

SYSTEMATIC REVIEW

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Effects of seven types of exercise in the treatment of rotator cuff-related shoulder pain (RCRSP): a systematic review and Bayesian network meta-analysis

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Abstract

Background Rotator cuff-related shoulder pain (RCRSP) is the most common cause of shoulder pain and represents one of the most common musculoskeletal conditions affecting the shoulder. Despite ample evidence supporting the effectiveness of exercise therapy for RCRSP, no consensus exists regarding the optimal exercise intervention. This systematic review aims to evaluate and compare the efficacy of specific versus conventional exercise interventions for improving pain and dysfunction in patients with RCRSP.

Methods The MEDLINE, Embase, Cochrane Library, CINAHL, SPORTiscus, and Web of Science databases were searched up to June 2025. Randomized controlled trials that diagnosed with RCRSP or a synonymous condition (e.g., rotator cuff tendinopathy, subacromial impingement, subacromial pain syndrome, subacromial bursitis, long-head biceps tendinopathy, or partial-thickness rotator cuff tear) were included, comparing at least two different types of exercise interventions and reporting on the effects associated with pain, dysfunction, related self-reported outcome metrics. A Bayesian network meta-analysis (NMA) was performed to compare seven exercise interventions, with treatments ranked using the surface under the cumulative ranking curve (SUCRA).

Results The Shoulder Pain Score Analysis Network contained 15 studies (n = 913; 45% female); the Shoulder Dysfunction Index Analysis Network contained 16 studies (n = 947; 47% female). In terms of shoulder dysfunction improvement, concentric strengthening training (CST) demonstrated a significant advantage in most comparisons and was identified as the most effective exercise intervention program for the treatment of RCRSP, eccentric strengthening training (ECT) and traditional training (TT) were moderately effective, and significantly superior to motor control exercise (MCE) and scapula-focused training (SFT). HLT, which had negative effect sizes in most comparisons, appeared to be the worst exercise intervention program. In terms of shoulder pain improvement, CST

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also has the highest probability of being ranked first, but comparisons between the other types of interventions were largely non-significant.

Conclusion CST performed best in improving both shoulder pain and shoulder dysfunction. When patients with rotator cuff-related shoulder pain are not suitable for CST, ECT and MCE can be used as alternatives for the treatment of RCRSP.

Trial registration PROSPERO Registration No. CRD420251022110.

Introduction

Among musculoskeletal disorders of the shoulder, rotator cuff tears rank among the most common upper extremity conditions encountered by primary care physicians, physiatrists, and orthopedic surgeons [1]. As a key component of rotator cuff-related shoulder pain (RCRSP), rotator cuff tears are encompassed by the umbrella term. This term encompasses multiple painful conditions related to rotator cuff structures, including rotator cuff tendinopathy, subacromial impingement syndrome, and symptomatic partial- and full-thickness rotator cuff tears. [2]. Its etiology is multifactorial including age, loading history, biomechanical factors, psychosocial factors, lifestyle, and overall health [3]. Given the multifactorial nature of RCRSP, its management requires a comprehensive strategy. Among these approaches, exercise therapy is widely recognized and recommended as the first-line non-surgical treatment option [4].

Components of exercise therapy reported in clinical trials include exercises for neck and chest muscles, scapular-focused exercises, motor control exercises, concentric or eccentric strengthening, and resistance training at various levels of high or low intensity, as well as total-body workouts and aerobic conditioning [5]. These exercise programs are designed to reduce pain and disability, increase muscular strength and endurance, improve neuromuscular control, and increase range of motion and load tolerance of rotator cuff structures [3].

Despite ample evidence supporting the effectiveness of exercise therapy for rotator cuff-related shoulder pain (RCRSP), no consensus exists regarding the optimal exercise intervention. There is also a lack of guidance for clinicians on how to design and develop effective exercise programs for individual patients. Littlewood et al. [6] examined intervention recipients and their background factors in patients with RCRSP and reported data on exercise type, content, and dosage, which, taken together, suggests that higher sets and repetitions and the application of resistance may be more beneficial, but the low quality of their report is somewhat confusing in drawing clear conclusions with some interference. A recent systematic review [7] suggests that motor-controlled exercise programs may be slightly superior to traditional exercise programs for short- to long-term reduction of pain and dysfunction. However, uncertainty remains

regarding eccentric and scapula-focused exercise protocols versus traditional exercise protocols, as well as high versus low load exercise protocols.

Network meta-analysis (NMA) enables simultaneous comparison of multiple treatment, integrates direct and indirect evidence, improves effect estimate precision, and allows ranking of all interventions. To date, no network meta-analysis has evaluated the evidence of exercise therapies in patients with RCRSP. The aim of this study was to assess the efficacy of different exercise therapies for patients with RCRSP through a systematic review and NMA, and to provide clinicians with more specific guidelines for exercise prescription.

Materials and methods

Protocol and registration

This review was prepared in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extended Statement (PRISMA-NMA) and the Cochrane Handbook for Systematic Reviews of Interventions, registered with PROSPERO (CRD420251022110). The PRISMA-NMA checklist is available in Table S1.

Eligibility criteria

Inclusion criteria

- (1) Population: participants diagnosed with RCRSP or a synonymous condition (e.g., rotator cuff tendinopathy, subacromial impingement, subacromial pain syndrome, subacromial bursitis, long-head biceps tendinopathy, or partial-thickness rotator cuff tear) [2, 7, 8].
- (2) Intervention: comparison of at least two different exercise intervention types.
- (3) Controls: comparisons between interventions of different exercise types.
- (4) Outcome: the effect of exercise on at least one self-reported outcome indicator related to pain or dysfunction was examined.
- (5) Study design: randomized controlled trials (RCTs) published in journals and written in English.

