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A systematic review of the effectiveness of Tai Chi on fall reduction among the elderly

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ABSTRACT

Falls among the elderly is a major public health concern. There has been recent extensive research on the effects of Tai Chi in fall prevention among the elderly. As such, we undertook a systematic review to look for evidence on the effect of this intervention. There were seven randomized controlled trials, which met our objective and inclusion criteria. Our review has shown that Tai Chi has the potential to reduce falls or risk of falls among the elderly, provided that they are relatively young and non-frail. Further review is needed to look into the non-English studies, which assess the effectiveness of Tai Chi on fall reduction.

1. Introduction

Falls among the elderly is a major public health concern (Verhagen et al., 2004; Voermans et al., 2007). It has been reported that falls occurred in more than one third of the elderly aged 65 years and older annually (Blake et al., 1988; Tinetti et al., 1988). These have contributed to morbidity resulting from injuries, nursing home admissions, high medical costs, and deterioration of cognitive functions and even mortality. There is also the concern about the reduction in the quality of life subsequent to fall(s) among the elderly (Tinetti and Williams, 1997; Voermans et al., 2007). As life expectancy increases, the problem of falls among the elderly will become more pertinent (Voermans et al., 2007).

Mobility impairment involving balance, leg extension strength and gait, has been identified as a major risk factor of falls among the elderly (Graafmans et al., 1996). Of note, Tai Chi is an ancient form of exercise, which has been reported to be beneficial in enhancing balance control (Wolf et al., 1996, 2003a). An earlier systematic review has reported limited evidence of its effects in preventing falls in view of paucity of randomized controlled trials (Verhagen et al., 2004). There has been recent extensive research on the effects of Tai Chi in fall prevention among the elderly. As such, we performed a recent systematic review to look for conclusive evidence on the effect of this exercise intervention.

The objective of this review was to assess the effect of Tai Chi in reducing falls among the elderly.

All randomized controlled trials were eligible. These studies should examine the effect of Tai Chi on fall prevention compared to other forms of intervention or no intervention. The population was adults aged 60 and over. The primary outcome measure was occurrence of one or more falls.

2. Methods

2.1. Search strategy

We performed an exploratory search for the relevant search terms. The population, intervention and outcome categories were filled with alternative terms considering the terminology and spelling variations. These included elderly, aged or old for population; Tai Chi or Tai Ji for intervention and falls for outcome.

The following databases were searched: Medline (1950–2007), Embase (1980–2007), Cochrane Library, Web of Science and CAB Direct. A combination of MeSH terms and natural language terms was used with Boolean operators "or" or "and". These include "Elderly", "Falls" and "Tai Chi". Text searches were truncated to retrieve articles to avoid missing ones. The results were limited to randomized controlled trials. There was no limitation by publication year. We did not search the non-English database. This initial search yielded 345 articles but only 8 articles met the inclusion criteria from the full-text.

In addition, a citation search from the reference list of the retrieved articles was done. There were two likely relevant articles.

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None of the articles met the inclusion criteria. The Google Scholar was also searched and one article met the inclusion criteria. The Journal of the American Geriatrics Society was hand searched from January 2001 to August 2007. There were three likely articles but all were duplicates from the earlier search.

The search ended on 6 August 2007. Seven studies from nine articles met the objective and inclusion criteria from full text. There were four articles that referred to the same study (two articles for each study).

2.2. Review strategy

There were two reviewers who independently extracted information on the study characteristics, interventions and outcomes. Three reviewers compared the quality assessments and resolved differences by discussion in order to give a less biased interpretation.

2.3. Data extraction

The information, which included study design, study population and outcome measures, was extracted using a data extraction table (Table 1). In view of the heterogeneity in program and trial design of the seven studies, and limited data reported, we did not carry out a statistical meta-analysis.

2.4. Quality assessment

A full quality appraisal for these papers was made using a checklist developed by National Institute for Health and Clinical Excellence (NICE) for randomized controlled trials (NICE, 2006).

