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Original Paper

Dose-effect Meta-analysis of Tai Chi Exercise in Improving Pain Symptoms of Knee Osteoarthritis

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Abstract

Objective: *To investigate the dose-effect relationship between the elements of Tai Chi exercise prescription and pain improvement in patients with knee osteoarthritis, aiming to provide evidence-based evidence for patients to provide more accurate Tai Chi intervention programs.* ***Methods:*** *Wanfang, CNKI, VIP, SinoMed, PubMed, Embase, Web of Science, and the Cochrane Library were searched for randomized controlled trials of Tai Chi exercise in patients with knee osteoarthritis in August 2024. Data were screened, evaluated, and extracted independently, and meta-analysis was performed using RevMan 5.3 software.* ***Results:*** *A total of 21 studies involving 1110 patients with KOA were included in this study. The results of meta-analysis showed that the effect of pain improvement was the strongest when the single exercise time was 21~40min (SMD was -0.79, P<0.05), and the effect of pain symptom improvement in patients with knee osteoarthritis would be decreased if the exercise time was too long or too short. The improvement effect of pain symptoms was strongest when the exercise frequency was 5 times a week (SMD was -1.09, P<0.05), and when the exercise cycle was 12 weeks, the pain symptom improvement effect was strongest (SMD was -0.7, P<0.05), and then the pain improvement effect decreased with the increase of exercise cycle.* ***Conclusion:*** *Patients with knee osteoarthritis are recommended to perform Tai Chi exercise for 21~40min 5 times a week for 12 weeks, and the maximum benefit of pain improvement can be obtained.*

Keywords

Tai Chi, knee osteoarthritis, Pain, Dose-effect

1. Introduction

Knee Osteoarthritis (KOA) is a chronic degenerative joint disease characterized by high disability and morbidity rates [1]. The pain symptoms caused by KOA severely impact patients' quality of life [2],

serving as a significant contributor to kinesiophobia and increasing the risk of depression among patients [2]. Current treatments for alleviating pain symptoms in KOA patients include pharmacological therapy and exercise therapy [3]. However, long-term pharmacological treatment in KOA patients may lead to various adverse reactions such as congestive heart failure and hypertension, and the development of drug resistance is highly probable with prolonged use [4]. The American College of Rheumatology recommends exercise therapy, which has no adverse side effects, as a first-line conservative treatment for KOA patients [5]. Among these, Tai Chi, a traditional Chinese fitness exercise, has been proven to effectively alleviate pain symptoms in KOA patients [6], and is recommended by multiple societies such as the Chinese Orthopaedic Association [7] and the Italian Society for Rheumatology [8] for improving pain in KOA patients. Compared to other types of exercise, Tai Chi offers advantages such as suitable intensity, easy control of exercise volume [9], and ease of long-term adherence [10]. However, the optimal exercise prescription for Tai Chi to improve pain symptoms in KOA patients has not yet been established. Therefore, this study systematically reviewed randomized controlled trials related to Tai Chi exercise in KOA patients, exploring the dose-effect relationship between Tai Chi exercise and pain improvement in patients, aiming to provide a basis for more precise Tai Chi intervention programs for patients.

2. Materials and Methods

2.1 Literature Search Strategy

Using "knee osteoarthritis/knee arthralgia" and "Tai Chi/Taiji quan" as Chinese search terms, and "Knee osteoarthritis/KOA" and "Taiji/Taiji quan" as English search terms, a systematic search was conducted in Chinese and English databases such as CNKI, VIP, Wanfang, China Biology Medicine, PubMed, Web of Science, Embase, and Cochrane Library for literature related to Tai Chi interventions in KOA patients. The search period covered from the inception of each database to August 2024.

2.2 Inclusion and Exclusion Criteria

Inclusion Criteria: 1. Study subjects: Patients with knee osteoarthritis; 2. Intervention measures: The intervention group practiced Tai Chi, while the control group received non-exercise interventions such as health education; 3. Outcome indicators: Pain intensity, measurable using scales such as the Visual Analog Scale (VAS) and the Arthritis Impact Measurement Scales (AIMS); 4. Study type: Randomized controlled trials (RCTs).