Exclusion criteria

- (1) Participants included patients with full-thickness rotator cuff tears, adhesive capsulitis, arthritis, fractures, and joint instability.
- (2) The intervention combined exercise with passive treatment modalities (e.g., joint release and manipulation, electrotherapy, cold therapy, and pain aids).
- (3) Publications for which relevant experimental data could not be extracted.

Literature retrieval strategy

Electronic literature searches were performed on the following databases: MEDLINE, Embase, Cochrane Register of Controlled Trials (CENTRAL), SPORTDiscus, CINAHL, and Web of Science.

All databases were initially searched from date of inception until June 2025. Subject terms were set specifically for each database. Search terms were retrieved individually and then combined using related Boolean terms. The full search strategy is shown in Table S2.

Study selection

Two researchers (W.Z. and M.H.D.) independently screened the titles and abstracts to determine if they met the inclusion criteria and compiled a list of articles that required full-text review. The initial screening process was thus completed. The two researchers then further assessed the full text to finalize the literature for inclusion. If there was a disagreement about the eligibility of a study, a third researcher (F.Q.H.) was consulted and resolved.

Data extraction

Data for each trial were extracted independently by two researchers (W.Z. and M.H.D.). Data extraction included study design, sample size, diagnosis, intervention details, and outcome data. In order to better analyze the clinical effects of different exercise interventions on patients with rotator cuff injuries, we classified the exercise intervention protocols into one of the following categories based on the RCT trial authors' descriptions of the exercise protocols in the experimental groups and/or the apparent differences in the types of exercise between the groups:

- (1) Traditional Training: more generalized shoulder resistance or strengthening exercise protocols that do not emphasize muscle control, scapular muscle/stability, high/low loads, or concentric/eccentric movements.
- (2) Scapula-Focused Training: focused on the scapular muscles and/or designed to increase scapular postural awareness and/or stability [9].

- (3) Concentric Strengthening Training: Exercise focused on concentric contractions, where the rotator cuff and/or other shoulder muscles shorten load [10].
- (4) Eccentric Strengthening Training: Exercise focused on eccentric contractions, involving controlled elongation of the rotator cuff and/or other shoulder muscles under load.
- (5) Motor Control Exercise: focusing on specific muscle control and/or coordination, dynamic muscle stabilization exercises, proprioceptive exercises, and sport-specific or motor control exercises [5].
- (6) High-load Training: include greater loads (use of external weights or resistance) or greater volume of exercise (repetitions, sets, frequency), with volume defined as the sum of all the exercises they perform [11].
- (7) Low-load Training: Exercise interventions that emphasize rotator cuff training with lower loading intensities (20RM and below) and/or fewer repetitions of the movement (with a noticeable sense of relief at completion) [11].

Risk of bias

Included trials were independently assessed by two researchers (W.Z. and M.H.D.) using the RoB 2 (Cochrane Risk of Bias version 2.0 tool) risk of bias assessment tool. The risk of bias assessment was performed in the specific context of the trial. There were five domains: the randomization process, deviation from the intended intervention, missing outcome data, outcome measures, and selection of reported outcomes. Trials were judged to be at "high risk of bias" when a high risk was identified in any domain or "some concern" was identified in three or more domains. When "some concern" was identified in one or two domains, we judged the trial to have "some concern". If all domains were judged to be "low risk", the trial had a "low risk of bias". If there was a disagreement, a third researcher (F.Q.H.) was consulted and resolved.

Statistical analysis

For pain, outcome indicators were numerical or visual analog scales based on 0 to 10 or 0 to 100 scales, with higher scores indicating more severe pain. All extracted scores were adjusted to the 0 to 10 scale for summarization. For dysfunction indicators, lower scores indicated lower dysfunction, and the sign of the score was adjusted to be negative when needed (i.e., higher scores on the Shoulder Score Questionnaire indicated more functionality). For all meta-analyses, the alpha level was set at 0.05 and 95% credible intervals (CrI) were calculated. The effect of exercise therapy was expressed as the standardized mean difference (SMD) for pain and dysfunction. A negative SMD indicates that the experimental intervention was beneficial for pain and dysfunction. The Visual

Analog Scale (VAS) and the Numeric Pain Rating Scale were considered similar instruments, and results were pooled to calculate SMD. When multiple indicators of dysfunction were reported, we used the primary outcome of the trial, or, if not specified by the authors, the most representative validated dysfunction outcome from the analysis.

A correlation between effect sizes was assumed to be 0.5. NMA integrated all direct evidence to construct a network for each outcome. The NMA model was fitted within a Bayesian framework using a Markov chain Monte Carlo method. Four chains were run, using a non-informative prior. Each chain had 50,000 iterations; the first 20,000 were discarded as warm-up iterations. Values were collected every 10 iterations. Convergence was assessed by visualization of tracking plots and potential scale reduction factors. Fixed-effects and random-effects models were also fitted and analyzed using a more concise model. Model fit was assessed by the deviance information criterion (DIC) and the posterior mean residual distortion. Heterogeneity was assessed by examining standard deviations (τ) and 95% credible intervals (95% CrI) across studies. Global inconsistency was assessed by comparing model fit, DIC, and variance parameters between the NMA model and the unrelated mean effects (UME) model. Local inconsistency was assessed by node splitting and was considered detected when the Bayesian p -value was <0.05 . Forest plots and rankings were generated to demonstrate relative effects. Cumulative area

under the ranking curve values were used to rank each condition from top to bottom; in addition, the probability of each condition being in the top three was calculated as a percentage of the area under the curve. The results of the NMA (network meta-analysis) are presented in the form of posterior standardized mean deviation (SMD) and 95% credible intervals (CrI), which are interpreted as intervals in which the probability of the parameter being in a certain range is 95%.

