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Evaluating the effectiveness of six exercise interventions for low back pain: a systematic review and meta-analysis

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Abstract

Objective To validate the effectiveness of six exercise therapies in treating low back pain using Meta-analysis methods, and to propose optimal exercise duration, frequency, and cycle.

Methods Databases such as PubMed, EMBASE, Cochrane Library, China National Knowledge Infrastructure, VIP Data, and SinoMed were searched. The RevMan 5.4 tool was utilized to conduct subgroup analyses on eight moderating variables, including types of exercise, duration, frequency, cycle, sample size, study quality, outcome indicator, and comparisons of different intervention methods with the control group from 42 included studies. Random effects models were employed to test for overall effects, heterogeneity, and bias.

Results The overall effect size for six exercise therapies for low back pain was significant (SMD= -1.21, $P < 0.00001$). Subgroup analyses showed yoga had the largest effect (SMD= -1.97, $P = 0.0001$). Exercise duration ≤ 30 min (SMD= -1.31, $P < 0.0001$), frequencies > 4 times/week (SMD= -1.56, $P < 0.00001$), and cycles ≤ 4 weeks (SMD= -1.61, $P < 0.00001$) were most effective. Sample sizes of 30~60 cases (SMD= -1.36, $P < 0.00001$) and studies with moderate bias risk (SMD= -1.37, $P < 0.00001$) also showed large effects. The Oswestry Disability Index scores demonstrated the most significant effect size (SMD= -3.35, $P < 0.00001$). The effect size of the physical factors in the control group was the largest (SMD= -1.85, $P < 0.00001$).

Conclusion All six exercise therapies effectively alleviated low back pain, with yoga showing the best results. The optimal exercise intervention protocol involved exercise duration not exceeding 30 min per session, frequency of more than 4 times per week, and cycle not exceeding 4 weeks. Additionally, exercise interventions exhibited the most significant improvements in Oswestry Disability Index scores for low back pain.

Keywords Low back pain, Exercise intervention, Effect size, Meta-analysis, Randomized controlled trial

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Introduction

Low Back Pain (LBP) typically refers to the pain symptoms in the area below the lower edge of the ribs on the back, encompassing the lower lumbar spine, lumbosacral region, and buttocks. This pain can manifest in various forms such as localized, diffuse, radiating, or referred pain [1, 2].

LBP affects people of all age groups, serving as the primary cause of disability and a significant contributor to the global burden of disease [3, 4]. The pervasive issue of opioid abuse continues to significantly increase costs for both individuals and society [5]. Unfortunately, there is currently no definitive treatment for persistent LBP, and supervised exercise therapy is recommended for the management of chronic LBP [6]. With the increasing attention to competitive and recreational sports, the impact of physical exercise on health has become a topic of great concern for people from children to the elderly. According to reports, exercise therapy is effective in reducing pain and disability, and it is also cost-effective [7, 8]. In 2017, the American Medical Association stated that exercise therapy is the preferred treatment for LBP [9, 10]. In Europe, exercise therapy is recommended as a first-line intervention for the management of chronic LBP [11]. The Chinese State Council has also advocated for improving the treatment of LBP through exercise therapy. Based on the " Exercise Therapy for Back Pain: Expert Consensus " [12], we have selected the following intervention methods: core stability training, Tai Ji, aquatic therapy or water exercises, yoga, sling exercise, and combined training. Combined training includes combinations of two or more items such as muscle strength training, flexibility training or stretching exercises, and postposture stabilizer muscle training.

LBP is a common problem that troubles many people, and various training methods have their own unique mechanisms and effects in relieving LBP. Core stability training is based on the principles of motor learning methods and emphasizes the activation of the deep muscles of the lower back. By strengthening the deep core muscles such as the Transversus Abdominis (TrA) and the Multifidus (MF), it promotes the coordinated development of multiple muscle groups including those in the abdomen, back, and buttocks, and enhances muscle endurance, providing more stable support for the spine and effectively reducing the burden on the lower back muscles [13]. In addition, during core training, the body continuously receives sensory information from muscles, joints, the inner ear, etc. After being integrated by the brain, it can not only regulate the nerve reflex arc, accelerate the nerve conduction speed, but also improve proprioception, correct postural disorders, and further enhance the stability of the spine [14].

Tai Ji, as a traditional Chinese training method, is of great benefit to health. Many studies targeting different patient groups have shown that Tai Chi can not only enhance muscle strength and endurance but also improve the body's balance and coordination abilities, significantly reducing pain related to symptoms [15–17]. Relevant studies have also pointed out [18, 19] that Tai Chi emphasizes the unity of the body and mind. When practicing Tai Chi, it is required to concentrate attention and coordinate with breathing, which helps practitioners relax both physically and mentally, reduce mental stress, and further relieve the tension pain of the lower back muscles.

Aquatic therapy is a therapeutic approach that utilizes the properties of water to relieve pain, relax muscles, and promote motor function [20]. The buoyancy of water can effectively reduce the pressure on the lower back and relieve the load on the intervertebral discs. Warm water dilates the blood vessels in the lower back muscles, accelerates the excretion of metabolic waste products, and relaxes the muscles. The resistance during aquatic exercise can enhance muscle strength, and since the impact on the joints is minimal, it helps to increase joint range of motion. At the same time, the stimulation of water can also enhance proprioception, improve neuromuscular control ability, and maintain the stability of the spine [21, 22].

Yoga is a complex and multi-dimensional therapeutic system that involves multiple aspects such as the musculoskeletal system, respiratory system, and nervous system. Relevant studies have shown [23, 24] that the mechanisms by which yoga relieves LBP are diverse. At the muscular level, numerous yoga poses can strengthen the deep muscles of the lower back, such as the erector spinae and multifidus, as well as the strength of the gluteus maximus and core muscle groups. Some stretching and relaxation poses can lengthen and relax the tense lower back muscles, alleviating soreness and stiffness [25]. In terms of joints, yoga poses cover various movements of the spine, including flexion, extension, lateral flexion, and rotation, which can expand the range of motion of the lumbar joints, promote the secretion and circulation of synovial fluid, and thus relieve LBP caused by joint problems. In addition, yoga emphasizes the coordination of breathing and movement. During practice, deep breathing activates the parasympathetic nervous system, enabling the body to return from a tense stress state to a relaxed state, thereby relieving pain [26].

The activation of skeletal muscles depends on a diffuse neuronal network. These neurons are widely distributed in multiple motor cortex regions, including the primary motor cortex (M1), the cingulate motor area, and the supplementary motor area [27]. The coordination between the TrA and the MF is crucial for maintaining lumbar spine stability [13]. Studies have found [28, 29] that in healthy individuals, the nerves of TrA and MF are closely organized in M1, while in patients with LBP, they are discretely organized, and there is a delay in postural adjustment, which may be related to the neural changes occurring in the motor cortex. As a high-order core stability training method, sling exercise creates an unstable support environment, prompting the body to recruit more deep muscles to participate in activities to maintain balance and stability. This training method can not only effectively improve the activity performance of TrA and MF but also prevent the recurrence of LBP by maintaining the stability of spinal segments [30, 31].

Combined training integrates various exercise methods and training techniques, which can comprehensively improve physical functions and athletic abilities. Through the superimposed training of muscle strength and stretching, it strengthens muscle strength, enhances muscle endurance, and increases the range of joint motion. The stretching exercises within it can effectively lengthen the muscles and fascia of the lower back and its surrounding areas, relieving the tension of the muscles and fascia. Regular stretching and relaxation training can also reduce the adhesion between muscle fibers, improve muscle function, and thus alleviate the pain and discomfort in the lower back [32].

Based on the above background, this study employed a Meta-analysis approach to verify the effectiveness of six exercise intervention therapies in treating LBP. Simultaneously, we established seven moderating variables for in-depth subgroup analysis, considering specific exercise intervention methods, exercise duration, exercise frequency, exercise period, sample size, study quality, and outcome indicators. This approach aims to comprehensively assess the effects of different exercise therapies on LBP and provide valuable references for exploring more precise exercise treatment plans. The seven moderating variables are as follows: (1) Types of exercise: The included studies were divided into six groups: core stability training, Tai Ji, aquatic therapy, yoga, sling exercise, and combined training. (2) Exercise Duration: The included studies were divided into three groups: less than or equal to 30 min, 35 ~ 50 min, and 60 min or more. (3) Exercise Frequency: The included studies were divided into three groups: less than 3 times per week, 3~4 times per week, and more than 4 times per week. (4) Exercise Cycle: The included studies were divided into three groups: 1~4 weeks, 5~8 weeks, and more than 12 weeks. (5) Sample Size: The included studies were divided into three groups: less than 30 cases, 30~60 cases, and more than 60 cases. (6) Study Quality: The included studies were divided into three groups: low, moderate, and high risk of bias. (7) Outcome Indicator: The included studies were divided into three groups based on the Visual Analogue Scale (VAS) or Numeric Rating Scale (NRS), Roland Morris Disability Questionnaire (RMDQ), and Oswestry Disability Index (ODI) [33]. In these assessment tools, higher scores signify more severe pain intensity and greater functional disability. (8) Types of control group: The control group was divided into conventional exercise (CE), physical factors (PF), conventional exercise plus physical factors (CE + PF), and no intervention of exercise and physical factors (NI-EPF) intervention methods. In summary, this study utilized eight moderating variables to evaluate the effectiveness of six exercise interventions for treating LBP, aiming to propose a more optimized exercise program.

Materials and methods

This meta-analysis was designed according to the guidelines for Preferred Reporting Items of Systems Review and Network Meta-Analysis (PRISMA-NMA) [34], registered in the PROSPERO database (CRD42024616961).

Literature search

PubMed, EMBASE, Cochrane Library, China National Knowledge Infrastructure, VIP Data, and SinoMed were searched to identify studies published from 2014 to 2024. The search takes a combination of subject words and free words. The search strategy is shown in Supplementary material_1. The main search terms included Low back pain, core stability, Tai Ji, aquatic therapy, yoga, sling exercise, muscle strength, muscle stretching exercises, posture stabilizes muscles, and randomized controlled trials.

Inclusion and exclusion criteria

Inclusion Criteria: (1) Type of Literature Research: Randomized controlled trials (RCTs) on LBP published domestically and internationally. (2) Study Population: Individuals from the general population diagnosed with chronic LBP by a physician or rehabilitation specialist, without other lumbar vertebral organic lesions. (3) Study Design: The RCTs compare exercise interventions with non-exercise or other general exercise training/physical factor therapies. (4) Extractable Outcome Indicators: Literature that uses VAS or NRS, ODI, and RMDQ as evaluation and research indicators. The above four scales all evaluate situations related to LBP. The values represented by them are similar, so they are comparable. To accurately measure the overall therapeutic effect of exercise interventions on LBP, we extracted one most representative indicator from each piece of literature for analysis. The selection of this indicator comprehensively considered the research objectives and the characteristics of each indicator, aiming to clearly demonstrate the effectiveness of exercise interventions in a concise and efficient manner. Relevant literatures also indicate [35, 36]that in the assessment of pain and functional status of LBP, VAS/NRS, ODI, and RMDQ have similar application values in measuring pain and functional status, and the meanings they represent are similar. Finally, the Standardized Mean Difference (SMD), which is applicable to different scales, is adopted to pool the effect sizes.