2.5. Description of studies

The description of the studies is shown in Table 1. Between 2001 and 2007 there were seven randomized controlled trials, which were conducted in the developed countries, like the United States for Study 1 (Wolf et al., 1996, 2003a), Study 3 (Wolf et al., 2003b), Study 2 (Nowalk et al., 2001), and Study 4 (Li et al., 2004, 2005), the Netherlands for Study 5 (Faber et al., 2006), Australia for Study 6 (Voukelatos et al., 2007) and Hong Kong for Study 7 (Woo et al., 2007).

The treatment allocation of Studies 1, 4–6 were single-blind, while Studies 3 and 7 were double-blind. The treatment allocation was not reported in Study 2.

Most of the studies provided a well coverage the primary objective of assessing the effect of Tai Chi on fall occurrences among the elderly. In Study 7, the main objective was to examine the effect of Tai Chi and resistance exercise on bone health, muscle strength and balance although their effect on fall occurrences was also reported.

The four famous styles of Tai Chi are Yang, Sun, Chen, and Wu, while Yang style Tai Chi is the most prevalent style today. Tai Chi styles vary in principle, form and function. The majority of the classes (83%) in Study 6 involved Sun-style Tai Chi, while the Tai Chi intervention in Studies 4 and 7 followed the 24-form Yang style. No specific Tai Chi style was identified in Studies 1 and 3, with Tai Chi forms synthesized into 10 and 6 forms, respectively. Studies 2 and 5 did not mention the specific styles and forms used in the Tai Chi intervention.

All the studies, except Studies 2 and 5, carried out purely Tai Chi without combining it with another form of intervention. Study 5 conducted in balance exercises which included principles or elements of Tai Chi while Study 2 combined Tai Chi with basic enhanced programming involving team management and education.

The choice of control differed across the studies. The controls in Studies 5–7 did not include any intervention during the study period. This was in contrast with the rest of the studies which included stretching, education, wellness program or basic enhanced programming for their controls.

Furthermore, Studies 1, 2, 5 and 7 examined the effect of other interventions in addition to Tai Chi and the controls. These included resistance exercise, functional walking, computerized balanced training and resistance/endurance plus basic enhanced programming.

All the studies reported fall occurrences as the outcome measure of the Tai Chi intervention. However, there were some outcome measures which were also reported but not common to all the studies. Examples were balance (Studies 4–7), grip strength (Studies 1–3, and 7) and fear of falling (Studies 1, 3–4).

All the studies involved community living elderly adults except for Studies 2–3 and 5 which involved elderly adults from long-term care or congregrate living facilities. The participants were at least 60 years of age.

It was interesting to note that although each study had its set of selection criteria, some selection criteria were similar in the studies. Participants with degenerating neurological disease (e.g., Parkinson's disease) were excluded in Studies 1 and 6; those neurological conditions with resultant mobility limitations were excluded in Study 7; and those unstable neurological conditions were excluded in Study 3. Studies 1–5 considered lack of cognitive impairment in their selection criteria although the severity or definition might have varied. Studies 6 and 7 excluded participants with dementia. Studies 1 and 6 also excluded participants with major stroke, severe or disabling arthritis or severe visual impairment. All the studies mentioned ambulation as a selection criteria: participants who could not ambulate (though to different extents in terms of distance) were excluded in Studies 5–7. Studies 1–2 and 4 included those who could ambulate; and Study 3 excluded those who were restricted to wheelchair. Studies 3–5 considered lack of medical conditions, lack of medical contra-indications to exercise or participation or clearance from doctor as selection criteria. Studies 3 and 7 excluded participants with severe cardiovascular disease and cardiopulmonary disease, respectively. Studies 1 and 3 excluded those with late-stage cancer. Study 6 included participants who had not practiced Tai Chi in the preceding 1 year while Study 7 excluded those who had already been practicing Tai Chi or other exercises regularly. Only Study 3 included participants who were in a transition phase to frailty and had experienced at least one fall in the preceding year.