To explore potential sources of heterogeneity among included studies, we plan to conduct a series of meta-regression analyses based on a Bayesian framework. We will test the covariates of mean age and intervention duration as pre-specified moderators to investigate possible sources of heterogeneity.

Additionally, to assess the robustness of our network meta-analysis findings, we plan to conduct sensitivity analyses by excluding studies at high risk of bias. This will involve restricting the analysis to studies rated as “low risk” or “some concerns” while excluding those rated “high risk” of bias, thereby evaluating the impact of methodological quality on overall conclusions. If the SUCRA ranking order remains fundamentally unchanged after sensitivity analyses, our primary conclusions will be considered robust.

Results

From 8327 potentially relevant articles, a total of 5347 records were obtained after eliminating duplicates, and 1065 documents were obtained after title/abstract screening. 1057 full-text articles were then evaluated for inclusion, and finally 16 trials [12–27] met the eligibility criteria (Fig. 1). The basic characteristics of the included studies are shown in Table 1. All the studies included were RCTs with short- and medium-term follow-up, and there were no RCTs on long-term treatment effects.

Network geometry

The network evidence map for the shoulder disability index is shown in Fig. 2A. The Shoulder Disability Index network meta-analysis (16 studies with a total sample size of 947 cases) covered seven conditions as well as seven direct comparisons. The largest node was TT (sample size of 235 cases), while the smallest node was CST (sample size of 30 cases). The most commonly compared conditions were TT versus ECT, TT versus MCT, and TT versus SFT (9 studies in total). The network evidence map on shoulder pain is shown in Fig. 2B. The network meta-analysis of shoulder pain scores (15 studies with a total sample size of 913 cases) similarly covered 7 conditions, as well as 7 direct comparisons. The largest node remained TT (sample size of 235 cases), while the smallest node was CST (sample size of 14 cases). The most