Exclusion Criteria: (1) Studies with unclear research types, non-randomized controlled studies, or case studies. (2) Articles that are reviews, systematic evaluations, or secondary analyses. (3) Studies involving patients diagnosed with lumbar disc herniation, spinal canal stenosis, fractures, vertebral dislocations, or spinal cord injuries, as well as those with waist pain caused by infectious diseases, or those who have undergone lumbar spine surgery. (4) Studies with specific patient populations, including amputees, disabled individuals with lumbar or spinal injuries, individuals with pain caused by scoliosis, ethnic minorities, congenitally disabled individuals, pilots, military personnel, athletes, pregnant women, etc. (5) Studies that merely mention research plans; studies lacking outcome indicators such as VAS/NRS, ODI, and RMDQ scales, or studies with a significant number of participants withdrawing from the trial. (6) Full-text articles with incomplete data; duplicate or unpublished literature; or studies with significant baseline differences between the experimental and control groups.

Date extraction

Two independent searchers used an independent, double-blind method to extract data, including authors, year of publication, sample size of experimental and control groups, age, gender, intervention method, intervention program (exercise duration, frequency, cycle), and outcome measures.

Risk of bias assessment

According to the Cochrane Collaboration's tool for assessing the risk of bias in randomized trials [37], the included studies were assessed for methodological quality in the following areas: random allocation methods, concealment of allocation schemes, blinding of researchers and participants, completeness of outcome data, selective reporting of study results, and other sources of bias. During the statistical process, the quality assessments are categorized as follows: low risk of bias with 5 or more criteria met; moderate risk of bias with 3 to 4 criteria met; and high risk of bias with fewer than 3 criteria met.

Statistical analysis

Using the RevMan 5.4 tool provided by the Cochrane Collaboration Network, the I^2 and Q tests were conducted for measurement [38]. If $I^2 \leq 50\%$ and the *P*-value of the Q test > 0.1, a fixed-effects model was selected; if $I^2 > 50\%$ and the *P*-value of the Q test < 0.1, indicating substantial heterogeneity among the studies, a random-effects model was chosen [39]. To explore the reasons for heterogeneity among studies, subgroup analysis with adjustment variables was performed. A funnel plot was used to assess whether there was publication bias in the included studies. A *P*-value ≤ 0.05 indicates that the combined statistics of multiple studies are statistically significant; if $P > 0.05$, the combined statistics of multiple studies are not statistically significant.

Results

Literature retrieval process

A total of 1,983 Chinese and English articles were initially retrieved from various databases. Firstly, 337 duplicate articles were excluded, and after screening the titles and abstracts, 775 articles such as reviews and systematic evaluations were eliminated. Subsequently, by reading the full texts, 829 articles were excluded due to mismatched research content, unreasonable experimental design, inconsistent outcome indicators, and incomplete data. Ultimately, 42 studies were included. The research flow chart is shown in Fig. 1.

Characteristics of included studies

A total of 42 articles were included, 23 of which were in English and 19 in Chinese. All of them were randomized controlled trials (Table 1). This study enrolled 2,335 subjects, with a mixed gender distribution and an age range of 16 to 72 years. The intervention measures for the experimental group included core stability, Tai Ji, aquatic therapy, yoga, sling exercise, and combined training. The intervention programs included in the various studies exhibited significant differences, with each exercise session ranging from 15 to 75 min in duration, the frequency of exercise per week varying from once to seven times, and the shortest exercise period lasted for 2 weeks, while the longest lasted for a year. The outcome indicators used the VAS/NRS to assess pain intensity and the ODI and RMDQ to evaluate lumbar dysfunction. Of all the included studies [40–81], 20 reported VAS, 2 reported NRS, 11 reported ODI, and 9 reported RMDQ.

Quality of assessment

A methodological quality assessment was conducted on the 42 included articles (Fig. 2), with 13 articles achieving a low risk of bias and high quality. Among these, 4 articles scored 7 points. The remaining 29 articles were classified as having a moderate risk of bias. Figure 3 presents a statistical chart of the proportion of various methodological assessment items, indicating that overall, the methodological quality of the included studies was good.

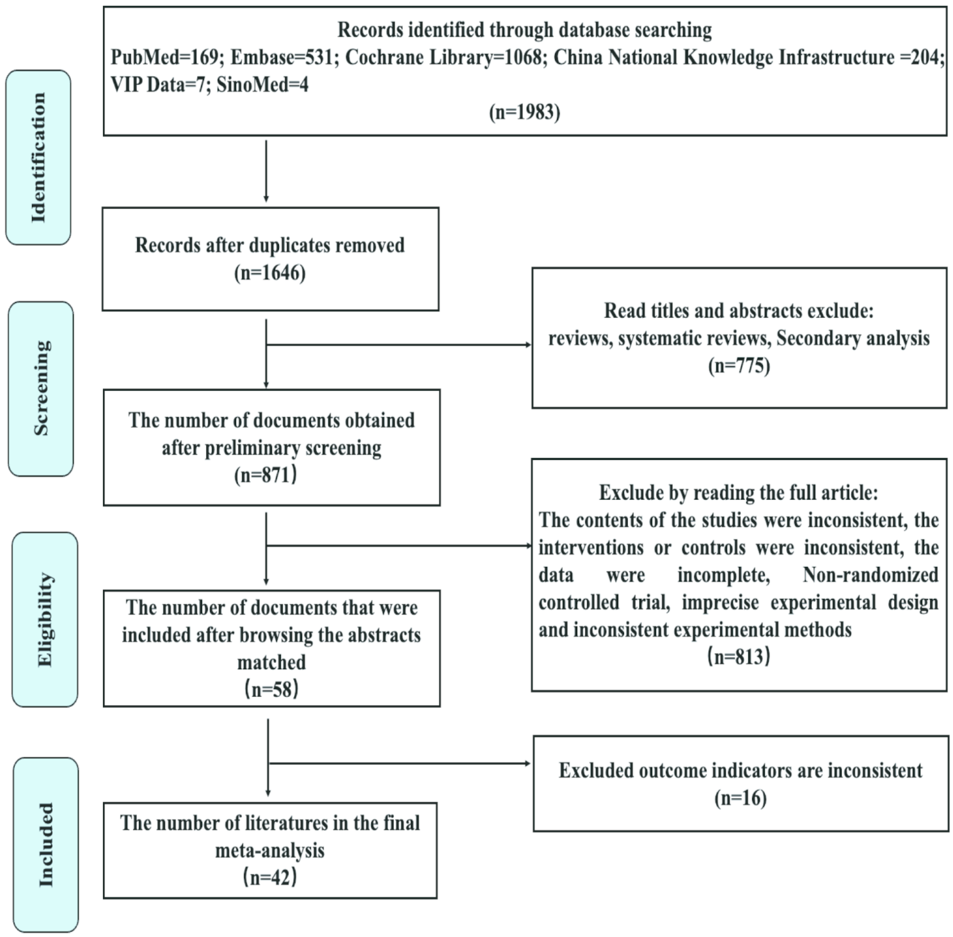

Fig. 1 Flow chart

Global effect test

Firstly, an overall effect test conducted on the sample of 42 selected articles revealed that all six types of exercise interventions had effects in alleviating LBP (Table 2). With $I^2 = 86\%$ and $P < 0.00001$, it indicated the presence of heterogeneity among the multiple datasets in this Meta-analysis, prompting the adoption of a random effects model. In this study, the combined effect size for the six exercise interventions on LBP was SMD= -1.21, which demonstrated an efficacy in alleviating LBP. The two-tailed test result ($P < 0.00001$) indicated that the combination of multiple datasets was statistically significant (Fig. 4).

Bias test

As shown in Fig. 5, the scatter points are mainly distributed in the upper-part area and are basically balanced on the left and right as a whole. The scatter points on the right side are evenly distributed, while several literatures on the lower-left side show a certain degree of deviation, but it is not serious and is not expected to have a significant impact on the results. It is preliminarily judged that there is no obvious publication bias among the studies. It should be noted that the asymmetry of the funnel plot cannot be simply attributed to publication bias. Firstly, there is research heterogeneity, such as differences in exercise methods, exercise duration, or exercise cycles. Secondly, in terms of methodological quality, factors like sample size and research quality may all lead to the asymmetry of the funnel plot. Based on this, we conducted a subgroup analysis of the eight moderating variables to further explore the relevant influencing factors.

Subgroup analysis

Based on the overall effect test, the possibility of the existence of potential moderating variables was identified. Therefore, this study conducted subgroup analyses on eight moderating variables that influence the relationship between exercise intervention and LBP (Table 3).

(1) Types of exercise: All six intervention methods can alleviate LBP. Among them, the yoga group (SMD= -1.97, $P < 0.00001$) exhibited the largest effect size, followed by the sling exercise group (SMD= -1.88,