There was a total of 1972 participants altogether. The studies varied in size from 112 to 702. The duration of the studies ranged from 15 weeks to 1 year. The mean age of the participants ranged from 68.2 to 84.9 years.

2.6. Methodological quality

In general, the included studies had methodological strengths and weaknesses according to the quality assessment checklist (NICE, 2006) (Table 2).

The main objective in most studies was appropriate in our systematic review. There was sufficient coverage of the randomization of participants in all the studies. Most of the studies ensured blinding of the participants or investigators as well as allocation concealment (Studies 1, 3–7). All the studies compared the baseline characteristics of the participants in the intervention and control groups. This was important for identifying possible confounding factors. The proportion of drop-outs was acceptable in most studies (Studies 1, 4–7). The intention-to-treat analysis was carried out in most studies (Studies 1–6).

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Table 1
Descriptions of selected papers

Study no.	Target group	Intervention/control	Months of follow-up (attrition rate)	Attendance
1	Community living adults aged ≥70 years. Relatively healthy and ambulant	Tai Chi (TC) for 15 weeks. Participants were expected to try TV forms for 15 min twice a day. Met twice a week, about 45 min a week contact with an instructor for each participant. Existing 108 forms of TC were synthesized into 10 forms; $n = 72$	4 months post-intervention; 13 drop-outs (7%)	13 participants were unable to complete participation (6 TC, 4 BT and 3ED)
	Mean age 76.2 years	Computerised balanced training (BT); $n = 64$		
	$n = 200$; 81% women	Control with Education (ED); $n = 64$		
2	Adults aged ≥65 years in long-term care facilities. Relatively ambulant	TC plus basic enhanced programming, also called "Living and Learning/Tai Chi" (LL/TC). 3 times a week for 1 year; $n = 38$	24 months following randomization; 30 drop-outs (2%)	24.2% average overall adherence for LL/TC group and 55.8% for FNBF group ($p < 0.001$)
	Mean age 84.7 years	Resistance/endurance plus basic enhanced programming, also called "Fit NB Free" (FNBF); $n = 37$		
	$n = 110$; 63.6% women	Control with Basic enhanced programming; $n = 35$		
3	Adults aged ≥70 years in congregate living facilities. Relatively healthy and ambulant Mean age 80.9 years (TC group) and 80.8 years (Wellness Education program, i.e. WE group)	TC for 48 weeks. Twice a week with duration increased from 60 min to ≥ 90 min over 48 weeks The 24 simplified TC forms were synthesized into 6 forms; n = 145.	11 months; 69 drop-outs (24%)	76% average attendance for TC group and 81% for WE group
	$n = 286$; 94.1% women	WE; $n = 141$		
4	Community living adults aged ≥70 years. Relatively healthy, inactive but ambulant	TC, 60-min session, 3 times a week for 6 months. Yang style with 24 forms; $n = 125$	6 months post-intervention; 47 drop-outs (21%), comprising 24 TC out of 115, and 23 Control out of 107	80% attendance on ≥ 50 sessions for TC group and 81% for control group. 61 out of 78 session sessions completed
	Mean age 77.48 years (S.D. 4.95)	Exercise stretching control, 60-min session, 3 times a week for 6 months; $n = 131$		
	$n = 256$; 69.9% women			
5	Elderly patients from 15 long-term care centres. Relatively ambulant	In balance (IB) exercises involving principles of TC for 20 weeks. 1 session per week for 4 weeks, followed by twice weekly sessions for 16 weeks. Each session 90 min, including 30 min social gathering. IB program included the 7 therapeutic elements of TC that have been identified as most beneficial for elderly; $n = 80$	Follow-up for 52 weeks; 6 drop-outs (2%)	84% median relative compliance for IB group and 88% for FW group. 32 out of 36 sessions completed on average
	Mean age 84.9 years (S.D. 6)	Functional walking (FW) exercises; $n = 66$		
	$n = 238$ (79% women)	Control with no change in usual pattern of activities; $n = 92$		
6	Community living adults aged ≥60 years. Relatively healthy and ambulant	TC classes conducted at 24 community venues. TC for 16 weeks. 1 h once per week	2 months of post-intervention; 18 drop-outs (3%) comprising 6 in TC, and 12 in Control	58.6% attendance in TC group for at least 13 out of 16 TC classes. 78.8% attendance for at least half of the classes. Overall attendance 71% of TC classes
	Mean age 69 years (S.D. 6.5)	The majority of classes involved Sun-style TC (83%), 2 classes involved Yang-style TC (3%), and the reminder involved a mixture of several styles (14%); $n = 353$		
	$n = 702$; 84% women	Control (no TC during study period but were offered a 16-week TC program at the end of study period); $n = 349$		
7	Community living adults aged 65–74 years. Relatively healthy and ambulant	TC for 12 months. 3 times a week. Yang style with 24 forms; $n = 60$	Prior to the 6-month follow-up, 4 drop-puts (2%)	81% mean attendance rate for TC group and 76.3% for RTE group
	Mean age 68.2 years	Resistance exercise (RTE) for 12 months. 3 times per week; $n = 60$	No attrition between 6 and 12 months	
	$n = 180$; 50% women	Control with no intervention; $n = 60$		