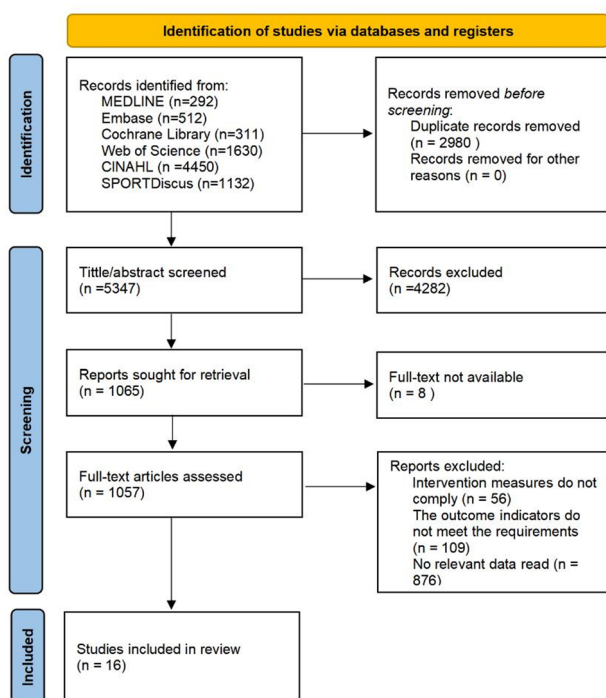


Fig. 1 PRISMA Flow Diagram of the Study Selection Process

Table 1 Characteristics of studies included in the network meta-analysis

Study	Population	Intervention (sample)	Comparison (sample)	Outcomes (measure-ment tool; follow-up)
Başkurt 2011	Adults with subacromial impingement syndrome; Mean age: 51.4 ± 9.9 years	SFT (20)	TT (20)	Dysfunction: WORC Pain: VAS Follow-up: 6 weeks
Clausen 2021	Adults with long-standing subacromial impingement; Mean age: 50.5 ± 10.5 years	HLT (100)	LLT (100)	Dysfunction: SPADI Pain: NRS Follow-up: 5 weeks
Blume 2015	Adults with subacromial impingement syndrome; Mean age: 49.4 ± 15.4 years	ECT (18)	CST (16)	Dysfunction: DASH Pain: NPRS Follow-up: 8 weeks
Chaconas 2017	Adults with subacromial pain syndrome; Mean age: 46.0 ± 17.4 years	ECT (25)	TT (23)	Dysfunction: WORC Pain: NPRS Follow-up: 6 weeks
Struyf 2013	Adults with shoulder impingement syndrome; Mean age: 45.8 ± 14.2 years	SFT (12)	ECT (10)	Dysfunction: SDQ Pain: VAS Follow-up: 12 weeks
Hotta 2020	Adults with subacromial pain syndrome; Mean age: 49.0 ± 9.0 years	SFT (30)	TT (30)	Dysfunction: SPADI Pain: NPRS Follow-up: 16 weeks
Ingwersen 2017	Adults with rotator cuff tendinopathy; Mean age: 46.1 ± 10.3 years	HLT (49)	LLT (51)	Dysfunction: DASH Pain: VAS Follow-up: 12 weeks
Boudreau 2019	Adults with rotator cuff tendinopathy; Mean age: 49.9 ± 12.0 years	MCE (21)	TT (21)	Dysfunction: DASH Pain: VAS Follow-up: 6 weeks
Berg 2021	Adults with chronic subacromial pain syndrome; Mean age: 48.5 ± 13.0 years	HLT (13)	TT (8)	Dysfunction: SPADI Pain: NPRS Follow-up: 8 weeks
Heron 2017	Adults with rotator cuff tendinopathy/shoulder impingement syndrome; Mean age: 50.0 ± NA years	HLT (40)	LLT (40)	Dysfunction: SPADI Pain: SPADI Follow-up: 6 weeks
Dejaco 2017	Adults with subacromial impingement syndrome; Mean age: 49.4 ± 11.5 years	ECT (20)	TT (16)	Dysfunction: CM Pain: VAS Follow-up: 6 weeks
Dubé 2023	Adults with rotator cuff-related shoulder pain; Mean age: 47.7 ± 15.2 years	MCE (41)	TT (41)	Dysfunction: DASH Pain: BPI Follow-up: 12 weeks
Kamonseki 2023	Adults with chronic shoulder pain and scapular dyskinesis; Mean age: 37.7 ± 12.4 years	SFT (32)	TT (32)	Dysfunction: DASH Pain: NPRS Follow-up: 8 weeks
Macías-Hernández 2021	Adults with partial rotator cuff tears and moderate to severe shoulder pain; Mean age: 54.3 ± NA years	ECT (12)	CST (14)	Dysfunction: CM Pain: VAS Follow-up: 12 weeks
Marzetti 2014	Adults with shoulder impingement syndrome; Mean age: 62.1 ± 12.6 years	MCE (24)	TT (24)	Dysfunction: DASH Pain: VAS Follow-up: 12 weeks
Maenhout 2013	Adults with unilateral subacromial impingement syndrome; Mean age: 39.8 ± 13.0 years	ECT (31)	TT (30)	Dysfunction: SPADI Pain: SPADI Follow-up: 8 weeks

Population Patients with rotator cuff-related shoulder pain (RCRSP) or synonymous conditions (e.g., subacromial impingement syndrome, rotator cuff tendinopathy)

Interventions and comparators See below for details of the exercise interventions compared in each study

Outcomes Shoulder pain and shoulder dysfunction, measured by the tools detailed below

Study design Randomized controlled trial

SPADI, Shoulder Pain and Disability Index; DASH, Disabilities of the Arm, Shoulder and Hand; NPRS, Numerical Pain Rating Scale; WORC, Western Ontario Rotator Cuff Index; VAS, Visual Analogue Scale; SDQ, Shoulder Disability Questionnaire; CM, Constant-Murley Score; BPI, Brief Pain Inventory; NRS, Numeric Rating Scale. CST, Concentric Strengthening Training; ECT, Eccentric Strengthening Training; HLT, High-Load Training; LLT, Low-Load Training; MCE, Motor Control Exercise; SFT, Scapula-Focused Training; TT, Traditional Training

common comparisons were the same as for the disability index.

Risk of bias

Figure 3 summarizes the risk of bias assessment for each trial. Six trials had a low risk of bias, accounting for 37.5% of the total included studies; six trials had some risk of bias, accounting for 37.5% of the total included studies, and four trials had a high risk of bias, accounting for 25% of the total included studies, with missing outcome data being the main potential area of bias.

Comparing seven types of exercise

The results of the network analysis for all 42 comparisons of shoulder disability index and shoulder pain scores are shown in Table 2. In the shoulder pain and shoulder disability network meta-analyses, the 95% credible intervals for 57.1% (12/21) and 4.7% (1/21) of the comparisons did not include 0 (null value), respectively. For the Shoulder Disability Index, CST showed a significantly greater effect than ECT (SMD = 3.49; 95%CrI [0.28, 6.7]), HLT (SMD = 23.87; 95%CrI [4.81, 42.92]), LLT (SMD = 22.90; 95%CrI [3.72, 42.1]), MCE (SMD = 12.04; 95%CrI [5.21, 18.88]), SFT (SMD = 12.65; 95%CrI [5.83, 19.4]), and TT (SMD = 5.91; 95%CrI [0.64, 11.17]), and the relative effect of ECT was greater than HLT (SMD = 20.38; 95%CrI [1.6,

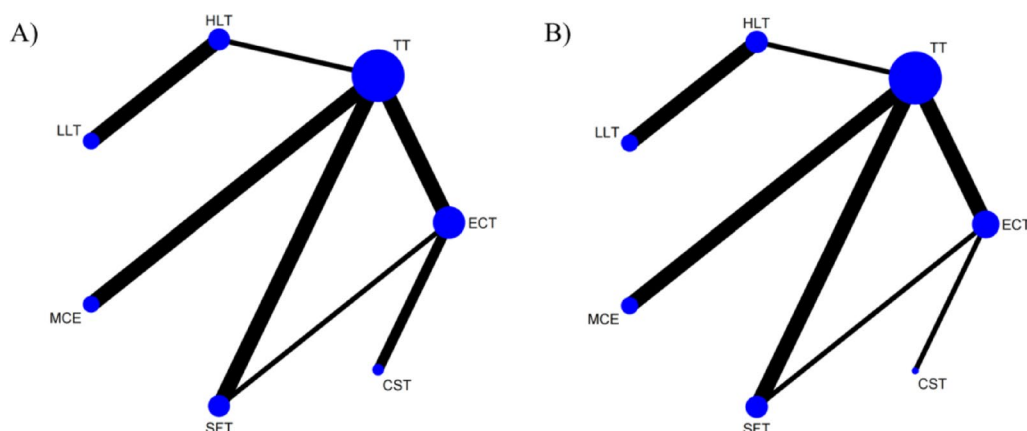


Fig. 2 Network geometry for the comparisons of **A** Shoulder Disability Index and **B** Shoulder Pain Score. TT, traditional training; ECT, eccentric strengthening training; CST, concentric strengthening training; SFT, scapula-focused training; MCE, motor control exercise; LLT, low-load training. The size of each node corresponds to the number of participants in that intervention arm. The width of the connecting lines represents the number of direct comparisons between intervention arms