Table 1 Characteristics of included studies

Study	Group	Gender	Age (mean (SD))	Types of exercise	Duration/Frequency/Cycle	Outcome Indicator
Simao Xu,2024 [38]	E=30 C=30	M=60	E=31.7±11.3 C=30.4±11.8	E=core stability C=conventional exercise	50–55 min;3 times/w;8w	VAS
M.-S. Peng,2024 [39]	E=56 C=57	M=54 F=59	E=22.24±2.12 C=21.9±2.36	E=aquatic therapy C=physical factors	60 min;2 times/w;12w	RMDQ
M. Plandowska,2024 [40]	E=26 C=26	M=34 F=18	18~25 years old	E=combined training C=no intervention	20 min;5 times /w;8w	ODI
Liansong Luo,2023 [41]	E=63 C=63	M=69 F=57	E=32.45±6.16 C=31.89±6.20	E=core stability C=conventional exercise	20–30 min;7times/w;2w	VAS
Yuying Zhang,2023 [42]	E=34 C=34	M=39 F=29	E=44.57±4.05 C=44.62±4.13	E=core stability C=conventional exercise	30 min;2 times /w;3w	ODI
L.Ge,2022 [43]	E=15 C=16	F=31	E=64.6±3.71 C=64.12±2.96	E=core stability C=physical factors	25–30 min;4 times /w;4w	VAS
Feng Zhang,2022 [44]	E=75 C=76	M=23 F=128	E=66.17±5.63 C=66.07±5.53	E=Tai Ji C=no intervention	60 min;3 times /w;8w	VAS
Xiaodi Zhang,2022 [45]	E=21 C=20	M=28 F=13	E=23.29±1.52 C=23.10±1.65	E=aquatic therapy C=land-based core exercise	50 min;3 times /w;8w	VAS
Yizu Wang,2021 [46]	E=28 C=28	M=30 F=26	E=27.71±1.98 C=28.07±3.08	E=aquatic therapy C=physical factors	50 min;2 times /w;12w	VAS
S. Mumtaz,2021 [47]	E=37 C=37	Unreported	25~30 years old	E=core stability C=conventional exercise plus physical factors	Unreported;5 times /w;5w	ODI
Wei Wu,2021 [48]	E=20 C=20	M=8 F=32	E=32.2±4.29 C=31.45±5.62	E=core stability C=physical factors	30 min;5 times /w;2w	ODI
Yanan Bai,2020 [49]	E=30 C=30	F=60	E=33.3±2.6 C=32.8±2.3	E=yoga C=health knowledge education	75 min;3 times /w;12w	VAS
Lianxiu Wang,2020 [50]	E=15 C=15	Unreported	55–65 years old	E=yoga C=health knowledge education	60 min;3 times /w;8w	VAS
Xiuming Li,2020 [51]	E=21 C=21	M=22 F=20	E=37.67±2.45 C=39.43±2.74	E=core stability C=conventional exercise	30 min;3 times /w;48w	VAS
E. Minobes-Molina,2020 [52]	E=15 C=15	F=30	E=50.1±9.8 C=50.9±11.0	E=core stability C=conventional exercise	30 min;3–5 times /w;4-6w	RMDQ
B. Kim,2020 [53]	E=22 C=24	M=22 F=24	E=47.4±9.48 C=47.5±9.70	E=core stability C=stretching exercise	30 min;3 times /w;6w	RMDQ
J. Calatayud,2020 [54]	E=42 C=43	Unreported	E=52±11 C=50±12	E=combined training C=conventional exercise	30 min;3 times /w;8w	RMDQ
Xiaoli Zou,2020 [55]	E=9 C=9	M=10 F=8	E=65.2±3.5 C=64.3±4.8	E=aquatic therapy C=no intervention	60 min;2 times /w;21w	VAS
Mengsi Peng,2020 [56]	E=27 C=26	M=26 F=27	E=27.704±5.44 C=26.58±5.18	E=aquatic therapy C=physical factors	60 min;2 times /w;12w	RMDQ
Zhiqiang Xu,2019 [57]	E=15 C=15	Unreported	E=45.1±2.6 C=45.8±3.1	E=sling exercise C=physical factors	40 min;5 times /w;3w	VAS
Jingjing Ji,2019 [58]	E=20 C=20	F=40	E=38±26.5 C=33±2.75	E=sling exercise C=physical factors	Unreported;2 times /w;12w	RMDQ
M. Brodsky,2019 [59]	E=30 C=30	Unreported	E=49.87±8.74 C=48.03±10.10	E=combined training C=health knowledge education	15–30 min;1 time /w;12w	RMDQ
Yanjie Wang,2019 [60]	E=30 C=30	M=42 F=18	E=16.80±5.55 C=18.25±11.83	E=core stability C=conventional exercise	10–20 min;7 times /w;8w	ODI
Xinxin Huang,2019 [61]	E=8 C=8	F=16	E=26.88±4.22 C=27.38±4.93	E=yoga C=no intervention	60 min;3 times /w;12w	ODI
G. Kuvačić,2018 [62]	E=15 C=15	M=16 F=14	E=33.6±4.30 C=34.7±4.83	E=yoga C=health knowledge education	75 min;2 times /w;8w	NRS
J. M. Cortell-Tormo,2018 [63]	E=11 C=8	F=19	E=35.6±7.9 C=35.6±9.7	E=combined training C=no intervention	45–60 min;2 times /w;12w	VAS
J. Chen,2018 [64]	E=13 C=12	F=25	E=42.68±3.57 C=45.61±4.26	E=core stability C=no intervention	60 min;2 times /w;6w	ODI

Table 1 (continued)

Study	Group	Gender	Age (mean (SD))	Types of exercise	Duration/Frequency/Cycle	Outcome Indicator
P. Noormohammadpour,2018 [65]	E=10 C=10	F=20	E=43.3±7.5 C=41.3±6.4	E=core stability C=no intervention	Unreported; 3 times /w;8w	RMDQ
N. Srivastav,2018 [66]	E=15 C=15	Unreported	30~50 years old	E=core stability C=conventional exercise plus physical factors	Unreported;5 times /w;6w	NRS
M. W. Akhtar,2017 [67]	E=53 C=55	Unreported	E=46.39±7.43 C=45.5±6.61	E=core stability C=conventional exercise	40 min;1time/w;6w	VAS
Qian Xu,2017 [68]	E=25 C=25	M=26 F=24	E=35.61±8.24 C=34.78±9.38	E=core stability C=conventional exercise plus physical factors	Unreported;5 times /w;8w	ODI
T. Thanawat,2017 [69]	E=62 C=64	M=21 F=106	E=45±5.4 C=44.7±5.4	E=combined training C=health knowledge education	30–40 min;3 times /w;8w	ODI
M. Salavati,2016 [70]	E=20 C=20	Unreported	E=32.6±7.8 C=29.93±5.18	E=core stability C=conventional exercise plus physical factors	Unreported;3 times /w;4w	VAS
Yuanshen Zeng,2016 [71]	E=15 C=15	Unreported	Average 51.34±7.35	E=sling exercise C=jogging	Unreported;3–4 times /w;4w	ODI
Z. G. Lin,2015 [72]	E=30 C=30	M=37 F=23	Average 41.00±9.22	E=Tai Ji C=conventional massage	Unreported;6 times /w;2w	VAS
Na Liu,2015 [73]	E=34 C=34	M=43 F=25	E=39.8±5.7 C=38.6±5.9	E=core stability C=physical factors	15–30 min;5 times /w;3w	VAS
Priscila Lawand,2015 [74]	E=31 C=30	M=14 F=47	E=45±5.4 C=44.7±5.5	E=combined training C=no intervention	60 min;1time/w;12w	RMDQ
Y. Yu-Lin,2015 [75]	E=7 C=5	Unreported	E=27.6±6.7 C=27.6±5.6	E=sling exercise C=no intervention	40 min;3 times /w;6w	ODI
J. Jee-Hun,2015 [76]	E=15 C=15	F=30	Twenties	E=Tai Ji C=stretching exercise	60 min;3 times /w;8w	VAS
Y. H. Cho,2014 [77]	E=20 C=20	M=40	Around 20 years old	E=Tai Ji C=stretching exercise	60 min;3 times /w;4w	VAS
H. M. Chen,2014 [78]	E=64 C=63	Unreported	E=30.67±4.45 C=37.7±8.8	E=combined training C=no intervention	50 min;3 times /w;24w	VAS
Zhihui Li,2014 [79]	E=39 C=39	M=45 F=33	Average 42 years old	E=sling exercise C=physical factors	Unreported;4 times /w;4w	VAS

Note: E: Experimental, C: Control, M: Male, F: Female, M±SD: mean±standard deviation. VAS: Visual analogue scale, NRS: Numeric Rating Scale, ODI: Oswestry Disability Index, RMDQ: Roland Morris Disability Questionnaire

$P=0.0004$) > Tai Ji (SMD = -1.59, $P=0.004$) > core stability training (SMD= -1.18, $P<0.00001$) > aquatic therapy (SMD= -0.67, $P<0.00001$) > combined training (SMD= -0.62, $P<0.00001$). The P-values for the effect sizes of all six groups were < 0.05, indicating statistical significance.

(2) Exercise Duration: Exercise durations across three groups all showed efficacy in alleviating LBP. The group with exercise durations less than or equal to 30 min (SMD= -1.31, $P<0.0001$) achieved the largest effect size. Following that was the group with durations 60 min or more (SMD= -1.08, $P<0.00001$). The group with durations between 35 and 50 min had the smallest effect size (SMD= -0.92, $P<0.00001$).

(3) Exercise Frequency: Exercise frequencies across three groups all demonstrated effects in reducing LBP. Firstly, the exercise frequency of more than 4 times per week showed the largest effect size (SMD= -1.56, $P<0.00001$). Secondly, the group with an exercise frequency of 3 to 4 times per week followed (SMD= -1.10, $P<0.00001$), Lastly, the group with an exercise frequency of less than 3 times per week had the smallest effect size (SMD= -1.06, $P<0.00001$).

(4) Exercise Cycle: Exercise cycles across four groups all showed benefits in alleviating LBP. The group with exercise cycles of less than or equal to 4 weeks had the largest effect size (SMD= -1.61, $P<0.00001$), followed by the group with cycles exceeding 12 weeks (SMD= -1.43, $P<0.00001$),and the group with cycles between 5 and 8 weeks had the smallest effect size (SMD= -0.80, $P<0.00001$).

(5) Sample Size: Exercise interventions across three groups, regardless of sample size, demonstrated efficacy in alleviating LBP. The group with 30 to 60 cases had the largest effect size (SMD= -1.36,

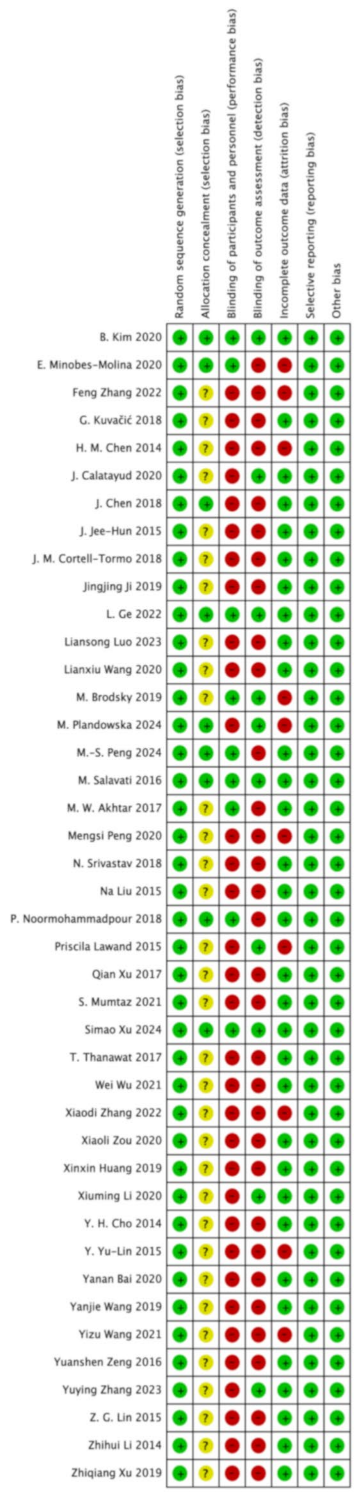

Fig. 2 Risk of bias summary. This study conducted a methodological quality assessment of the included 42 articles according to the RCT quality evaluation methods outlined in the Cochrane Handbook for Systematic Reviews of Interventions, version 5.4. The categories used for evaluation are: "+" indicating compliance with the standard, "-" indicating non-compliance, and "?" indicating that the information was not clearly stated in the article

$P < 0.00001$), followed by the group with fewer than 30 cases (SMD= -1.17, $P = 0.0002$).

(6) Study Quality: A subgroup analysis based on study quality revealed that the group with moderate bias risk had the largest effect size (SMD= -1.37, $P < 0.00001$), followed by the group with low bias risk (SMD= -0.85, $P < 0.00001$).

(7) Outcome Indicator: A subgroup analysis of the three outcome measures included in this study found that the group using the ODI score to assess the alleviation of LBP had the largest effect size (SMD = -3.35, $P < 0.00001$), followed by the group using the RMDQ score (SMD = -2.25, $P = 0.004$) and the group using the VAS/NRS score (SMD = -1.54, $P < 0.00001$).

(8) Types of control groups: Through subgroup analysis of the different intervention methods of the included control groups, it was found that the treatment effect size of simple physical factor therapy was the largest (SMD= -1.85, $P < 0.00001$), followed by the group with no exercise and physical factor intervention (SMD= -1.08, $P < 0.00001$), conventional exercise (SMD= -1.04, $P < 0.00001$), and the combined effect size of conventional exercise and physical factors was the smallest (SMD= -0.52, $P = 0.005$). This indicates that the experimental groups with the six exercise interventions are more effective in treating LBP than simple physical factor therapy.