Exclusion Criteria: 1. Duplicate publications; 2. Literature with unavailable full text.

2.3 Literature Screening and Data Extraction

Two researchers trained in evidence-based medicine independently conducted literature screening and data extraction, with cross-verification. In cases of disagreement, a third researcher was involved to make a final decision.

2.4 Bias Risk Assessment of Included Studies

The Cochrane Collaboration's tool for assessing risk of bias in RCTs was used to evaluate the bias risk

of the included studies.

2.5 Statistical Analysis

The included studies were analyzed using RevMan 5.3 software. Heterogeneity testing was performed on the data. If there was no significant heterogeneity (I^2<50%, P>0.1), a fixed-effects model was used; if there was significant heterogeneity (I^2≥50%, P≤0.1), a random-effects model was applied. The outcome indicators of this study were continuous variables measured using different tools, represented by the standard mean difference (SMD) and 95% confidence interval (CI). The SMD values were interpreted as large (SMD≥0.8), moderate (0.5-<0.8), small (0.2-<0.5), and minimal (<0.2) effects [11]. Funnel plot analysis was used to test for publication bias, and sensitivity analysis was conducted using the one-by-one exclusion method.

3. Results

3.1 Literature Screening Process and Results

Initially, 544 articles were retrieved, and ultimately, 21 RCTs were included in the study. The specific literature screening process is shown in Figure 1.