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Table 2
Methodological quality of studies[a]

	Study no.	1	2	3	4	5	6	7
1.1	The study addresses an appropriate and clearly focused question	Well covered	Well covered	Well covered	Well covered	Well covered	Well covered	Adequately addressed
1.2	The assignment of subjects to treatment groups is randomized	Well covered	Well covered	Well covered	Well covered	Well covered	Well covered	Well covered
1.3	An adequate concealment method is used	Poorly addressed	Not reported	Well covered	Well covered	Adequately addressed	Poorly addressed	Well covered
1.4	Subjects and investigators are kept 'blind' about treatment allocation	Adequately addressed	Not reported	Well covered	Well covered	Adequately addressed	Adequately addressed	Well covered
1.5	The treatment and control groups are similar at the start of the trial	Well covered	Well covered	Well covered	Adequately addressed	Well covered	Adequately addressed	Adequately addressed
1.6	The only difference between groups is the treatment under investigation	Poorly addressed	Poorly addressed	Poorly addressed	Poorly addressed	Poorly addressed	Well covered	Well covered
1.7	All relevant outcomes are measured in a standard, valid and reliable way	Well covered	Adequately addressed	Well covered	Well covered	Adequately addressed	Adequately addressed	Poorly addressed
1.8	What percentage of the individuals or clusters recruited into each treatment arm of the study dropped out before the study was completed?	7%	29%	24%	13%	17%	3%	2%
1.9	All the subjects are analyzed in the groups to which they were randomly allocated (often referred to as intention-to-treat analysis)	Well covered	Adequately addressed	Well covered	Well covered	Well covered	Well covered	Poorly addressed
1.10	Where the study is carried out at more than one site, results are comparable for all sites	Not applicable	Not reported	Poorly addressed	Not applicable	Not addressed	Not addressed	Not applicable

[a] From the NICE methodological checklist for randomised controlled studies.

However, a few studies included additional treatment in the control group such as stretching, education, wellness program or basic enhanced programming for their controls (Studies 1–4). The additional treatment might act as a potential confounder and affect the findings of the studies (NICE, 2006).

Most studies have ensured validity and reliability of the outcome measurements. These methods included verification with other sources of report other than fall counts as reported/recorded by the participants (Studies 1, 4–5) and using a falls calendar for all participants (Studies 4–6).

The overall methodological quality was good in all the studies which have fulfilled at least half of the criteria in the methodological checklist.