Discussions

Lower back pain (LBP) is a prevalent musculoskeletal issue and a major cause of disability in both developed and developing countries. According to the 2021 Global Burden of Disease public data, LBP ranks sixth, and the associated medical costs have soared, encompassing direct expenses (such as examination fees, medication costs, and hospitalization expenses) and indirect costs arising from reduced work efficiency [82, 83]. Consequently, LBP has emerged as a significant public health challenge that requires urgent global attention.

To alleviate the pain and improve related functional impairments associated with LBP, exercise therapy is considered an effective means, but the key lies in determining which kind of exercise therapy holds the greatest potential for effectiveness. In view of this, this study aimed to explore the specific effects of different exercise types on pain relief and physical function improvement in patients with low back pain, and six exercise types were evaluated for this purpose. Through analysis, the research results showed that the combined effect sizes of these six exercise types for the treatment of LBP were significant, confirming the effectiveness of exercise intervention in relieving LBP. Meta-analysis can objectively integrate the effect sizes of multiple independent studies simultaneously. Based on the overall effect size test,

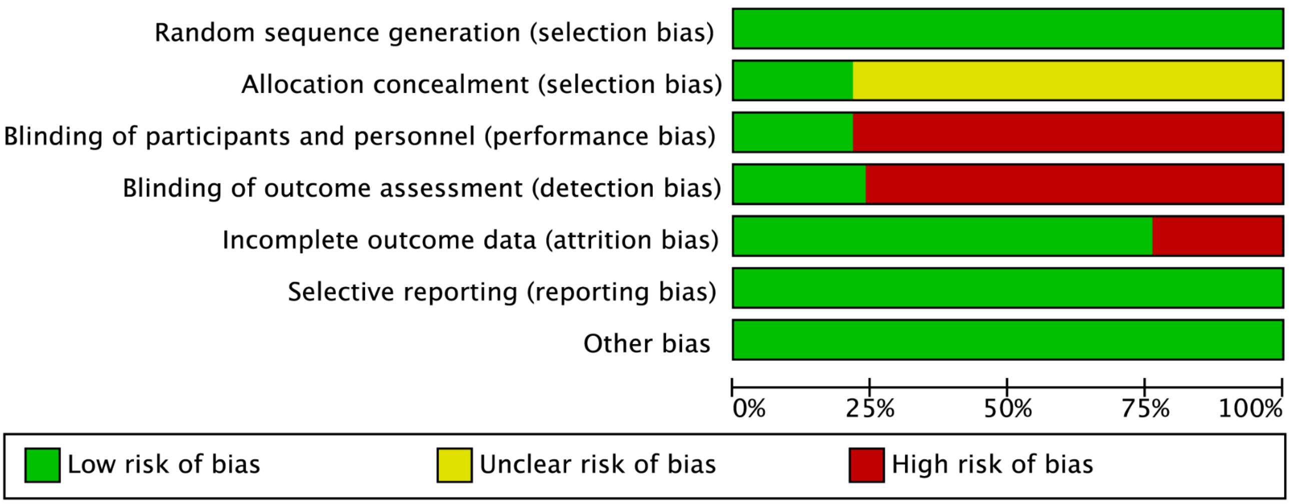

Fig. 3 Risk of bias graph. Summary of the literature methodology of this study to evaluate the proportion of each item statistics

Table 2 Statistical analysis of the association of exercise intervention with low back pain

	Samples	Homogeneity test			Two-tailed test		Effect size and SMD(95% CI)
		X^2	*P*	I^2	Z	*P*	
Random effects model	42	284.08	*P* < 0.00001	86%	10.39	*P* < 0.00001	-1.21(-1.45, -0.96)

the results indicated the existence of heterogeneity, and its sources were diverse. Therefore, we conducted effect tests based on exercise type, exercise duration, exercise frequency, exercise cycle, etc., to explore the potential factors affecting the effectiveness of exercise intervention for LBP.

(1) Different exercise types may have different intervention effects on LBP. Through the test of the moderating variable of exercise type, the yoga has the best potential effect in relieving LBP. The effect size of the yoga group reached – 1.97, indicating a difference between the yoga group and the control group. This change has important clinical significance for LBP patients in terms of pain level and functional ability. First, in terms of pain level, compared with the control group, the pain level of LBP patients receiving yoga intervention can be effectively reduced. In practice, it can be manifested as a significant reduction in the pain intensity felt by patients in daily life. For example, patients who originally had difficulty bending over or getting up due to pain, after yoga intervention, the frequency and severity of pain attacks have decreased significantly, and the impact on daily activities has been significantly reduced. They can freely perform simple lumbar activities, and their quality of life has been significantly improved. Second, in terms of functional ability, yoga intervention can effectively improve the lumbar and related physical functions of LBP patients. The body flexibility, muscle strength and endurance of patients may be effectively enhanced, and the limb balance function is strengthened. For example, patients who originally could not stand or walk for a long time due to limited lumbar function, after yoga intervention, can stand and walk for a longer time and can also participate in some mild physical activities. The lumbar function impairment index has been significantly improved, and the ability to return to normal life and work has been enhanced. In addition to the above potential factors, there are other potential mechanisms by which yoga improves LBP. Firstly, yoga can adjust the spinal alignment and enhance spinal stability. For example, postures such as the “Cat-Cow Pose” and the “Mountain Pose” in yoga help to relieve the pressure between the vertebral discs and reduce the compression on the surrounding nerves and muscles. Postures like the “Triangle Pose” and the “Boat Pose” in yoga can strengthen the muscles around the spine. These muscles are like a “natural corset,” providing stable support for the spine and reducing abnormal movements and swaying of the spine during daily activities. Secondly, yoga can promote the regulation of nerve function. Various postures in yoga require the body to maintain specific postures and balance. In this process, it is necessary to continuously receive and process proprioceptive information from muscles, joints, and the inner ear. Therefore, the proprioceptive system is constantly activated and strengthened. For patients with LBP, good proprioception helps them better control the movement of their lower back and avoid aggravating the pain due to incorrect movement patterns. Some related studies [84, 85] all indicate that yoga can reduce pain and disability. Moreover, the American College of Physicians and the American Pain Society recommend yoga as one of the effective means for the treatment of LBP [62]. Therefore,

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
B. Kim 2020	11.23	2.62	22	11.29	1.25	24	2.6%	−0.03 [−0.61, 0.55]
E. Minobes−Molina 2020	3.4	2.2	19	3.8	3.3	21	2.5%	−0.14 [−0.76, 0.48]
Feng Zhang 2022	1.828	1.378	75	3.404	1.999	76	2.8%	−0.91 [−1.25, −0.58]
G. Kuvačić 2018	1.73	0.59	15	2.93	0.59	15	2.1%	−1.98 [−2.87, −1.08]
H. M. Chen 2014	2.17	1.42	64	3.48	1.77	63	2.8%	−0.81 [−1.17, −0.45]
J. Calatayud 2020	4.97	4.2	42	7.9	5.35	43	2.7%	−0.60 [−1.04, −0.17]
J. Chen 2018	8.41	7.26	13	9.49	6.48	12	2.3%	−0.15 [−0.94, 0.63]
J. Jee−Hun 2015	2.1	0.6	15	2.5	0.6	15	2.3%	−0.65 [−1.39, 0.09]
J. M. Cortell−Tormo 2018	1.5	1.5	11	4.4	1.4	8	1.8%	−1.90 [−3.03, −0.76]
Jingjing Ji 2019	8.2	0.83	15	13.2	0.84	15	1.2%	−5.83 [−7.56, −4.09]
L. Ge 2022	3.8	1.35	15	5.5	0.63	16	2.2%	−1.59 [−2.41, −0.77]
Liansong Luo 2023	2.43	0.86	63	4.17	1.55	63	2.8%	−1.38 [−1.77, −0.99]
Lianxiu Wang 2020	0.44	0.78	15	3.31	0.97	15	1.8%	−3.17 [−4.29, −2.05]
M. Brodsky 2019	3.56	3.72	30	3.93	3.85	30	2.6%	−0.10 [−0.60, 0.41]
M. Plandowska 2024	9.5	4.9	26	14	6.1	26	2.6%	−0.80 [−1.37, −0.23]
M.−S. Peng 2024	3.23	2.9	56	4.63	3.98	57	2.8%	−0.40 [−0.77, −0.03]
M. Salavati 2016	2.61	1.96	20	2.87	1.46	20	2.5%	−0.15 [−0.77, 0.47]
M. W. Akhtar 2017	2.69	0.93	53	3.69	0.79	55	2.8%	−1.15 [−1.56, −0.74]
Mengsi Peng 2020	2.482	2.592	27	4.577	4.42	26	2.6%	−0.57 [−1.12, −0.02]
N. Srivastav 2018	0.8	0.862	15	1.27	0.961	15	2.4%	−0.50 [−1.23, 0.23]
Na Liu 2015	2.1	0.56	34	4.11	0.52	34	2.3%	−3.68 [−4.47, −2.88]
P. Noormohammadpour 2018	1.7	2.4	10	7.9	3.3	10	1.8%	−2.06 [−3.19, −0.93]
Priscila Lawand 2015	7.2	5.2	31	11.4	5.5	30	2.6%	−0.78 [−1.30, −0.25]
Qian Xu 2017	11.38	2.85	25	13.83	2.17	25	2.5%	−0.95 [−1.54, −0.36]
S. Mumtaz 2021	14.8	5.9	37	17.7	6.7	37	2.7%	−0.45 [−0.92, 0.01]
Simao Xu 2024	1.11	0.81	30	2.11	1.52	30	2.6%	−0.81 [−1.34, −0.28]
T. Thanawat 2017	14.8	4.8	62	16.6	8.7	64	2.8%	−0.25 [−0.60, 0.10]
Wei Wu 2021	10.9	2.67	20	18.15	4.33	20	2.3%	−1.98 [−2.74, −1.21]
Xiaodi Zhang 2022	2.4	0.66	21	2.93	0.73	20	2.5%	−0.75 [−1.38, −0.11]
Xiaoli Zou 2020	2.56	2.13	9	5.88	4.16	8	2.0%	−0.97 [−2.00, 0.05]
Xinxin Huang 2019	8.5	1.78	8	11.38	2.26	8	1.8%	−1.34 [−2.45, −0.22]
Xiuming Li 2020	1.45	0.25	21	2.38	0.18	21	1.8%	−4.19 [−5.31, −3.07]
Y. H. Cho 2014	2.1	0.5	20	2.8	0.5	20	2.4%	−1.37 [−2.07, −0.68]
Y. Yu−Lin 2015	8.86	6.41	7	18.5	11.82	5	1.7%	−0.99 [−2.24, 0.25]
Yanan Bai 2020	1.38	0.41	30	2.26	0.55	30	2.5%	−1.79 [−2.40, −1.19]
Yanjie Wang 2019	14.83	3.04	30	19.9	3.74	30	2.6%	−1.47 [−2.04, −0.89]
Yizu Wang 2021	1.79	0.955	28	3.29	1.357	28	2.6%	−1.26 [−1.84, −0.68]
Yuanshen Zeng 2016	8.42	1.68	15	10.62	3.21	15	2.3%	−0.84 [−1.59, −0.08]
Yuying Zhang 2023	15.58	3.06	34	17.49	3.17	34	2.7%	−0.61 [−1.09, −0.12]
Z. G. Lin 2015	1.78	0.24	30	2.9	0.37	30	2.2%	−3.54 [−4.37, −2.72]
Zhihui Li 2014	1.74	0.77	39	3.38	1.14	39	2.6%	−1.67 [−2.19, −1.15]
Zhiqiang Xu 2019	0.4	0.5	15	1.1	0.6	15	2.3%	−1.23 [−2.02, −0.44]
Total (95% CI)			**1167**			**1168**	**100.0%**	**−1.21 [−1.45, −0.96]**