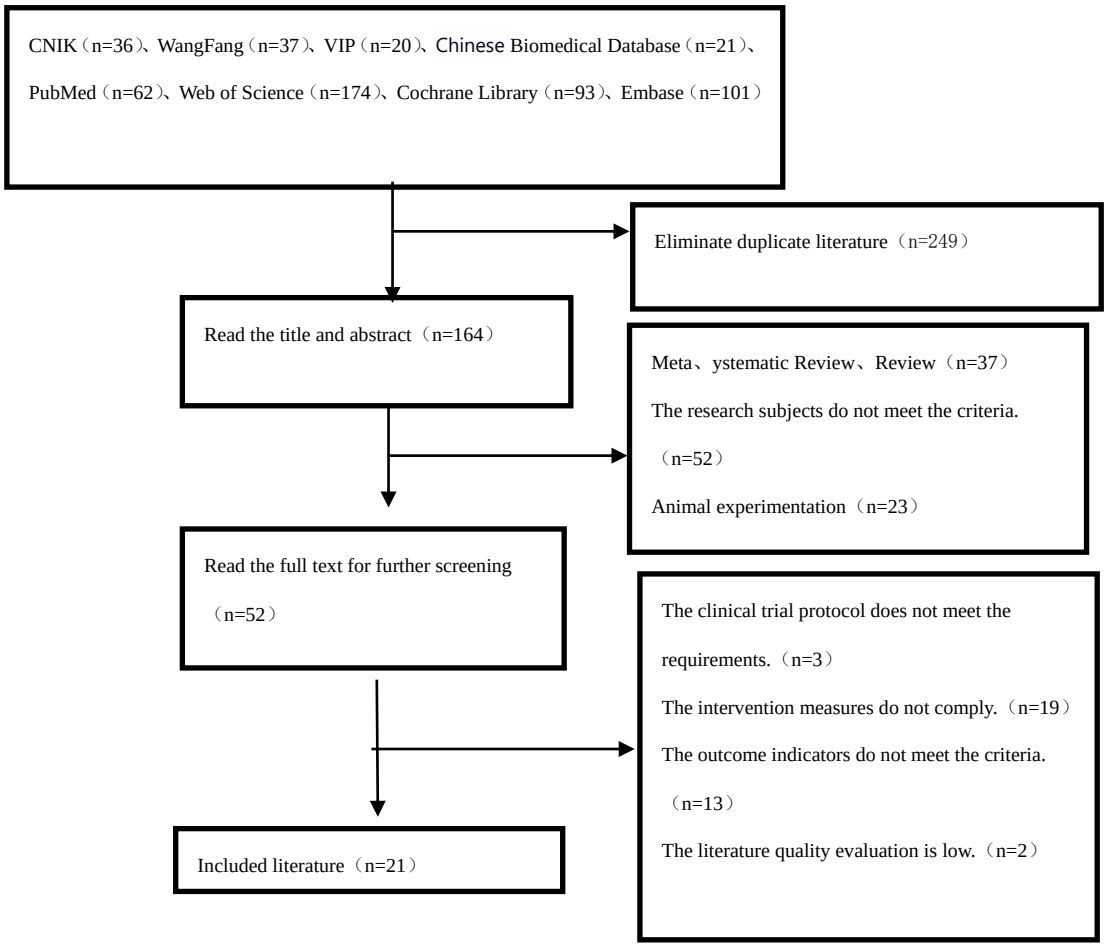

Figure 1. Flowchart of Literature Screening

3.2 Basic Characteristics of Included Literature

A total of 21 articles published between 2000 and 2022 were included, encompassing 1,110 patients with knee osteoarthritis. The research subjects were primarily concentrated in the 60-80 age group. Regarding the measurement of pain as an outcome variable, 14 articles utilized the pain subscale of the WOMAC (Western Ontario and McMaster Universities Arthritis Index), 3 articles used the Visual Analog Scale (VAS), 2 articles employed the pain subscale of the KOOS (Knee Injury and Osteoarthritis Outcome Score), and 2 articles used the Arthritis Impact Measurement Scales (AIMS). The remaining basic characteristics are presented in Table 1.

Table 1. Basic Characteristics of Included Literature

Author	Year	Country	Diagnostic Criteria	Number of Cases		Year（x±s）		Intervention Measures (for the Intervention Group)			Intervention Measures (for the Control Group)	Outcome Measurement Tools	Literature Quality Evaluation
				Control Group	Intervention Group	Control Group	Intervention Group	Duration of Single Exercise Session	Exercise Frequency	Duration of Intervention			
Hartman[12]	2000	UAS	X-ray	18	15	68.6±7.9	67.5±6.1	60min	2/week	12week	Health Education	④	B
Song[13]	2003	South Korea	ACR	22	21	64.8±6.0	62.5±5.6	20min	3/week	12week	Health Education	①	B
Adler[14]	2007	USA	X-ray	8	6	71.6±6.8	72.8±5.4	15min	3/week	10week	Attention Training	①	B
Brismée[15]	2007	USA	ACR	18	13	70.89±9.8	68.89±8.9	40min	3/week	12week	Health Education	②	B
Fransen[16]	2007	Australia	ACR	56	41	70.8±6.3	69.6±6.1	60min	2/week	12week	Health Education	①	B
Lea[17]	2008	South Korea	X-ray	22	24	76.00±5.88	74.96±6.71	60min	2/week	12week	Health Education	①	B
Song[18]	2009	South Korea	ACR	30	39	62.36±7.56	59.94±7.83	60min	2/week	6month	Health Education	①	B
Wang[19]	2009	USA	ACR	20	20	63±8.1	68±7.0	60min	2/week	12week	Attention Training	②	B
Tsai[20]	2013	UAS	X-ray	28	27	78.89±6.91	78.93±8.03	30min	3/week	20week	Health Education	④	B

Zhu[21]	2016	China	ACR	23	23	64.61±3.40	64.53±3.43	60min	3/week	24week	Health Education	①	B
Zhang[22]	2017	China	X-ray	33	32	64.33±6.62	64.28±7.53	40min	--	12week	Routine Care	①	B
Zhu[23]	2017	China	ACR	23	23	64.6±3.4	64.5±3.4	60min	3/week	24week	Health Education	①	B
Lee[24]	2017	USA	ACR	41	34	59.9±10.1	60.9±10.8	60min	2/week	12week	Physical Therapy	①	B
Hu[25]	2018	China	ARA	28	26	58.34±7.66	56.97±7.75	60min	5/week	12week	Health Education	①	B
Hu XY[26]	2020	China	X-ray	52	40	66.32±4.16	65.54±3.59	60min	3/week	24week	Health Education	②	B
Kang[27]	2022	China	X-ray	12	15	63.4±4.6	64.7±6.1	60min	3/week	36week	Health Education	①	B
LI[28]	2019	China	ACR	30	30	65.8±6.7	66.0±5.0	60min	--	16week	No Intervention	①	B
Liu[29]	2019	China	ACR	28	24	--	--	60min	5/week	12week	Health Education	③	B
Li[30]	2019	China	X-ray	54	53	69.6±4.3	68.5±3.5	45min	5/week	12week	--	①	B
song[31]	2022	China	ACR	20	20	64.15±8.56	64.15±8.56	60min	3/week	12week	Health Education	①	B