3. Results

Table 3 and Fig. 1 showed the results of the studies. In Studies 3–6, there were less fallers among the Tai Chi group compared to the control group. However, only Study 4 reported that the difference in number of fallers was statistically significant ($p = 0.01$), while Studies 5 and 6 reported that there was no statistical difference. While Study 3 did not report whether there was any difference between the 2 groups, we found a statistical significant difference ($p < 0.05$) from our own computation based on the number of fall events per participant by intervention in the paper.

There were less fall counts among the Tai Chi group (or Tai Chi inspired in balance exercise group) than the control group in Studies 1, 4 and 7. The difference in fall counts was only reported to be statistically significant in Study 4 ($p = 0.007$) but not in Study 1 (no p-value reported) and Study 7.

Studies 1, 4 and 6 found a lower risk of falls among the Tai Chi group than the control group, with p value for hazard ratio or risk ratio ranging from <0.001 to 0.13. In Study 5, the risk of fall among the frail elderly was higher for the Tai Chi group than for the control group (hazard ratio 2.95; 95% CI 1.64–5.32; $p < 0.001$). However, the risk was lower among the pre-frail elderly for the Tai Chi inspired in balance exercise group than for the control group (hazard ratio 0.39; 95% CI 0.18–0.88; $p < 0.001$).

In Study 3, there was no statistically significant difference in fall risk in the Tai Chi and Wellness Program group over the 48-week intervention period (risk ratio 0.75; 95% CI 0.52–1.08; $p = 0.13$). However, most participants took about 3 months to practice Tai Chi movements independently and with intensification. Post hoc analyses were performed only from the 4th month to the 12th month and showed that the risk was significantly lower among those in the Tai Chi group (RR 0.54; 95% CI 0.36–0.81). This was also reduced if the 4th month was excluded from the analysis (RR 0.61; 95% CI 0.40–0.94).

In Study 5, there was no statistically significant difference in fall incidence rate among the elderly in the Tai Chi inspired in balance exercise group, functional walking groups and the control group ($p = 0.278$). Similarly, Study 2 reported that there was no significant difference in the fall rates among the "Living and Learning/Tai Chi", "Fit NB Free" and the control groups ($p = 0.53$).

Overall, Studies 1, 4 and 6 reported a reduction of falls among the Tai Chi group whereas Studies 2 and 7 found that there was no effect of Tai Chi on the number of falls in the study sample. Study 5 found a positive effect of Tai Chi on fall risk reduction among the pre-frail but not the frail elderly. Study 3 reported a statistically lower fall risk among the Tai Chi group in the post hoc analysis but not over the entire 48-week intervention period.

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Table 3
Results among the elderly with Tai Chi or Tai Chi inspired exercise