Heterogeneity: Tau² = 0.52; Chi² = 284.08, df = 41 (P < 0.00001); I² = 86%

Test for overall effect: Z = 9.67 (P < 0.00001)

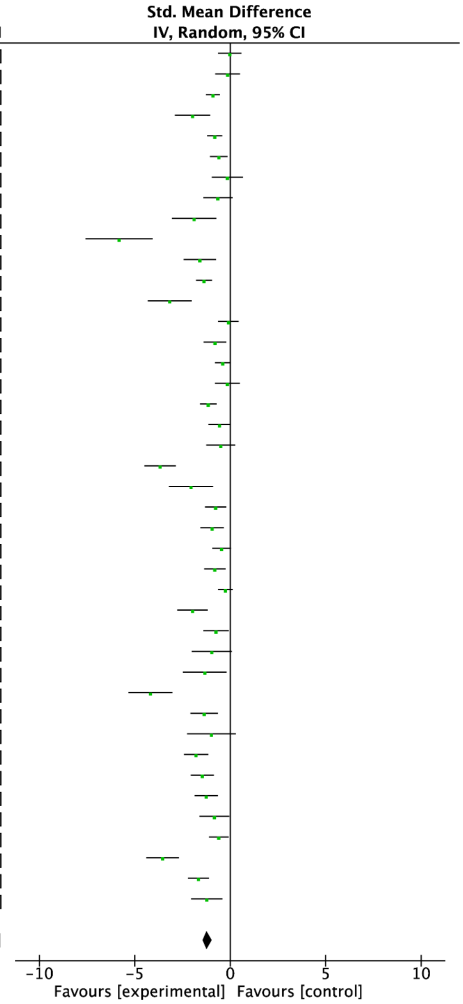

Fig. 4 Forest map of meta-analysis of the effects of various exercise interventions on low back pain. E: Experimental, C: Control, Std. Mean Difference: standardized mean difference(SMD), Random: random effects model, 95% CI: 95% confidence interval, I^2: heterogeneity score

in summary, in this study, compared with other exercise interventions, yoga is more effective in reducing patients' pain and improving physical function. The results demonstrate that yoga has the potential to relieve LBP. Sling exercise also shows a relatively good therapeutic effect, Kim et al. [86]confirmed that sling exercise is superior to conventional training. Sling exercise activates core muscle groups by suspending part of the body in an unstable state, thereby improving muscle imbalance and enhancing neuromuscular control. In the authoritative guidelines on the treatment of LBP published by the American Medical Association in 2017, Tai Ji was recommended as an effective treatment option [9]. The findings of this study are in line with the research results of Qin et al. [87], once again confirming the positive role of Tai Ji in alleviating LBP. According to relevant research reports, Tai Ji not only significantly enhances body flexibility but also strengthens muscle endurance and improves limb balance function [88, 89]. More importantly, Tai Ji helps reduce serum B-type natriuretic peptide levels, an effect that improves blood circulation and facilitates the delivery of blood calcium and other nutrients to the lumbar spine, thereby accelerating the metabolic process of lumbar vertebrae, enhancing the absorption capacity of other minerals, and ultimately increasing bone density in the lumbar area [90]. Additionally, this study also found that other exercise therapies, such as core stability training, combined training, and aquatic therapy, demonstrate positive therapeutic effects on LBP, effectively reducing pain. A study has found [91] that increased loading on lumbar intervertebral discs and paraspinal ligaments in some patients with LBP leads to lumbar instability and decreased postural control, with "core stability" being considered crucial for effective biomechanical function. Compared to conventional exercises, multiple studies [92–94]have demonstrated that core stability training can activate both local and global muscles of the spine, train the core muscles of the spine, and increase lumbar

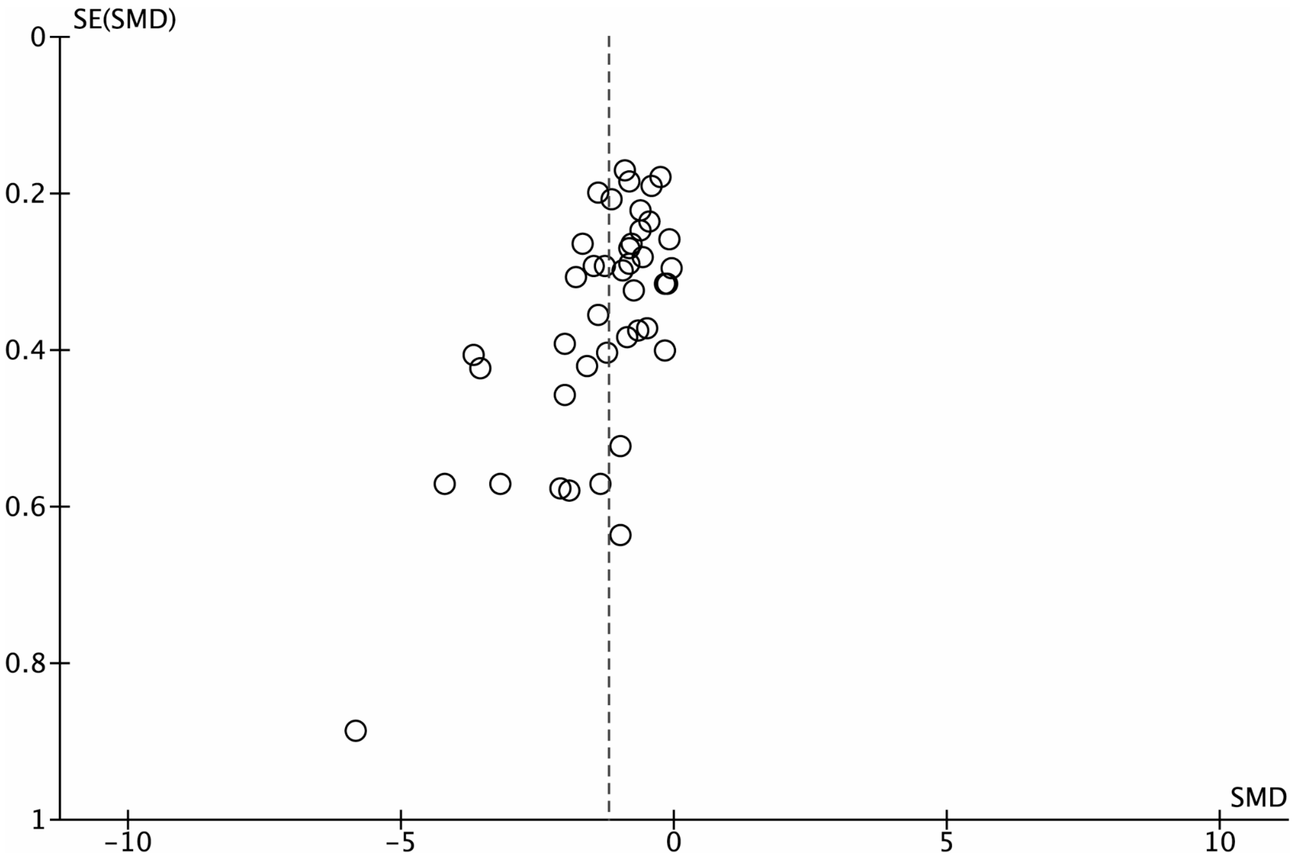

Fig. 5 Funnel-shaped diagram of various exercise interventions for low back pain

stability. This study also confirms this finding. Aquatic therapy fully utilizes the characteristics of water's buoyancy, resistance, and pressure, providing a new approach to the treatment of LBP. It combines safety, painlessness, and diversity, demonstrating unique therapeutic advantages and broad application potential [95]. Further research by Shi et al. [96] has shown that, compared to conventional exercise, aquatic therapy can more effectively reduce pain and improve physical function in patients with LBP. Additionally, other studies [21, 97] have consistently confirmed the significant effectiveness of aquatic therapy in treating LBP. Moreover, the studies [98]have pointed out that for acute or subacute LBP, a single exercise therapy often has poor curative effects. In terms of relieving symptoms and improving lumbar spine functions, combined training may be more effective than conventional exercise. Although conventional training also includes muscle strength training, flexibility training, and training of postural stability muscle groups, combined training organically integrates these elements. According to the rehabilitation needs of patients, the training intensity, frequency, and movement combinations are carefully designed to achieve synergistic effects.

(2) Different exercise durations, exercise frequencies, and exercise cycles can also affect the effectiveness of treating LBP. The results indicated that the optimal therapeutic effects were achieved when each exercise session was controlled within 30 min, the exercise frequency reached four times or more per week, and the total exercise cycle did not exceed four weeks. This suggests that a short-duration, short-term, but high-frequency exercise cycle may be the optimal strategy for treating LBP.

Even if the duration of each exercise session is relatively short, if a high frequency of practice is maintained, it is possible to continuously stimulate the muscles and joints. This continuous stimulation can gradually enhance the muscle strength of the lower back, increase flexibility, and optimize joint mobility, laying a solid foundation for the relief of LBP. From the literature included in this study, it can be found that sling exercise and core stability training are excellent examples of benefiting from the short -duration, high-frequency, and short-term training mode. In this mode, the core muscle groups can be repeatedly activated within a short period. Take sling exercise as an example. By using an unstable suspension device, the core muscle groups are stimulated multiple times in a short time, enabling them to quickly adapt and enhance their strength. This effectively improves the supporting and stabilizing abilities of the waist and rapidly corrects the muscle imbalance. Similarly, high-frequency