Outcome Measures:① Pain Subscale of the Western Ontario and McMaster Universities Arthritis Index (WOMAC) ② Visual Analog Scale (VAS) ③ Pain Subscale of the Knee Injury and Osteoarthritis Outcome Score (KOOS)④ Arthritis Impact Measurement Scales (AIMS)

3.3 Quality Evaluation of Included Literature

All 21 articles included in this study were rated as Grade B. The results of the bias risk assessment are shown in Figure 2.

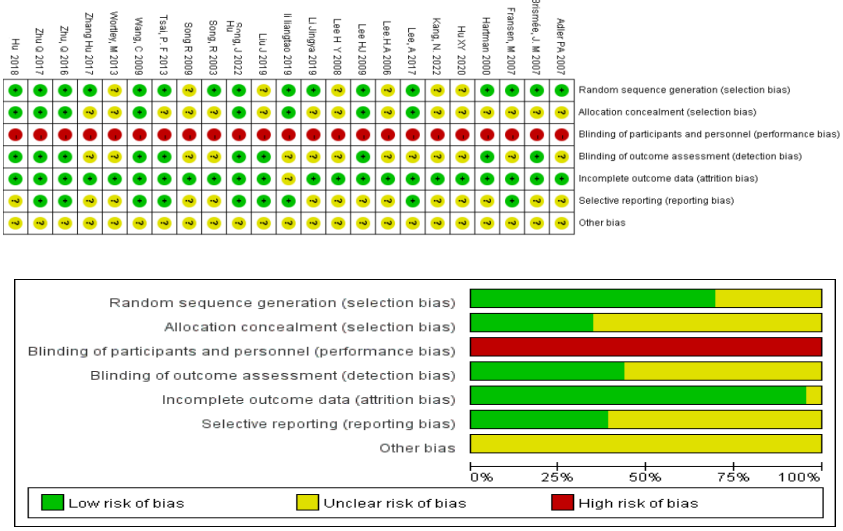

Figure 2. Quality Evaluation of the Included Literature

3.4 Results of Meta-Analysis

In this study, the parameters of Tai Chi exercise were categorized to conduct subgroup analyses, aiming to explore the optimal dosage effects of various elements of Tai Chi exercise on pain improvement in patients with knee osteoarthritis (KOA).

3.4.1 Effect of Single Exercise Duration on Pain Improvement in KOA Patients

Based on 21 articles that reported the duration of a single Tai Chi session, the duration was categorized into three dosage groups: 15-20 minutes, 21-40 minutes, and 60 minutes. The I^2 values within each subgroup were 0%, 39%, and 44%, respectively. Since all I^2 values were <50%, a fixed-effects model was adopted. The results showed that pain symptoms improved in KOA patients after interventions with Tai Chi exercise of different single durations. Specifically, the standardized mean difference (SMD) values for single exercise durations of 15-20 minutes, 21-40 minutes, and 60 minutes were -0.48, -0.79, and -0.70, respectively, all of which were statistically significant ($P < 0.05$). The greatest improvement in pain symptoms was observed when the single exercise duration was 21-40 minutes. See Figure 3 for details.