39.14]), LLT (SMD = 19.40; 95%CrI [0.49, 38.35]), MCE (SMD = 8.55; 95%CrI [2.52, 14.55]) and SFT (SMD = 9.16; 95%CrI [3.19, 15.11]). For the Shoulder Pain Score, CST showed a significantly greater effect than MCE (SMD = 1.00; 95%CrI [0.21, 1.96]).

Superiority of ranking

Figure 4 illustrates the SUCRA curves that show the percentage probability that each intervention can rank as the best intervention for shoulder disability and shoulder pain. For shoulder disability (Fig. 4A), the top three ranked interventions were concentric strengthening exercise program (CST, 99.19%), followed by eccentric strengthening exercise program (ECT, 80.73%) and traditional exercise program (TT, 67.88%). For shoulder pain (Fig. 4B), the top three interventions included (CST, 92.19%), scapula-focused movement program (SFT, 66.62%), and eccentric strengthening exercise program (ECT, 65.29%).

Model fits and network inconsistency

Figure S1 provides node splitting analyses. For network meta-analysis (NMA) of Shoulder Disability Index, the results showed good consistency, indicating that the combined results are reliable. However, from a clinical perspective, there was a large difference in the direct and indirect evidence point estimates for the pair SFT vs ECT comparison. This may stem from the heterogeneity of studies providing direct evidence. Although the combined model stabilized the results, caution is needed when interpreting the comparative efficacy of SFT vs ECT. For Shoulder Pain Score, no statistically or clinically significant inconsistencies were found. The entire evidence network showed a high degree of consistency. The combined results suggest that the three interventions, ECT, SFT, and TT, may be equally effective in relieving

pain, showing no clear relationship of superiority or inferiority. The combined results of this network have a high degree of confidence.

Publication bias analysis

In the funnel plot illustrating publication bias, each colored dot corresponded to a pairwise comparison between different interventions (Fig. 5). The number of dots increased with the frequency of pairwise comparisons. The symmetrical distribution of points in the funnel plot suggested a low risk of publication bias. As shown in Fig. 5A,B, the points were symmetrically distributed in the plots, indicating minimal publication bias for the Shoulder Disability Index, Shoulder Pain Score.

Meta-regression analysis

We conducted meta-regression analyses on the primary outcomes of shoulder dysfunction index and shoulder pain score to explore the impact of prespecified covariates on heterogeneity. Within the scope of studies included in this analysis, neither mean age nor intervention duration showed a significant association with treatment effect size. They contributed minimally to heterogeneity, with results summarized in Table S3. The limited number of studies included in this network meta-analysis restricted our ability to incorporate additional potential moderators (e.g., specific exercise dosage, sample size) into the model, potentially leaving some unexplained heterogeneity.

Sensitivity analysis

After excluding four studies deemed to have a high overall risk of bias [13, 19, 23, 27], the network structure of the Shoulder Disability Index changed (Figure S2A). We reanalyzed the modified Shoulder Disability Index network. Key findings are as follows: CST, ECT, and TT

	Risk-of-Bias Domains					
	D1	D2	D3	D4	D5	Overall
Baskurt 2011	+	+	+	+	+	+
Struyf 2012	+	?	+	+	+	?
Maenhout 2012	+	+	+	+	?	?
Marzetti 2014	+	+	+	+	+	+
Blum C 2015	+	+	+	+	+	+
Chaconas 2017	+	+	!	+	+	!
Dejaco 2017	+	+	+	+	?	?
Herson 2017	+	+	!	+	+	!
Ingwersen 2017	+	+	+	+	+	+
Boudreau 2019	+	+	+	+	?	?
Hotta 2020	+	+	+	+	+	+
BERG 2020	!	?	+	+	?	!
Macias Hernandez 2021	+	+	+	+	!	!
Bek Clausen 2021	+	?	+	+	+	?
Kamonseki 2022	+	+	+	+	+	+
Dube 2023	+	+	+	+	?	?

Domains:

D1: Randomization process

D2: Deviations from intended interventions

D3: Missing outcome data

D4: Measurement of the outcome

D5: Selection of the reported result

Judgement

Low risk +

Some concerns ?

High risk !

Fig. 3 Summary of the risk of bias assessment for the included randomized controlled trials. The assessment was performed using the Cochrane Risk of Bias tool (RoB 2.0)

remained the top three interventions, with CST still ranking first (Table S4). The results of the sensitivity analysis indicate that the primary conclusion—that CST is the optimal exercise program for improving shoulder dysfunction in RCRSP patients—remains robust and unaffected by individual low-quality studies. Additionally, since CST disconnected from the main network in the shoulder pain network after excluding high-risk studies (Figure S2B) and comparisons between other interventions were largely non-significant, we did not perform a sensitivity analysis for the shoulder pain network.