Table 3 Subgroup analysis of effect of exercise intervention on lower back pain

Subgroup	Studies	Heterogeneity test		Meta analysis	
		P	I^2	SMD(95%CI)	*P*
Types of exercise					
core stability	17	< 0.00001	88%	-1.18(-1.61, -0.76)	< 0.00001
Tai Ji	4	< 0.00001	92%	-1.59(-2.65, -0.52)	= 0.004
aquatic therapy	5	= 0.16	39%	-0.67(-0.91, -0.43)	< 0.0001
yoga	4	= 0.11	50%	-1.97(-2.39, -1.54)	< 0.00001
sling exercise	5	< 0.0001	86%	-1.88(-2.92, -0.84)	= 0.0004
combined training	7	= 0.02	59%	-0.62(-0.91, -0.33)	< 0.0001
Exercise Duration					
≤ 30 min	12	< 0.00001	91%	-1.31(-1.88, -0.74)	< 0.00001
35 ~ 50 min	9	= 0.01	59%	-0.92(-1.21, -0.62)	< 0.00001
≥ 60 min	12	< 0.00001	75%	-1.08 (-1.45, -0.71)	< 0.00001
Exercise Frequency					
< 3 times/w	12	< 0.00001	83%	-1.04(-1.47, -0.61)	< 0.00001
3 ~ 4 times/w	20	< 0.00001	83%	-1.10(-1.42, -0.77)	< 0.00001
> 4 times/w	10	< 0.00001	90%	-1.56(-2.17, -0.96)	< 0.00001
Exercise Cycle					
≤ 4w	11	< 0.00001	89%	-1.61(-2.18, -1.04)	< 0.00001
5 ~ 8w	19	< 0.00001	73%	-0.80(-1.06, -0.54)	< 0.00001
> 12w	12	< 0.00001	89%	-1.43(-1.96, -0.89)	< 0.00001
Sample Size					
< 30 cases	6	= 0.06	52%	-1.17(-1.80, -0.55)	= 0.0002
30 ~ 60 cases	24	< 0.00001	87%	-1.36(-1.75, -0.96)	< 0.00001
> 60 cases	12	< 0.00001	88%	-1.00 (-1.35, -0.65)	< 0.00001
Research Quality					
low risk of bias	13	< 0.00001	83%	-0.85(-1.23, -0.46)	< 0.0001
moderate risk of bias	29	< 0.00001	86%	-1.37 (-1.67, -1.07)	< 0.00001
high risk of bias	—	—	—	—	—
Outcome Indicator					
VAS/NRS	22	< 0.00001	86%	-1.54(-1.89, -1.19)	< 0.00001
ODI	11	= 0.003	62%	-3.35(-4.47, -2.22)	< 0.00001
RMDQ	9	< 0.00001	92%	-2.25(-4.14, -0.76)	= 0.004
Types of control group					
CE	11	< 0.00001	84%	-1.04 (-1.45,-0.62)	< 0.00001
PF	9	< 0.00001	92%	-1.85 (-2.59,-1.10)	< 0.00001
CE + PF	4	= 0.32	15%	-0.52 (-0.80,-0.23)	= 0.0005
NI-EPF	15	< 0.00001	78%	-1.08(-1.43,-0.73)	< 0.00001

Note: VAS: Visual analogue scale, NRS: Numeric Rating Scale, ODI: Oswestry Disability Index, RMDQ: Roland Morris Disability Questionnaire, CE: conventional exercise, PF: physical factors, CE + PF: conventional exercise plus physical factors, NI-EPF: no intervention of exercise and physical factors

practice creates continuous stimulation for the core muscle groups and the muscles around the spine. Within a relatively short time, it can significantly strengthen the muscle strength and effectively alleviate the symptoms of LBP. Moreover, the short-duration and high-frequency training mode also avoids the problem of muscle overfatigue caused by long-term training. At the same time, it reduces the likelihood of patients developing boredom, enabling the training to proceed more efficiently and continuously, which greatly contributes to the relief of LBP. From the multiple pieces of literature included in the study on sling exercise for the intervention of LBP, although most of them did not report the specific training time, it was mentioned that the training was carried out 4 to 5 times a week, and the intervention period was 3 to 4 weeks. In the literature on core stability training for the intervention of LBP that was included, most of the literature showed that each training session lasted 20 to 30 min, the training was conducted 4 to 7 times a week, and the intervention period was 2 to 4 weeks. These data further confirm the application of the short-duration, high-frequency, and short-term training mode in practice, as well as its positive role in relieving LBP. However, although this study suggests that short-duration, short-term but high-frequency exercise cycles might be the most optimal for treating LBP, it is still vulnerable to interference from various factors, which can significantly impact the effectiveness of exercise-based LBP treatment. For example, in terms of individual physical fitness differences, due to different basic physical fitness levels, individuals have different adaptation abilities and responses to exercise duration, frequency, and cycle. People with good physical fitness can withstand longer and more frequent exercise and can relieve LBP through exercise in a short period of time; while those with poor physical fitness may suffer from excessive fatigue or even injuries due to exercise, affecting the treatment effect. Metabolic levels also have an impact. People with a fast metabolic rate can quickly eliminate exercise metabolic waste products and recover their physical strength, and can adapt to more frequent and longer exercise cycles, which is beneficial for improving LBP; while people with a slow metabolic rate take a longer time to recover, and too high exercise frequency and too long exercise cycle are likely to accumulate fatigue, instead aggravating the symptoms of LBP. The severity of LBP should not be overlooked either. For patients with mild symptoms, short-term and low-frequency exercise may have a significant effect, and they can quickly enter a long-term exercise cycle to consolidate the therapeutic effect; for patients with severe symptoms, their bodies have poor tolerance and need a longer time to adapt to exercise. Increasing the exercise duration and frequency rashly is very likely to intensify the pain and have a negative impact on the overall treatment effect.

(3) The sample size, research quality, and outcome indicators can all lead to biases in the treatment effect of LBP. This study shows that when the sample size is between 30 and 60 cases, the research quality is at a moderate risk of bias, and when the ODI is used as the evaluation indicator, the effect size of treating LBP is the largest. However, it should be noted that this meta-analysis only included studies with low and moderate risk of bias and excluded studies with a high risk of bias, which has limitations in terms of research quality and may lead to biased results. In the future, the scope of literature inclusion should be broadened to cover studies of different quality levels, to comprehensively and accurately evaluate the impact of research quality on the treatment effect. In addition, different outcome indicators can reflect the treatment effect of LBP from multiple dimensions. In this study, the ODI, RMDQ, and the VAS/NRS were selected as the outcome indicators for evaluating LBP. Although these indicators have different focuses, the scale values are all used to assess the situations related to LBP, and they are consistent in meaning and comparable. The results of the research analysis show that each indicator presents a relatively large effect size, and the *P*-value is less than 0.05, which is statistically significant. Among them, the ODI group has the largest effect size, followed by the RMDQ group, and the VAS/NRS group has a relatively smaller effect size. The subgroup analysis further indicates that ODI may be more sensitive to the treatment effect. However, these indicators still have certain limitations. On the one hand, there are subjective differences in the evaluation. Patients may overestimate or underestimate their own functional impairments and pain levels, resulting in poor comparability of the results among different patients. On the other hand, the applicability of each indicator varies at different stages of the disease. Therefore, to accurately verify the influence of the outcome indicator as a moderating variable, future studies should conduct multi-center studies with large sample sizes to improve the diversity and representativeness of the research subjects and reduce the heterogeneity caused by differences in sample characteristics. At the same time, when analyzing the data, methods such as stratified analysis and multi-factor correction should be used to control confounding factors such as age, gender, underlying diseases, and treatment methods.

(4)The results of the subgroup analysis conducted on different intervention methods of the control group show that When the six exercise interventions were compared with the simple physical factor treatment in the control group, the six exercise interventions showed the largest effect size. This result clearly indicates that, in terms of the overall effect, the six exercise interventions are significantly more effective than simply using physical factor treatment in the treatment of LBP. When further compared with the combination of conventional exercise and physical factors, the results show that the effect size of the six exercise interventions is the smallest. This phenomenon indicates that although the treatment method of combining conventional exercise and physical factors shows a smaller effect size when compared with the six exercise interventions, it still has unique advantages compared with the simple physical factor treatment. It implies that by optimizing the specific treatment plan of combining conventional exercise and physical factors, such as adjusting the intensity, frequency, and type of exercise, as well as the selection, duration of use, and dosage of physical factors, it is expected to further improve its effect in alleviating low back pain. Therefore, it has certain potential in the field of treating LBP.

Strengths and limitations

This study encompassed and analyzed literature in both English and Chinese. From an evidence-based medicine perspective, it is imperative to include literature that is not indexed in the Science Citation Index or is non-English to gather research evidence as comprehensively as possible. This approach enhances the comprehensiveness and accuracy of the analysis, mitigating the risk of omitting significant studies due to language or database limitations. Secondly, while certain Chinese literature may exhibit shortcomings in the articulation of research methodologies and the reporting of statistical analyses, it nonetheless qualifies as research. In the context of meta-analysis, it is essential to acknowledge the limitations inherent in these studies while also recognizing their contributions to the field. By undertaking an objective assessment of methodological quality, we can discern existing biases and evaluate their specific effects on the overall findings. Moreover, the corpus of English literature on this topic is relatively limited. Incorporating Chinese literature not only expands the sample size but also enhances the statistical power of the analysis. Additionally, certain Chinese studies demonstrate significant academic merit in terms of research design, data analysis, and result presentation, underscoring the necessity of their inclusion in the meta-analysis.

In summary, this study employed methods of meta-analysis and systematic review, comprehensively considering evidence for six types of exercise interventions, robustly demonstrating that these interventions can effectively treat LBP. Furthermore, we conducted an in-depth and detailed analysis based on multiple dimensions, including the specific content of the interventions, the intervention program (including duration, frequency, and cycle), sample size, study quality, and assessment indicators. This approach significantly differs from the practice of most previous reviews, which simply categorize different exercise therapies into one group. By doing so, our study significantly reduced the heterogeneity and uncertainty of the results. However, this study also has certain limitations. In the Meta-analysis of exercise interventions for the treatment of LBP, there are various factors that affect the reliability and universality of the results: First, the heterogeneity of the included studies: When conducting the overall effect size test, the study found the existence of heterogeneity and subsequently carried out subgroup analysis. However, the impact of heterogeneity remains. In different studies, the specific contents and implementation methods of exercise interventions vary widely, and the characteristics of the participants also differ. These factors will all lead to different intervention effects. For example, yoga interventions may produce different effects in different studies due to differences in pose selection and teaching methods; participants of different ages and physical conditions may also have different responses to the same exercise intervention. This heterogeneity makes the interpretation of the results complex, and it is difficult to simply attribute them to the exercise intervention itself. When generalizing the research results to a wider group of low back pain patients, there will also be limitations. Second, potential publication bias: This study did not search for unpublished literature, which is very likely to lead to the problem of publication bias. In the academic field, published studies often tend to show statistically significant results, while those studies with negative results or insignificant effects are often not published. This leads to the inclusion of only studies presenting positive effects in the analysis, while missing studies that may indicate poor effects of exercise interventions, thus causing us to overestimate the actual effects of exercise interventions. When interpreting the research results, the role of exercise interventions will be exaggerated. Third, small sample size: Some studies have the problem of a small sample size. A small sample size will reduce the statistical power of the study, making the research results unstable and vulnerable to random factors, and unable to accurately reflect the true intervention effect. For example, a small sample may happen to include individuals who have an extremely good or extremely poor response to the exercise intervention, thus affecting the overall results. Due to the limited sample size, the research results are difficult to represent a wider range of patients, severely limiting the generality and applicability of the research conclusions and cannot be widely applied to various LBP patients. Fourth, methodological weaknesses: Relatively few of the included studies adopted blinding and allocation concealment schemes, which is a major weakness in the research methodology. The absence of blinding and allocation concealment schemes can easily introduce bias during the research process, thereby affecting the accuracy of the research results. This bias may lead to overestimating or underestimating the effects of exercise interventions and make it impossible to accurately judge the true effects of the interventions. When interpreting the results, there will be deviations; when applying the research results in practice, it is also difficult to obtain reliable references. In view of this, future studies need to include high-quality studies for verification.