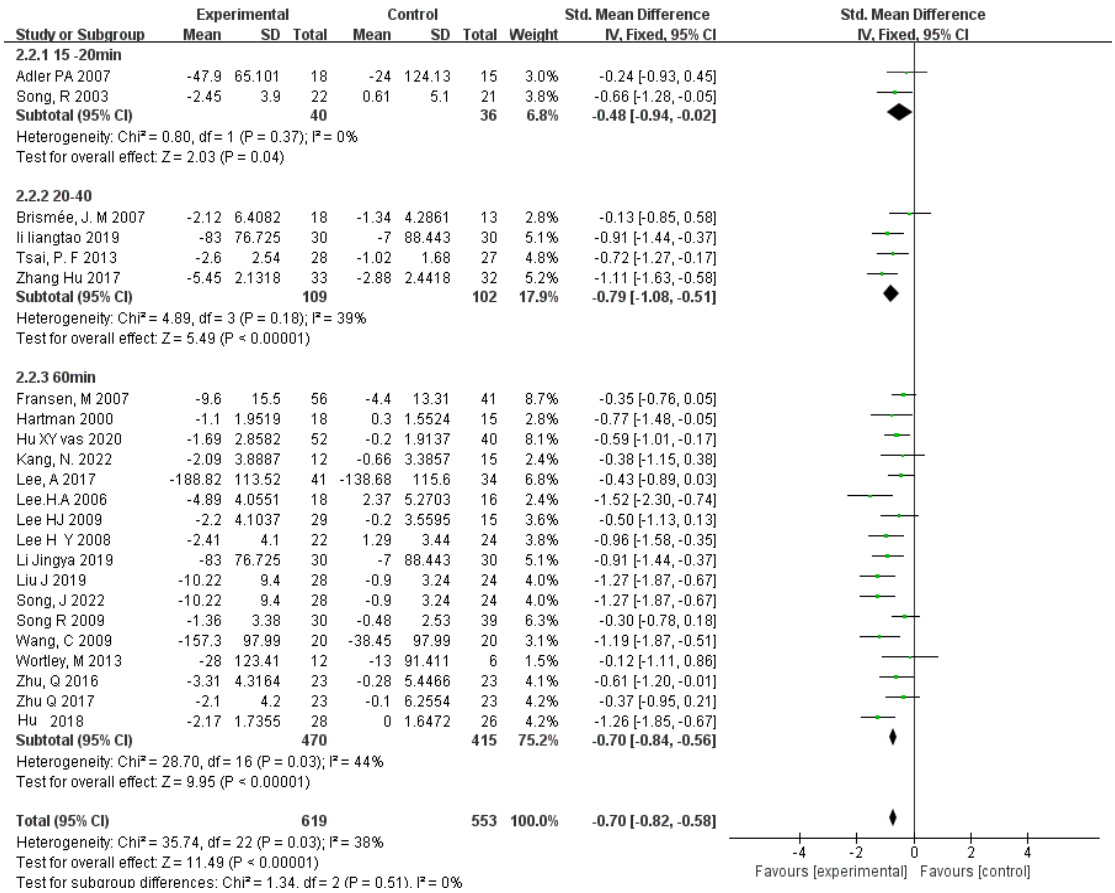

Figure 3. Forest Plot Illustrating the Effect of Single Exercise Duration on Pain Relief in Patients with Knee Osteoarthritis (KOA)

3.4.2 Effect of Exercise Frequency on Pain Improvement in KOA Patients

Nineteen articles in this study reported the frequency of Tai Chi exercise, which was categorized into three dosage groups: 2 times per week, 3 times per week, and 5 times per week. The I^2 values within each subgroup were 48%, 58%, and 54%, respectively. For the subgroups with 3 times per week and 5 times per week, where $I^2 > 50\%$, a random-effects model was adopted. For the subgroup with 2 times per week, where $I^2 < 50\%$, a fixed-effects model was used based on the heterogeneity test. The results of the subgroup analysis showed that the standardized mean difference (SMD) values for the three dosage groups were -0.61, -0.47, and -1.00, respectively. The greatest improvement in pain symptoms was observed in KOA patients when the frequency of Tai Chi exercise was 5 times per week. See Figure 4 for details.