Discussion

Primary findings and comparison with previous reviews

This NMA compared the effectiveness of seven exercise interventions for improving shoulder dysfunction and pain in RCRSP. To our knowledge, it is the first NMA to compare such a wide range of exercise therapies for this condition, providing valuable evidence for guideline developers and clinicians.

The network comparisons revealed significant differences among the seven exercise interventions in improving shoulder dysfunction, with 57.1% (12/21) of comparisons showing 95% credible intervals excluding

Table 2 The pooled effect estimates from both direct and indirect comparisons across all interventions are presented (A. Shoulder Disability Index; B. Shoulder Pain Score)

A)

CST	3.49 (0.28, 6.7)	23.87 (4.81, 42.92)	22.9 (3.72, 42.1)	12.04 (5.21, 18.88)	12.65 (5.83, 19.4)	5.91 (0.64, 11.17)
-3.49 (-6.7, -0.28)	ECT	20.38 (1.6, 39.14)	19.4 (0.49, 38.35)	8.55 (2.52, 14.55)	9.16 (3.19, 15.11)	2.43 (-1.75, 6.59)
-23.87 (-42.92, -4.81)	-20.38 (-39.14, -1.6)	HLT	-0.96 (-3.54, 1.61)	-11.84 (-30.64, 7.04)	-11.21 (-30.27, 7.81)	-17.95 (-36.27, 0.36)
-22.9 (-42.1, -3.72)	-19.4 (-38.35, -0.49)	0.96 (-1.61, 3.54)	LLT	-10.86 (-29.88, 8.17)	-10.27 (-29.47, 8.92)	-16.99 (-35.5, 1.48)
-12.04 (-18.88, -5.21)	-8.55 (-14.55, -2.52)	11.84 (-7.04, 30.64)	10.86 (-8.17, 29.88)	MCE	0.61 (-6.06, 7.27)	-6.13 (-10.47, -1.8)
-12.65 (-19.4, -5.83)	-9.16 (-15.11, -3.19)	11.21 (-7.81, 30.27)	10.27 (-8.92, 29.47)	-0.61 (-7.27, 6.06)	SFT	-6.73 (-11.78, -1.69)
-5.91 (-11.17, -0.64)	-2.43 (-6.59, 1.75)	17.95 (-0.36, 36.27)	16.99 (-1.48, 35.5)	6.13 (1.8, 10.47)	6.73 (1.69, 11.78)	TT

B)

CST	0.45 (-0.08, 0.97)	1.55 (-0.51, 3.6)	1.24 (-0.88, 3.37)	1.0 (0.21, 1.96)	0.45 (-0.5, 1.39)	0.65 (-0.08, 1.37)
-0.45 (-0.97, 0.08)	ECT	1.1 (-0.9, 3.09)	0.8 (-1.27, 2.86)	0.64 (-0.06, 1.34)	0 (-0.79, 0.79)	0.2 (-0.31, 0.71)
-1.55 (-3.6, 0.51)	-1.1 (-3.09, 0.9)	HLT	-0.3 (-0.82, 0.22)	-0.46 (-2.45, 1.52)	-1.1 (-3.12, 0.93)	-0.9 (-2.83, 1.03)
-1.24 (-3.37, 0.88)	-0.8 (-2.86, 1.27)	0.3 (-0.22, 0.82)	LLT	-0.16 (-2.22, 1.89)	-0.79 (-2.89, 1.3)	-0.6 (-2.6, 1.39)
-1.09 (-1.96, -0.21)	-0.64 (-1.34, 0.06)	0.46 (-1.52, 2.45)	0.16 (-1.89, 2.22)	MCE	-0.64 (-1.44, 0.16)	-0.44 (-0.92, 0.04)
-0.45 (-1.39, 0.5)	0 (-0.79, 0.79)	1.1 (-0.93, 3.12)	0.79 (-1.3, 2.89)	0.64 (-0.16, 1.44)	0 (-0.44, 0.84)	0.2 (-0.44, 0.84)
-0.65 (-1.37, 0.08)	-0.2 (-0.71, 0.31)	0.9 (-1.03, 2.83)	0.6 (-1.39, 2.6)	0.44 (-0.04, 0.92)	-0.2 (-0.84, 0.44)	TT

CST, Concentric Strengthening Training; ECT, Eccentric Strengthening Training; HLT, High-Load Training; LLT, Low-Load Training; MCE, Motor Control Exercise; SFT, Scapula-Focused Training; TT, Traditional Training