Clinical and future perspectives

Currently, most clinical guidelines, both domestically and internationally, prioritize exercise therapy as the preferred treatment for LBP [9–12]. PubMed defines exercise therapy as "A regimen or plan of physical activities designed and prescribed for specific therapeutic goals, with the purpose of restoring normal musculoskeletal function or reducing pain caused by diseases or injuries". Patients seeking primary care for LBP are typically prescribed exercise therapy by physiotherapists or rehabilitation physicians. To date, there is no conclusive evidence that one type of exercise is superior to another [99]. Our meta-analysis results merely provide insights into the effectiveness of various exercises. Additionally, the outcomes studied in our systematic review focused primarily on pain and disability; Future research should incorporate additional outcome indicators, such as quality of life, muscle endurance assessments, fear avoidance behaviors, and pain catastrophizing tendencies, all of which play a crucial role in assessing LBP. Furthermore, this study only included six types of exercise therapy; future research should further expand the range of exercises, striving to collect literature and analyze evidence as comprehensively as possible.

Conclusions

In conclusion, the findings of this meta-analysis suggest that all six exercise intervention measures are effective in relieving low back pain, among which yoga has the best potential therapeutic effect. The most effective exercise regimen consists of sessions lasting less than 30 min, conducted more than four times per week, over a period not exceeding four weeks. Notably, the greatest improvement in ODI scores for LBP is observed with these exercise interventions. To enhance the accuracy in verifying the effectiveness of exercise interventions for the treatment of LBP, it is imperative to incorporate a greater number of high-quality, rigorously designed randomized controlled trials in future research.

Abbreviations

LBP	Low Back Pain
VAS	Visual Analogue Scale
NRS	Numeric Rating Scale
RMDQ	Roland Morris Disability Questionnaire
ODI	Oswestry Disability Index
SMD	Standardized Mean Difference

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

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Author contributions
Mei Cheng: Conceptualization, Methodology, formal analysis, Data curation, Writing-Original draft preparation. Yu Tian, Qi Ye, and Jun Li: Software, Validation, Visualization. Lin Xie: Investigation, Supervision, Writing- Reviewing and Editing. Fan Ding: Resources, Project administration, Funding acquisition.

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Data availability
All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate
Not applicable.

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Competing interests
The authors declare no competing interests.

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References

1. Chen S, Chen M, Wu X et al. Global, regional and National burden of low back pain 1990–2019: A systematic analysis of the global burden of disease study 2019 [J].J Orthop Translat,2022,32.49-58.
2. Urits I, Burshtein A, Sharma M et al. Low back pain, a comprehensive review: pathophysiology, diagnosis, and treatment [J].Curr Pain Headache Rep,2019,23.23.
3. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the global burden of disease study 2017 [J].Lancet,2018,392.1789-1858.
4. Wirth, B. Schweinhardt P. Personalized assessment and management of non-specific low back pain [J]. Eur J Pain,2024,28.181-198.
5. Deyo R A, von Korff M. Duhrkoop D. Opioids for low back pain [J]. Bmj,2015,350.g6380.
6. Koes B W, van Tulder M W. Thomas S. Diagnosis and treatment of low back pain [J].Bmj,2006,332.1430–1434.
7. W I J, Oosterhuis T. Hayden J A, Exercise therapy for treatment of acute non-specific low back pain [J].Cochrane database Syst Rev,2023,8.Cd009365.
8. Hayden JA, Ellis J, Ogilvie R et al. Exercise therapy for chronic low back pain [J].Cochrane database Syst Rev,2021,9.Cd009790.
9. Qaseem A, Wilt T J, McLean RM et al. Noninvasive treatments for acute, subacute, and chronic low back pain: A clinical practice guideline from the American college of physicians [J].Ann Intern Med,2017,166.514-530.
10. Wang R, Weng L M Pengms et al. Exercise for low back pain: A bibliometric analysis of global research from 1980 to 2018 [J].J Rehabil Med,2020,52. jrm00052.
11. Airaksinen O, Brox J I, Cedraschi C, et al. Chapter 4. European guidelines for the management of chronic nonspecific low back pain [. J] Eur Spine J. 2006;15(Suppl 2):S192–300.
12. Xueqiang W, Peijie C, Wei J et al. Exercise therapy for back pain: expert consensus [J].Chinese Journal of evidence-based Medicine,2019,39.19-29.
13. Vleeming A, Schuenke M D Danneelsl et al. The functional coupling of the deep abdominal and paraspinal muscles: the effects of simulated paraspinal muscle contraction on force transfer to the middle and posterior layer of the thoracolumbar fascia [J].J Anat,2014,225.447-462.
14. Hlaing SS, Puntumetakul R, Khine E E et al. Effects of core stabilization exercise and strengthening exercise on proprioception, balance, muscle thickness and pain related outcomes in patients with subacute nonspecific low back pain: a randomized controlled trial [J].BMC Musculoskelet Disord,2021,22.998.
15. Zou L, Han J, Li C et al. Effects of Tai Chi on lower limb proprioception in adults aged over 55: A systematic review and Meta-Analysis [J].Arch Phys Med Rehabil,2019,100.1102-1113.
16. Zou L, Sasaki J E, Zeng N et al. A systematic review with Meta-Analysis of mindful exercises on rehabilitative outcomes among poststroke patients [J]. Arch Phys Med Rehabil,2018,99.2355-2364.
17. Zou L, Wang H, Xiao Z et al. Tai Chi for health benefits in patients with multiple sclerosis: A systematic review [J].PLoS One,2017,12.e0170212.
18. Morone N E, Greco C M, Weiner. D K. Mindfulness meditation for the treatment of chronic low back pain in older adults: a randomized controlled pilot study [J].Pain,2008,134.310–9.
19. Zou L, Zhang Y, Liu Y et al. The effects of Tai Chi Chuan versus core stability training on Lower-Limb neuromuscular function in aging individuals with Non-Specific chronic Lower Back Pain [J].Medicina (Kaunas),2019,55.

20. Ma J, Zhang T, He Y et al. Effect of aquatic physical therapy on chronic low back pain: a systematic review and meta-analysis [J].BMC Musculoskelet Disord,2022,23.1050.
21. Heidari F, Mohammad Rahimi N, Aminzadeh. R. Aquatic exercise impact on pain intensity, disability and quality of life in adults with low back pain: A systematic review and Meta-analysis [J].Biol Res Nurs,2023,25.527-541.
22. Baena-Beato P, Artero E G, Arroyo-Morales M, et al. Aquatic therapy improves pain, disability, quality of life, body composition and fitness in sedentary adults with chronic low back pain. Controlled Clin Trial [J] Clin Rehabil. 2014;28:350–60.
23. Saper RB, Lemaster C. Delitto A, Yoga, physical therapy, or education for chronic low back pain: A randomized noninferiority trial [J].Ann Intern Med,2017,167.85-94.
24. Joyce C T, Chernofsky A, Lodi S et al. Do physical therapy and yoga improve pain and disability through psychological mechanisms?? A causal mediation analysis of adults with chronic low back pain [J].J Orthop Sports Phys Ther,2022,52.470–83.
25. Nambi GS, Inbasekaran D, Khuman R et al. Changes in pain intensity and health related quality of life with Iyengar yoga in nonspecific chronic low back pain: A randomized controlled study [. J] Int J Yoga,2014,7.48-53.
26. Sherman K J, Cherkin D C, Wellman R D et al. A randomized trial comparing yoga, stretching, and a self-care book for chronic low back pain [J].Arch Intern Med,2011,171.2019-2026.
27. Kakei S, Hoffman D S, Strick. P L. Muscle and movement representations in the primary motor cortex [J].Science,1999,285.2136-2139.
28. Li X, Liu H. Ge L, Cortical representations of transversus abdominis and multifidus muscles were discrete in patients with chronic low back pain: evidence elicited by TMS [J].Neural Plast,2021,2021.6666024.
29. Knox M F, Chipchase L S, Schabrun S M et al. Anticipatory and compensatory postural adjustments in people with low back pain: a systematic review and meta-analysis [J].Spine J,2018,18.1934-1949.
30. Saliba SA, Croy T, Guthrie R et al. Differences in transverse abdominis activation with stable and unstable bridging exercises in individuals with low back pain [J].N am J Sports Phys Ther,2010,5.63-73.
31. Kirkesola G. Neurac-a new treatment method for long-term musculoskeletal pain [J].J Fysioterapeuten,2009,76.16-25.
32. Shamsi M, Mirzaei M. Shahsavari S, Modeling the effect of static stretching and strengthening exercise in lengthened position on balance in low back pain subject with shortened hamstring: a randomized controlled clinical trial [J].BMC Musculoskelet Disord,2020,21.809.
33. Ma K, Zhuang Z G, Wang L et al. The Chinese association for the study of pain (CASP): consensus on the assessment and management of chronic nonspecific low back pain [J].Pain Res Manag,2019,2019.8957847.
34. Hutton B, Salanti G, Caldwell D M et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations [J].Ann Intern Med,2015,162.777-784.
35. Adhikari P, Çetin E, Çetinkaya M et al. Ability of visual analogue scale to predict Oswestry disability index improvement and surgical treatment decision in patients with adult spinal deformity [J].Brain Spine,2022,2.100934.
36. Grotle M, Brox J I,Vøllestad N. K.Concurrent comparison of responsiveness in pain and functional status measurements used for patients with low back pain [J].Spine (Phila Pa 1976),2004,29.E492-501.
37. Higgins JP, Altman D G, Gøtzsche PC et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials [J].Bmj,2011,343.d5928.
38. Huedo-Medina T B, Sánchez-Meca J, Marín-Martínez F et al. Assessing heterogeneity in meta-analysis: Q statistic or I2 index? [J].Psychol Methods,2006,11.193-206.
39. Colditz G, A, Burdick E, Mosteller F. Heterogeneity in meta-analysis of data from epidemiologic studies: a commentary [J]. Am J Epidemiol,1995,142.371-382.
40. Xu S, Wang R, Ma S et al. Interventional effect of core stability training on pain and muscle function of youth with chronic non-specific lower back pain: a randomized controlled trial [J].Heliyon,2024,10.e32818.
41. Wang Pengms, Wang Y Z R et al. Efficacy of therapeutic aquatic exercise vs physical therapy modalities for patients with chronic low back pain: A Randomized Clinical Trial [J].JAMA Netw Open,2024,5.e2142069.
42. Plandowska M, Labecka M K, Truszczynska-Baszak A et al. A randomized controlled trial of active stretching of the hamstrings and core control for low back pain and musculoskeletal discomfort during prolonged sitting among young people [J].Journal of clinical medicine,2024,13.
43. Liansong LUO, Yanhua Wanng. Effect of core stability training on neuromuscular function in patients with chronic Non-specific low back pain [J]. Heilongjiang Med J. 2023;47:2641–3.
44. Yuying Zhang, Zhengwen Yuan, Guang Wang. The application effect of core muscle stability training in the treatment of patients with low back pain [J]. Renowned Doctor, 2023, 150–2.
45. Ge L, Huang H, Yu Q et al. Effects of core stability training on older women with low back pain: a randomized controlled trial [J].European review of aging and physical activity,2022,19.10.
46. Feng Zhang. The clinical effect of Tai Chi on chronic pain in the elderly and the mechanism. of microRNA Regulation [D]; 2022.
47. Xiaodi Zhang. A study on the intervention effect of aquatic core stability training on chronic. Nonspecific Low Back Pain in College Students [D]; 2022.
48. Yizu Wang. The Effect of Aquatic Exercise on Posture Control in Patients with Chronic Low Back Pain [D], 2021.
49. Mumtaz S, Javed A, Mustansar A et al. Effect of core stability exercises with conventional physiotherapy in reducing pain among patients with non-specific low back pain: RCT [J].Pakistan journal of medical and health sciences,2021,15.3063-3065.
50. Wei Wu, Bo Ni, Jiajia Shi. Efficacy of core muscle stability training combined with transcutaneous electrical nerve stimulation for nonspecific low back pain [J]. Traditional Chin Med Rehabilitation, 2021, 1227–29.
51. Yanan Bai, Shiying Xing, Huiquan Zhang. Intervention effect of yoga exercise on occupational low back pain of ICU nurses [J]. Industrial Health Occup Dis, 2020, 46.363–365.
52. Lianxiu Wang. A study on the rehabilitation effect of fitness yoga on patients with nonspecific. Chronic Low Back Pain [D]; 2020.
53. Xiuming Li, Ya Zong, Qing Xie, Weiming Zhang, Haibiao Ji Longgang Hua. Long-term efficacy of spinal core stability training for unilateral chronic nonspecific low back pain [J]. Chin J Rehabilitation,2020,35.357-361.
54. Minobes-Molina E, Nogués M R, Giralt M et al. Effectiveness of specific stabilization exercise compared with traditional trunk exercise in women with nonspecific low back pain: a pilot randomized controlled trial [J].PeerJ,2020,8.e10304.
55. Kim B, Yim JC. Stability and hip exercises improve physical function and activity in patients with Non-Specific low back pain: a randomized controlled trial [J].Tohoku journal of experimental medicine,2020,251.193-206.
56. Calatayud J, Guzmán-González B AndersenlI et al. Effectiveness of a Group-Based progressive strength training in primary care to improve the recurrence of low back pain exacerbations and function: A randomised trial [J].Int J Environ Res Public Health,2020,17.
57. Xiaoli Zou, Mengyuan Zhao, Yiming Zhang et al. Effect of water sport on old patients with chronic non-specific low back pain [J]. Chinese Journal of Gerontology,2020,40.5221-5224.
58. Mengsi Peng. Effect of aquatic exercise on patients with chronic low back pain. Randomized Controlled Trial [D]; 2020.
59. Zhiqiang X. Peipeng L, Le W. Study on the effect of sling exercise therapy cure chronic low back pain [J].Journal of Practical Medical Techniques,2019,26.828-830.
60. Jingjing Ji, Jie Liu, Yonjin Xia Chaoxu. A study on the therapeutic effect of Suspension-based core control training on occupational low back pain in nurses [J]. Traditional Chinese Medicine Rehabilitation,2019,10.10–1.
61. Brodsky M, Hansen A, Bjerke W. Randomized Pilot Trial for a Community-Based Group Stretching Exercise Program for Chronic Low Back Pain [J]. Global advances in health and medicine,2019,8.2164956119846055.
62. Yanjie W, Yuliang S, Benxiang, H E. Observation on core stability training in treating chronic nonspecific low back pain [J].Western journal of Traditional Chinese Medicine,2018,31.93-96.
63. Xinxin Huang. The Experimental Study on the Effect of Arial Yoga on the Chronic Nonspecific Low Back Pain of Young Women [D], 2019.
64. Kuvačić G, Fratini P. Padulo J, Effectiveness of yoga and educational intervention on disability, anxiety, depression, and pain in people with CLBP: a randomized controlled trial [J].Complementary therapies in clinical practice,2018,31.262-267.
65. Cortell-Tormo J M, Sánchez P T, Chulvi-Medrano I et al. Effects of functional resistance training on fitness and quality of life in females with chronic nonspecific low-back pain [J].J Back Musculoskelet Rehabil,2018,31.95–105.
66. Chen J, Wang C. Core stability training improves back muscle endurance and increases peak values of isokinetic strength of back muscles [J].Chinese journal of tissue engineering research,2018,22.5797-5802.

