cochrane Collaboration’s tool for assessing the risk of bias in randomized trials: focus groups, online survey, proposed recommendations and their implementation. Syst Rev 3: 37. doi: 10.1186/2046-4053-3-37 PMID: 24731537
43. Higgins JPT, Thompson SG, Deeks JJ, Altman DG (2003) Measuring inconsistency in meta-analyses. Br Med J 327: 557–560.
44. Minton O, Richardson A, Sharpe M, Hotopf M, Stone P (2008) A systematic review and meta-analysis of the pharmacological treatment of cancer-related fatigue. J Natl Cancer Inst 100: 1155–1166. doi: 10.1093/jnci/djn250 PMID: 18695134
45. Lan C, Lai JS, Chen SY, Wong MK (2001) 12-month Tai Chi training in the elderly: its effect on health fitness. Medicine & Science in Sports & Exercise 35: 12–19. doi: 10.1097/00005768-200301000-00020 PMID: 12612327
46. Motivala SJ, Soliers J, Thayer J, Irwin MR (2006) Tai Chi Chih Acutely Decreases Sympathetic Nervous System Activity in Older Adults. J Gerontol A Biol Sci Med Sci 61: 1177–1180. PMID: 17167159
47. Fu X, Guo J (2009) The effect of Tai Chi training on the function and component of physical health in the elderly. Journal of Gansu Normal Colleges 14: 73–76.
48. Nguyen MH, Kruse A (2012) The effects of Tai Chi training on physical fitness, perceived health, and blood pressure in elderly Vietnamese. Open Access J Sports Med 3: 7–16. doi: 10.2147/OAJSMD.S27329 PMID: 24198581
49. Lu WA, Kuo CD (2012) Effect of 3-Month Tai Chi Chuan on Heart Rate Variability, Blood Lipid and Cytokine Profiles in Middle-Aged and Elderly Individuals. International Journal of Gerontology 6: 267–272.
50. Tu HL (2005) The effects of different exercise on the elderly cardiovascular system. Journal of Wuhan Institute of Physical Education 39: 70–73.
51. Xu M, Wen ZH (1997) The changes in cardiorespiratory function following before and after Tai Chi training in the elderly. Journal of Chengdu Physical Education Institute 3: 79–82.
52. Liu XD, Jin HZ (2010) The effect of Tai Chi training on cardiovascular fitness in the elderly. China Practice Medicine 5: 34–35.
53. Yan Y, Fu X (2010) The effect of Tai Chi on physical health in the mid-aged and elderly. Science Information 28: 271–272.
54. Lan C, Lai JS, Chen SY, Wong MK (1998) 12-month Tai Chi training in the elderly: its effect on health fitness. Med Sci Sports Exerc 30: 345–351. PMID: 9526879
55. Chang MY, Yeh SC, Chu MC, Wu TM, Huang TH (2013) Associations Between Tai Chi Chung Program, Anxiety, and Cardiovascular Risk Factors. Am J Health Promot 28: 16–22. doi: 10.4278/ajhp.120720-QUAN-356 PMID: 23470186
56. Thornton EW, Sykes KS, Tang WK (2004) Health benefits of Tai Chi exercise: improved balance and blood pressure in middle-aged women. Health Promot Int 19: 33–38. PMID: 14976170
57. Lu WA, Kuo CD (2003) The effect of Tai Chi chuan on the autonomic nervous modulation in older persons. Med Sci Sports Exerc 35: 1972–1976. PMID: 14652490
58. Rong XJ, Li CZ, Liang DD (2009) The effect of Tai Chi exercise on cardiorespiratory function in the mid-aged and elderly. Chinese Journal of Rehabilitation Medicine 24: 345–347.
59. Yan Y (2013) The effect of 24-type Tai Chi exercise on cardiorespiratory function in the mid-ade and elderly. Journal of Liaoning Normal University (Natural Science Edition) 36: 124–127.
60. Li KH (2008) The effect of Tai Chi training on cardiorespiratory function in the male elderly. Journal of Hunan Normal University (Natural Science) 36: 123–125.
61. Peng CZ (2006) The effect of Tai Chi training on body composition and cardiorespiratory function in the elderly. Fighting and martial science 6: 32–34.
62. Liang YW (2001) The effect of Tai Chi exercise on cardiorespiratory function in the elderly. Journal of Physical Education 8: 64–66.
63. Lai JS, Lan C, Wong MK, Teng SH (1995) Two-Year Trends in Cardiorespiratory Function Among Older Tai Chi Chuan Practitioners and Sedentary Subjects. J Am Geriatr Soc 43:1222–1227. PMID: 7594155
64. Lan C, Chou SW, Chen SY, Lai JS, Wong MK (2004) The Aerobic Capacity and Ventilatory Efficiency During Exercise in Qigong and Tai Chi Chuan Practitioners. Am J Chin Med 32: 141–150. PMID: 15154293
65. Lei XS, Ni HY, Chen QY, Zheng HW, Huang YF et al. (2001) The effect of 42-type Tai Chi exercise on cardiovascular function and Respiratory endurance in the mid-ade and elderly. Modern Rekabilititltion Journal 5: 64–65.
66. Han YZ (2010) Study on the phased evaluation of Tai chi training on Lung and Heart Function and ability of balance for elderly person. National Traditional Sports College, Northeast Normal University.