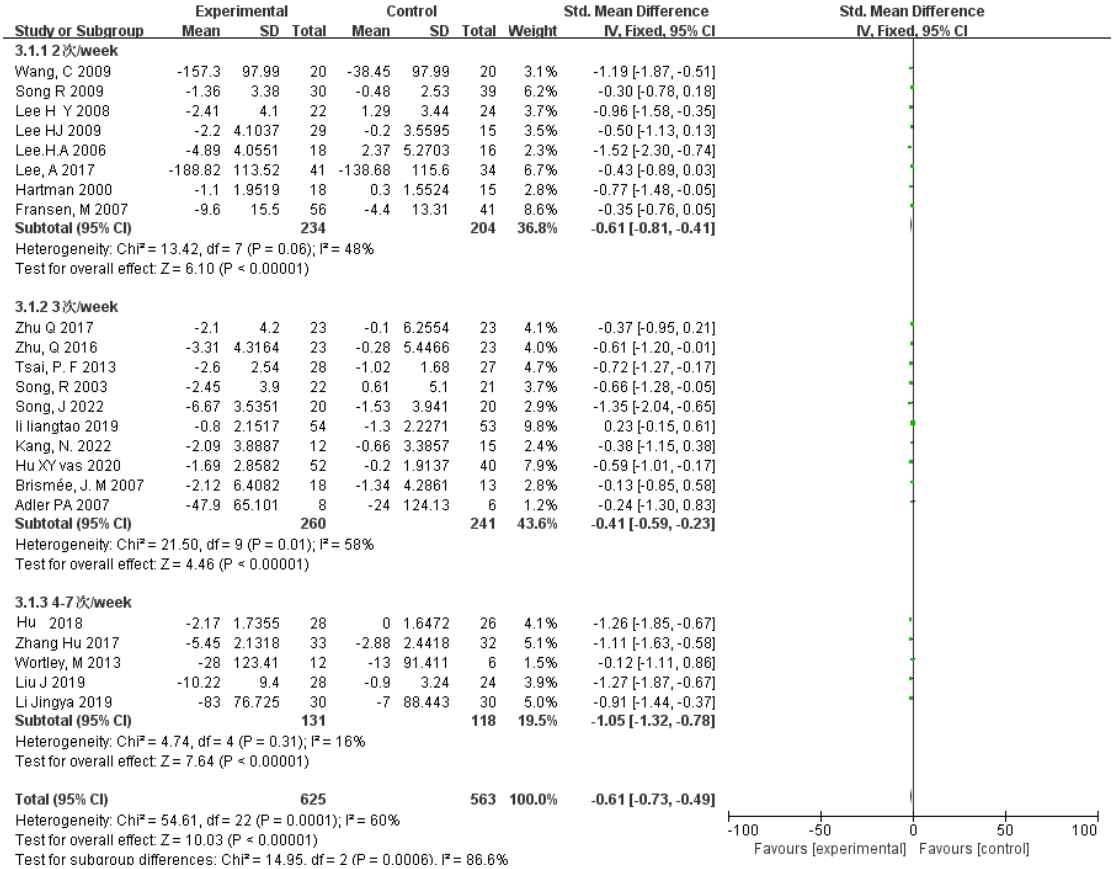

Figure 4, Forest Plot of Exercise Frequency for Pain Improvement in KOA Patients

3.4.3 Effect of Exercise Duration on Pain Improvement in KOA Patients

In this study, 21 articles reported on the duration of a single exercise cycle, categorizing them into five exercise duration doses: 9-10 weeks, 12 weeks, 13-20 weeks, and 24-36 weeks. The I^2 values within each subgroup were 75%, 0%, 77%, 33%, and 0%, respectively. For subgroups with $I^2 > 50\%$, specifically for 6-8 weeks and 12 weeks, a random-effects model was adopted. For subgroups with $I^2 < 50\%$, specifically for 9-10 weeks, 13-20 weeks, and 24-36 weeks, a fixed-effects model was used based on the heterogeneity test. The results showed that there was no statistical significance in pain improvement when the Tai Chi intervention duration was 6-8 weeks or 9-10 weeks. However, statistically significant improvements in pain were observed when the intervention duration was 12 weeks, 14-16 weeks and 24-28 weeks The effect sizes (SMD) for these durations were -0.7, -0.62, and -0.52, respectively. The greatest improvement in pain symptoms was observed in KOA patients when the exercise duration was 12 weeks. See Figure 5 for details.