Study no.	No. of fallers with one or more falls (%)	Adjusted risk (HR/RR) of one or more falls	Remarks
1		RR: 0.525 (95% CI 0.321–0.860); $p = 0.01$, statistically significant If patient fell the year before entering the study, RR: 2.016 (95% CI 1.378–2.950);	No. of falls in TC was 29, BT 44 and Control 37; p-value not reported
2		$p = 0.0003$, statistically significant	Rate of falls in LL/TC was 58%, FNBF 72%, Control 75%; $p = 0.27$, reported not statistically significant
3	TC: 69 (47.6%), WE: 85 (60.3%); p-value not reported	Adjusted for centers over the entire 48 weeks, RR: 0.75 (95% CI 0.52–1.08); $p = 0.13$, not statistically significant Post hoc analyses since it took about 3 months for most TC participants to perform TC movements without support and increase the intensity of exercise Adjusted for center from Month 4 through Month 12, RR: 0.54 (95% CI 0.36–0.81); statistically significant Month 4 eliminated from the analysis due to marked increase in falls during that month for the WE group, RR: 0.61 (95% CI 0.40–0.94); statistically significant	No. of falls in TC was 127, WE: 170; $p = 0.042$ (based on own computation)
4	TC: 27 (28%), Control: 43 (46%); $p = 0.01$, statistically significant	For multiple falls, HR: 0.45 (95% CI 0.30–0.70); $p < 0.001$, statistically significant	No. of falls in TC was 38, Control: 73; $p = 0.007$, statistically significant
5	IB: 45 (57.7%), FW: 40 (62.5%), Control: 48 (53.3%); $p = 0.524$, not statistically significant	For IB, HR: 1.09 (95% CI 0.72–1.64); not statistically significant For FW, HR: 1.59 (95% CI 1.04–2.44); $p < 0.05$, statistically significant Intervention effect of IB and FW were comparable ($p = 0.096$), hence the groups were combined into a single exercise group For exercise group, HR: 1.36 (95% CI 0.94–1.96); not statistically significant Among frail elderly in the exercise group, HR: 2.95 (95% CI 1.64–5.32); $p < 0.001$, statistically significant Among pre-frail elderly in the exercise group after 11 weeks, HR: 0.39 (95% CI 0.18–0.88); $p < 0.05$, statistically significant	Fall incidence rate per year in IB was 2.3 ± 4.6, FW 3.3 ± 5.6, Control 2.5 ± 4.6; $p = 0.278$, not statistically significant
6	At 16 weeks, TC: 61 (21.3%), Control: 70 (26.2%) At 24 weeks, TC: 71 (25.7%), Control: 81 (31.6%); p-value not reported, reported not statistically significant	At 16 weeks, HR: 0.72 (95% CI 0.50–1.03); p = 0.07), not statistically significant At 24 weeks, HR = 0.66 (95% CI 0.47–0.92); $p = 0.02$, statistically significant	
7			No. of falls in TC was 15; RTE: 24; Control: 31; p-value not reported, reported not statistically significant

4. Discussion

4.1. Main findings of the review

There were almost equal numbers of studies which showed that Tai Chi was effective in fall reduction and which found no evidence of effectiveness of Tai Chi on fall reduction in the study sample. However, it was worth noting that the studies which supported the effectiveness of Tai Chi in reducing falls were generally of higher quality (all three studies 1, 4 and 6 have adequately addressed at least 70% of the methodological criteria) compared with those which did not find any evidence of effectiveness of Tai Chi (only Study 7 of the 2 studies has adequately addressed 70% of the methodological criteria).

4.2. Factors affecting the effectiveness of Tai Chi

An earlier systematic review has reported limited evidence of effects Tai Chi in preventing falls in view of paucity of randomized controlled trials (Verhagen et al., 2004).

Tai Chi has the potential to reduce falls or fall risks among the elderly. However, the effectiveness of the Tai Chi intervention may be affected by several factors. The age of the study sample might have influenced the outcomes of the intervention. The participants were generally younger in Studies 1, 4 and 6 with mean age 69, 77.5 and 76.2 years, respectively, when compared to those in Study 2 with mean age 84.7 years.

The participants were generally ambulant in all the studies. However, the study sample in Study 2 was frailer than those in previous studies. Similarly, the study sample in Study 3 was in the transition phase to fragility. The contribution of fragility as a determinant of the outcomes was reflected in the findings in Study 5 which found that Tai Chi reduced the risk of fall in the pre-frail but not in the frail participants.

The dropout rate was low in the 3 studies (Studies 1, 4 and 6) which supported the effectiveness of Tai Chi (2%–7%). However, the two studies (Studies 2 and 7) which found no evidence of effectiveness of Tai Chi had low drop-out rates (2%). Similarly, Studies 1, 4 and 6 revealed a relatively high compliance or attendance rate of 58.6% for 13 out of 16 sessions, 84%, and 80% for