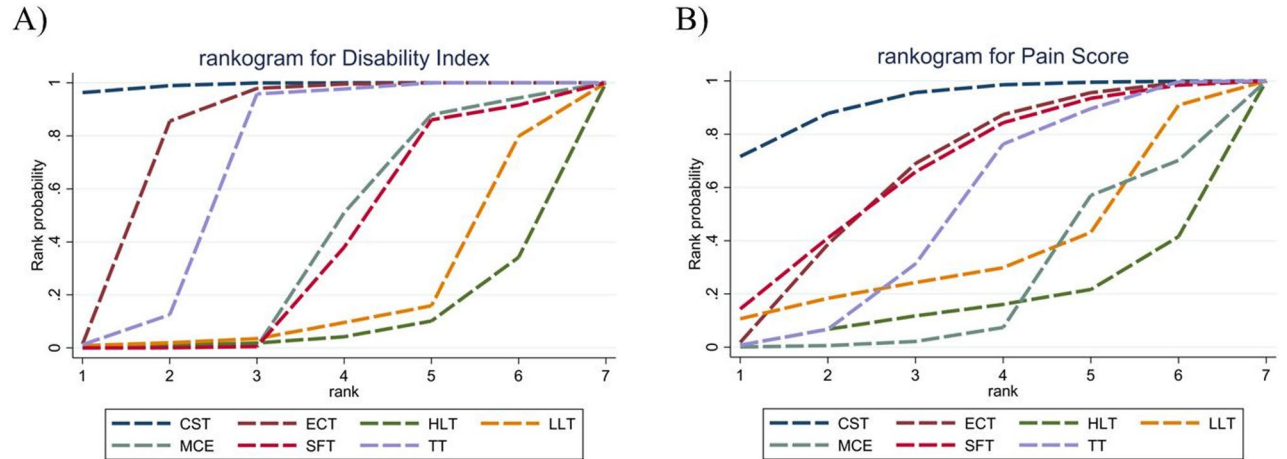


Fig. 4 Surface Under the Cumulative Ranking Curve (SUCRA) for Exercise Interventions. **A** Shoulder disability index. **B** Shoulder pain score. Higher SUCRA values indicate a higher probability of being the most effective intervention. CST, Concentric Strengthening Training; ECT, Eccentric Strengthening Training; HLT, High-Load Training; LLT, Low-Load Training; MCE, Motor Control Exercise; SFT, Scapula-Focused Training; TT, Traditional Training

zero. The interventions could be broadly categorized into three tiers. The Concentric Strengthening Training (CST) protocol alone constituted the first tier as the optimal exercise intervention. This conclusion is being reported for the first time and has not been revealed in previous studies. The Eccentric Strengthening Training (ECT) and Traditional Training (TT) protocols formed the second tier and may serve as alternative interventions. Shire *et al.* [28] compared specific exercise programs (including ECT and SFT) with TT in adults with RCRSP and found insufficient evidence to determine whether specific exercises were superior to traditional exercise. This review was published eight years ago and used different eligibility

criteria, excluding recent trials. Our study found that ECT and TT were significantly superior to SFT for improving shoulder disability; however, no significant difference was found between these interventions and TT for improving shoulder pain. Regarding eccentric exercise, Larsson *et al.* [29] reported low-certainty evidence suggesting ECT is slightly more effective for short-to-medium-term pain relief but not function—contrary to our findings. We found that ECT had a significant advantage in improving shoulder dysfunction compared to HLT, LLT, MCE, and SFT, but no significant difference was observed for pain improvement. The Motor Control Exercise (MCT), Scapula-Focused Training (SFT), High-Load Training (HLT),

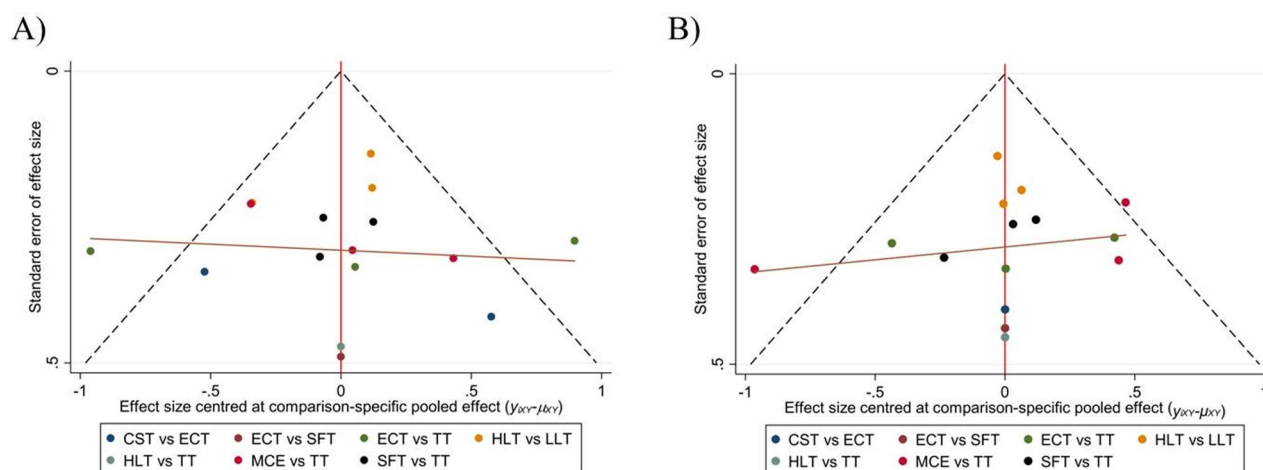


Fig. 5 Funnel plots assessing potential publication bias for each outcome. **A** Shoulder Disability Index. **B** Shoulder Pain Score. Symmetrical distribution of the plotted comparisons suggests a low risk of publication bias. CST, Concentric Strengthening Training; ECT, Eccentric Strengthening Training; HLT, High-Load Training; LLT, Low-Load Training; MCE, Motor Control Exercise; SFT, Scapula-Focused Training; TT, Traditional Training

and Low-Load Training (LLT) protocols comprised the third tier, demonstrating comparatively poorer outcomes. A recent systematic review by Simon Lafrance et al. [7] based on low-to-moderate certainty evidence, concluded that MCE is slightly superior to traditional training TT for reducing both pain and dysfunction. In contrast, our study found a significant difference between MCE and TT for improving shoulder disability, but not for shoulder pain. Regarding shoulder pain improvement, the CST program again demonstrated a significant advantage. In contrast, the other six interventions appeared largely equivalent in efficacy, with 95.3% (20/21) of comparisons showing 95% credible intervals that included zero.