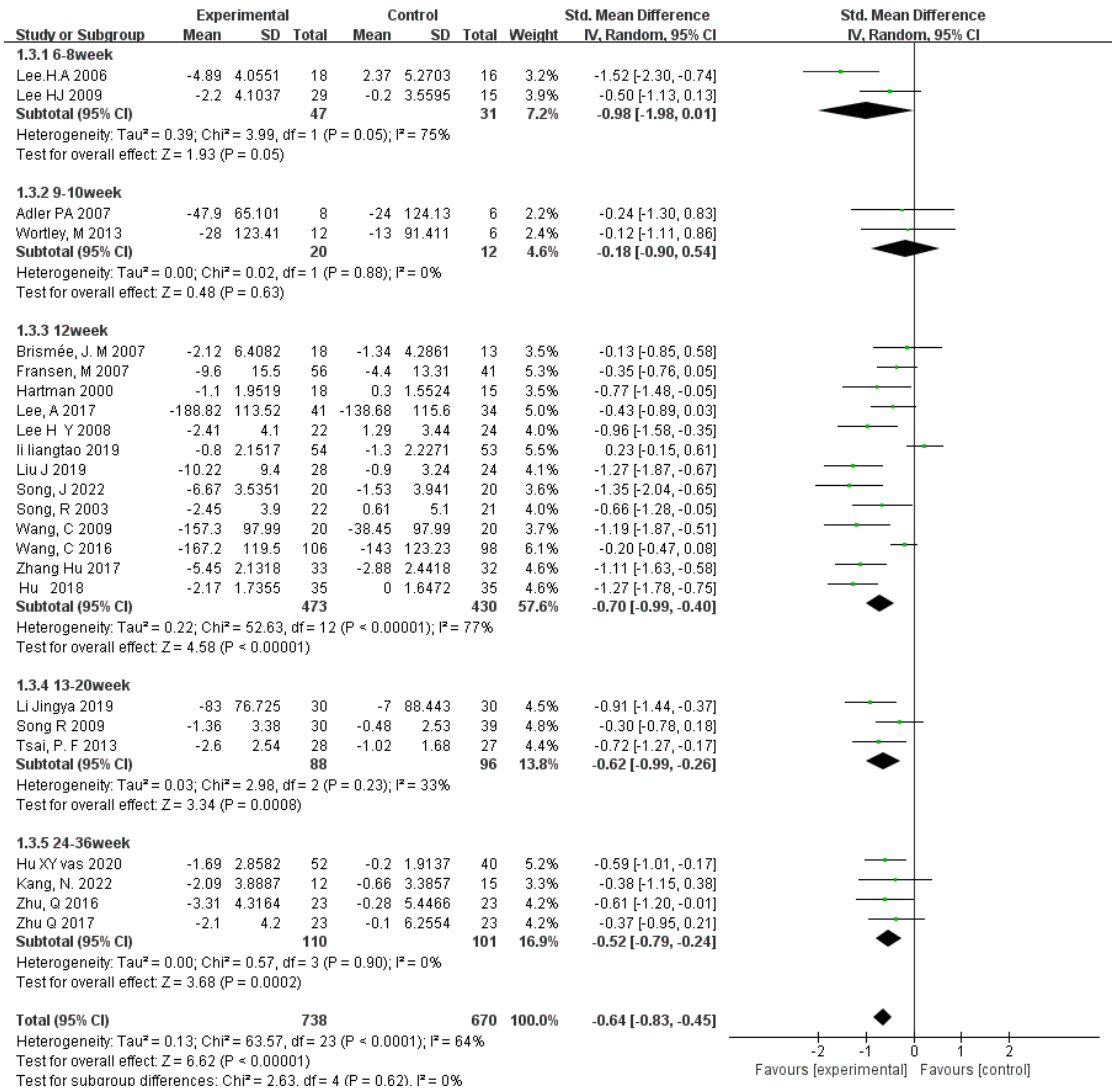

Figure 5. Forest Plot of Exercise Duration for Pain Improvement in KOA Patients

3.5 Publication Bias

A publication bias test was conducted on the three studies included in this research, as shown in Figure 6. The observation revealed that there was no publication bias in this study.