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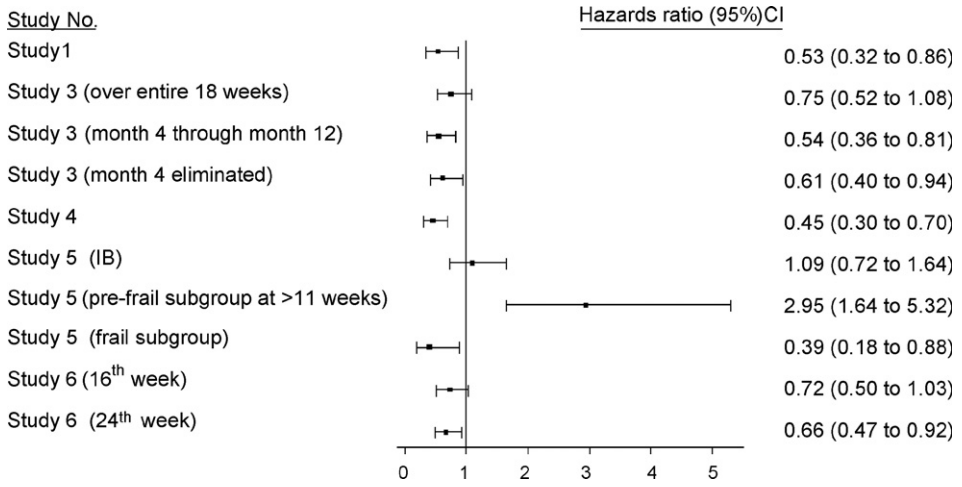

Fig. 1. Effect of Tai Chi in reducing falls among elderly.

≥50 sessions, respectively. In Study 2 where the adherence rate for the LL/TC group was reportedly low (24.2%), it was suggested that the exercise programs might need to be tailored to the needs, preferences and abilities of the elderly.

The duration of the studies might have an impact on the success of the intervention. It was observed that the duration of the intervention in Studies 1, 4 and 6 was 15 weeks, 6 months and 16 weeks, respectively. This was shorter than the 1-year duration in Studies 2 and 7. The compliance rate might be higher in studies with shorter duration. In view of the latent effects of Tai Chi in Study 3, it is essential that this intervention takes an acceptably long period which does not compromise the adherence of the participants.

4.3. Limitations of the review

Some selection criteria were common to the studies as described above. However, there still remained a source of bias due to some differences in the eligibility of participation in the studies.

It was noted that participants with no experience of practicing Tai Chi either in the preceding year had been included in Study 6 and those who had been practicing Tai Chi on a regular basis were excluded in Study 7. It was not known if there was a learning curve effect especially on those who had experience of practicing Tai Chi. In this review, these two studies had different findings of the effect of Tai Chi on fall reduction among the elderly.

Moreover, potential bias could arise from studies involving different styles and forms of Tai Chi. Two of the studies, Studies 4 and 7 involved Tai Chi intervention of the 24-form Yang style, while the majority of the classes in Study 6 was focused on the Sun-style Tai Chi. There was no clear specification of the Tai Chi style in the other four studies, i.e. Studies 1–3 and 5, which impeded direct comparison of these studies.

Overall, the validity of the selected studies was high due to the study design (i.e. randomized controlled trial). However, these studies were conducted in the developed countries. It was not known if the findings could be generalized to the developing countries where the resources were poorer.

Publication bias was also a limitation in this review. Although we did not limit our search by English, we did not find articles published in other languages. An earlier systematic review has suggested that there could be other databases which yield articles in other languages such as Chinese. Since Tai Chi was an ancient Chinese exercise, it was possible that the health benefits could have been explored in studies published in Chinese (Verhagen et al., 2004). Further research could be done to look into studies conducted in other languages.

5. Conclusions

Our review has shown that Tai Chi has the potential to reduce falls or fall risk among the elderly, provided that they are relatively young and non-frail. It is important to ensure the compliance rates are kept high for the intervention to be effective. It is important to note the different factors which might affect the effectiveness of Tai Chi in reducing falls among the elderly. Further review may be required to look into the non-English studies which assess the effectiveness of Tai Chi on fall reduction.

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