67. Wang GJ (2010) The effect of Tai Chi training on cardiorespiratory function in the elderly. Chinese Journal of Gerontology 12: 3802–3803.

68. Thornton EW, Sykes KS, Tang WK (2004) Health benefits of Tai Chi exercise: improved balance and blood pressure in middle-aged women. Health Promot Int 19: 33–38. PMID: 14976170

69. Lan C, Chen SY, Lai JS (2004) Relative exercise intensity of Tai Chi Chuan is similar in different ages and gender. Am J Chin Med 32:151–60. PMID: 15154294

70. Lan C, Chen SY, Lai JS (2008) The exercise intensity of Tai Chi Chuan. Med Sport Sci 52:12–9. doi: 10.1159/000134225 PMID: 18467882

71. Yeh GY, Wang C, Wayne PM, Phillips R (2009) Tai chi exercise for patients with cardiovascular conditions and risk factors: A SYSTEMATIC REVIEW. J Cardiopulm Rehabil Prev 29:152–60. doi: 10.1097/HCR.0b013e3181aa3379 PMID: 19471133

72. Ng SM, Wang CW, Ho RT, Zea TC, He J, et al. (2012) Tai chi exercise for patients with heart disease: a systematic review of controlled clinical trials. Altern Ther Health Med 18:16–22. PMID: 22875558

73. Li JX, Hong Y, Chan KM (2001) Tai Chi: physiological characteristics and beneficial effects on health. Br J Sport Med 35: 148–156. PMID: 11375872

74. Lan C, Chen SY, Wong MK, Lai JS (2013) Tai chi chuan exercise for patients with cardiovascular disease. Evid Based Complement Alternat Med 2013:983208. doi: 10.1155/2013/983208 PMID: 24348732

75. Gatts S (2008) A Tai Chi Chuan training model to improve balance control in older adults. Curr Aging Sci 1: 68–70. PMID: 20021375

76. Verhagen AP, Immink M, van der Meulen A, Bierma-Zeinstra SM (2004) The efficacy of Tai Chi Chuan in older adults:a systematic review. Fam Pract 21: 107–113. PMID: 14760055

77. Ho RT, Au Yeung FS, Lo PH, Law KY, Wong KO et al. (2012) Tai-Chi for Residential Patients with Schizophrenia on Movement Coordination, Negative Symptoms, and Functioning: A Pilot Randomized Controlled Trial. Evid Based Complement Alternat Med 2012: 923925. doi: 10.1155/2012/923925 PMID: 23304224

78. Yeh GY (2008) Commentary on the Cochrane review of Tai Chi for rheumatoid arthritis. Explore (NY) 4: 275–27. doi: 10.1016/j.explore.2008.04.011 PMID: 18602623