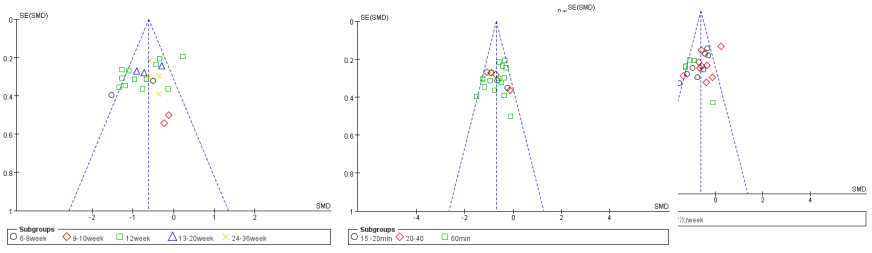

Figure 6. Funnel Plots for Various Subgroups

3.6 Sensitivity Analysis

During the Meta-analysis process, each study was sequentially excluded and then re-analyzed. None of the studies had a significant impact on the combined results, indicating that this study had good stability.

4. Discussion

This study shows that regardless of the frequency or duration of exercise, Tai Chi can improve pain symptoms in patients with knee osteoarthritis (KOA). However, the maximum benefit in pain improvement was observed when patients with KOA performed Tai Chi for 21-40 minutes per session, five times a week. This finding is consistent with the research results of Brossaeu [32], who recommended that patients with KOA should perform Tai Chi for 20-40 minutes each day. Additionally, this study found that when the exercise duration was extended to 60 minutes, the effect on pain improvement decreased. The research by TOrstensen [33] et al. showed that a 20-30-minute exercise intervention improved pain more than a 70-90-minute intervention, supporting this study's findings. The decrease in pain improvement benefit with prolonged single exercise duration may be due to the increased difficulty of the exercise, leading to a decrease in the exercise execution rate among patients with KOA, resulting in reduced pain improvement benefits [34]. Therefore, it is not recommended to extend the single exercise duration for patients with KOA when performing Tai Chi. Furthermore, the Chinese Guidelines for Primary Care Diagnosis, Treatment, and Rehabilitation of Knee Osteoarthritis also indicate that patients with KOA should engage in physical activity for 5 days a week [35], which is consistent with the findings of this study. However, due to the limited number of studies included in this Meta-analysis that focused on Tai Chi exercise frequencies exceeding five times per week, it was not possible to determine the benefit of frequencies above this threshold on pain improvement in patients with KOA.

This study reveals that when the Tai Chi intervention duration was 9-10 weeks, there was no significant difference in pain improvement benefits compared to the control group. Wang Lidong et al. [36] found that when the Tai Chi exercise period was less than 12 weeks, there was no significant improvement in pain symptoms among patients with KOA, which is consistent with the findings of this study. However, there are currently few studies exploring the improvement of pain symptoms in patients with KOA through short-term Tai Chi exercise, and this study only included two related studies [37]. Therefore, there is insufficient evidence to determine whether short-duration Tai Chi exercise can improve pain symptoms in patients with KOA. Additionally, this study found that when the intervention duration was 12 weeks, patients experienced the maximum degree of pain improvement. After 12 weeks, the effect of Tai Chi on pain gradually decreased. A systematic review by Gon et al. [37] showed that the benefit of exercise intervention on pain improvement in patients with KOA peaked at 2 months and then gradually declined, which is similar to the findings of this study. Although the effect of Tai Chi on pain improvement decreased after 12 weeks, the decrease was not significant, and it still maintained a

moderate effect on pain improvement. This may be because long-term regular Tai Chi exercise has the effect of maintaining pain improvement. In other words, as the duration of Tai Chi exercise for patients with KOA increases, the effect of pain improvement is maintained, and further significant improvement in pain is not observed. Therefore, patients with KOA should perform Tai Chi for at least 12 weeks to obtain the maximum effect on pain improvement. At the same time, patients with KOA are encouraged to continue performing Tai Chi to maintain the improvement in pain.

In summary, this study explores the optimal exercise dosage of Tai Chi for improving pain in patients with KOA, aiming to provide evidence-based support for more precise Tai Chi intervention programs for patients. The recommended Tai Chi exercise prescription for patients with knee osteoarthritis is to perform Tai Chi five times a week, each session lasting 21-40 minutes, and continuing for 12 weeks to achieve the maximum benefit in pain improvement.

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