67. Noormohammadpour P. The role of a Multi-Step core stability exercise program in the treatment of nurses with chronic low back pain: a Single-Blinded randomized controlled trial [J].Asian spine journal,2018,12.490-502.
68. Srivastav N, Joshi S, Kushwah S S. Comparison between effectiveness of lumbar stabilization exercises and conventional physical therapy in the management of mechanical low back pain [J].Indian journal of physiotherapy & occupational therapy,2018,12.28-33.
69. Akhtar M, W, Karimi H, Gilani S A. Effectiveness of core stabilization exercises and routine exercise therapy in management of pain in chronic nonspecific low back pain: a randomized controlled clinical trial [J].Pakistan journal of medical sciences,2017,33.1002-1006.
70. Qian X U, Shan-Shan J I, Liang W et al. Clinical efficacy of core muscle stability training using Bobath ball combined with health education for chronic nonspecific low back pain [J].Guangxi Medical Journal,2017,39.1358-1361.
71. Thanawat, T, Nualnetr N. Effects of an intervention based on the Transtheoretical. Model on back muscle endurance, physical function and pain in rice farmers with chronic low back pain [J].J Back Musculoskelet Rehabil,2017,30.847-856.
72. Salavati M, Takamjani I E Akhbarib et al. Effect of spinal stabilization exercise on dynamic postural control and visual dependency in subjects with chronic non-specific low back pain [J].Journal of bodywork and movement therapies,2016,20.441-448.
73. Yuan-Sheng Z. On comparison of effect of SET and jogging training on improvement of symptoms and core strength of chronic low back pain [J].Journal of Southwest China Normal University(Natural Science Edition),2016,41.167-172.
74. Lin Z G, Gong D G, Wang X C et al. Tai Chi Yun hand to improve the proprioception of patient with chronic low back pain for 30 cases [J].Chinese medicine modern distance education of china,2015,13.127-129.
75. Na Liu, Yindi Sun, Da Shi. Observation on the therapeutic effect of core stability training in 34 Middle-aged and young patients with nonspecific low back pain [J]. Shaanxi Med J. 2015;44:598–600.
76. Lawand P, Lombardi Junior I, Jones A et al. Effect of a muscle stretching program using the global postural reeducation method for patients with chronic low back pain: a randomized controlled trial [J].Joint, bone, spine,2015,82.272-277.
77. Yu-Lin Y, Tzu-Kai S, Lih-Jiun L et al. The effect of six weeks of sling exercise training on trunk muscular strength and endurance for clients with low back pain [J].Journal of physical therapy science,2015,27.2591-2596 2596p.
78. Jee-Hun J, Tae-Yong C, Yong-Ho C. The effects of t'ai chi on muscle activity, pain, and balance in females in their 20s with acute low back pain [J].Journal of physical therapy science,2015,27.725-727.
79. Cho YH. Effects of Tai Chi on pain and muscle activity in young males with acute low back pain [J].Journal of physical therapy science,2014,26.679-681.
80. Chen HM, Wang H H, Chen C H et al. Effectiveness of a stretching exercise program on low back pain and exercise self-efficacy among nurses in Taiwan: a randomized clinical trial [J].Pain management nursing,2014,15.283-291.
81. Zhihui LI, Renjun Zhang, Yuling Wei, Xiaopeng Liu, Junsheng, GE, Facheng Fang. Analysis of sling exercise therapy for chronic nonspecific low back pain [J]. China Mod Doctor, 2014, 52.144–146.
82. Maher C. Underwood M, Buchbinder R. Non-specific low back pain [J]. Lancet,2017,389.736-747.
83. Cheng M, Xue Y, Cui M et al. Global, Regional, and National Burden of Low Back Pain: Findings from the Global Burden of Disease Study 2021 and Projections to 2050 [J].Spine (Phila Pa 1976),2025. https://doi.org/10.1097/brs.0000000000005265.
84. Chang D G, HOLT J A, SKLAR M et al. Yoga as a treatment for chronic low back pain: A systematic review of the literature [J].J Orthop Rheumatol,2016,3.1-8.
85. Tankha H, Gaskins D. Shallcross A, Effectiveness of virtual yoga for chronic low back pain: A randomized clinical trial [J].JAMA Netw Open,2024,7.e2442339.
86. Kim Y W, Kim N Y, Chang W H et al. Comparison of the therapeutic effects of a sling exercise and a traditional stabilizing exercise for clinical lumbar spinal instability [J].J Sport Rehabil,2018,27.47-54.
87. Qin J, Zhang Y, Wu L et al. Effect of Tai Chi alone or as additional therapy on low back pain: systematic review and meta-analysis of randomized controlled trials [J]. Medicine (Baltimore),2019,98.e17099.
88. Lauche Konglj, Klose R. P, Tai Chi for chronic pain conditions: A systematic review and Meta-analysis of randomized controlled trials [J].Sci Rep,2016,6.25325.
89. Lauche R, Stumpe C, Fehr J et al. The effects of Tai Chi and neck exercises in the treatment of chronic nonspecific neck pain: A randomized controlled trial [J].J Pain,2016,17.1013-1027.
90. Yeh G Y, Wood M J, Lorell B H et al. Effects of Tai Chi mind-body movement therapy on functional status and exercise capacity in patients with chronic heart failure: a randomized controlled trial [. J] Am J Med,2004,117.541-548.
91. Kibler W B, Press, J. Sciascia A. The role of core stability in athletic function [J]. Sports Med,2006,36.189-198.
92. Salik Sengul Y, Yilmaz A, Kirmizi M et al. Effects of stabilization exercises on disability, pain, and core stability in patients with non-specific low back pain: A randomized controlled trial [J].Work,2021,70.99–107.
93. Shamsi M, Mirzaei M, Hamedirad M. Comparison of muscle activation imbalance following core stability or general exercises in nonspecific low back pain: a quasi-randomized controlled trial [J].BMC sports Sci Med Rehabil,2020,12.24.
94. Smrcina, Z, Woelfel S, Burcal C. A Systematic. Review of the effectiveness of core stability exercises in patients with Non-Specific low back pain [J]. Int J Sports Phys Ther,2022,17766–774.
95. Konlian C. Aquatic therapy: making a wave in the treatment of low back injuries [J].Orthop Nurs,1999,18.11-18; quiz 19–20.
96. Shi Z, Zhou H. Lu L, Aquatic exercises in the treatment of low back pain: A systematic review of the literature and Meta-Analysis of eight studies [J].Am J Phys Med Rehabil,2018,97.116-122.
97. Waller B, Lambeck, J. DALY D.Therapeutic aquatic exercise in the treatment of low back pain: a systematic review [J].Clin Rehabil,2009,23.3–14.
98. Del Pozo-Cruz B, Gusi N, Del Pozo-Cruz J et al. Clinical effects of a nine-month web-based intervention in subacute non-specific low back pain patients: a randomized controlled trial [J].Clin Rehabil,2013,27.28-39.
99. Stochkendahl MJ, Kjaer P, Hartvigsen J, et al. National clinical guidelines for non-surgical treatment of patients with recent onset low back pain or lumbar radiculopathy [J]. Eur Spine J. 2018;27:60–75.

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