Overall, the findings of this NMA diverge from those of some previous systematic reviews.

Clinical implications and possible therapeutic mechanisms Shoulder disability index

For shoulder dysfunction, the CST regimen demonstrated a significant advantage over the other six exercise interventions and is likely the optimal approach for improving shoulder disability in RCRSP patients. Consequently, developers of clinical guidelines and clinicians may prioritize the CST regimen, particularly for patients experiencing significant shoulder dysfunction. The potential mechanisms and advantages of CST for improving dysfunction include: (1) Promotion of muscle structure and function reconstruction: Mechanical loading, such as that provided by concentric contraction, is essential to counteract the shift from protein synthesis to degradation observed in rotator cuff muscle atrophy. This process likely involves the positive regulation of key anabolic pathways (e.g., mTOR and AKT) that are negatively affected in the unloaded state of a torn cuff [1, 30–32]. (2) Optimization of neuromuscular control: CST may aid

in restoring normal movement patterns by enhancing coordination and recruitment efficiency of rotator cuff muscles, thereby reducing compensatory movements and rebuilding dynamic stability [1]. (3) Biomechanical balance recovery: The primary biomechanical defect in RCRSP lies in the loss of rotator cuff torque, where the cuff fails to effectively counteract the upward pull of the deltoid muscle during shoulder elevation, leading to subacromial impingement. CST-enhanced rotator cuff muscles directly address this imbalance by restoring humeral head depression, thereby reducing subacromial pressure [1]. (4) Regulation of the inflammatory environment: Rotator cuff tendinopathy and tears are associated with a pro-inflammatory state characterized by upregulation of cytokines such as IL-6 and IL-1 β . The mechanical loading induced by CST may influence this environment, potentially promoting a shift toward tissue repair and matrix generation. This is supported by the reactive behavior of subacromial bursa cells, which express mesenchymal markers and can upregulate anabolic signaling pathways [1].

The ECT regimen also showed significant advantages over other interventions besides CST, positioning it as a likely second-tier option for short-to-medium-term improvement of shoulder dysfunction. However, compared to CST, the ECT regimen requires more specialized instruction, places greater tensile stress on tendons, and may be associated with lower patient compliance. Therefore, clinicians should consider the patient's understanding of eccentric exercise and their pain tolerance before prescribing it. Conversely, the CST regimen involves movements with lower technical difficulty, is easier to perform, and may thus achieve higher compliance. The TT regimen, compared to CST and ECT, lacks targeted loading, produces weaker improvements in

muscle strength, shows less significant effects on tendon repair and functional reconstruction [12]. Nevertheless, the TT program is simpler and safer to administer. In the network comparison, the MCT, SFT, HLT, and LLT protocols appeared less effective for improving dysfunction. However, this does not negate their clinical value. The SFT protocol has a more pronounced therapeutic effect on scapular positioning and is recommended for patients with evident scapular dyskinesis (e.g., winging) [12]. The MCE protocol can effectively reduce compensatory movements such as shrugging [25].

Shoulder pain score

For shoulder pain, only one comparison showed a significant advantage: CST over the MCE regimen. Thus, CST appears to be the optimal exercise intervention for improving shoulder pain in RCRSP patients. Clinicians and guideline developers may prioritize the CST protocol, especially for patients with significant pain. The potential mechanisms by which CST alleviates rotator cuff pain include: (1) Neuromuscular Mechanism: CST may reduce pain perception in RCRSP patients by improving motor control, enhancing muscle strength, and increasing joint range of motion [31]. (2) Tissue-Level Mechanisms: CST may increase local blood circulation, delivering more oxygen and nutrients to tissues to promote tendon tissue repair and adaptive changes. It also stimulates type I collagen production, enhancing tendon strength [31]. (3) Psychological Mechanism: CST may enhance patients' self-efficacy, boosting confidence in performing activities or managing pain while reducing fear avoidance [31]. Based on SUCRA values, SFT and ECT may be the second and third-ranked interventions, respectively, for short-to-medium-term pain improvement. Compared to CST, SFT better addresses periscapular muscle imbalances but requires more specialized instruction; it should be considered for patients with significant periscapular muscle imbalance. Although ECT can also improve pain in the short-to-medium term, it often induces stronger pain sensations during exercise than CST, potentially reducing compliance. Notably, ECT may be superior for improving tendon tensile strength. The MCT, TT, HLT, and LLT protocols were relatively less effective for pain improvement in the network comparison, in comparative network analyses, MCT, TT, HLT, and LLT demonstrated relatively inferior efficacy in pain relief. However, each approach may offer distinct advantages: for instance, MCE reduces compensatory movements [25]; TT is generally more familiar to the public and may suit patients seeking simpler exercises..

Based on our results and existing literature, a stepped-care approach for RCRSP is recommended. Clinicians should first prescribe Concentric Strengthening Training (CST), considering its superior efficacy for both pain and

dysfunction. Should conservative management fail, surgical options can be explored. In such cases, the choice between arthroscopic and mini-open repair can be guided by surgeon experience and patient factors, as both have been proven to yield similar clinical outcomes [33].

Limitations

This study has several limitations. Risk of bias was frequently introduced through performance bias (lack of blinding), deviations from intended interventions, and selective reporting of outcomes. Many studies were rated as having 'some concerns' because participants were not blinded to the intervention, intention-to-treat analyses were not always conducted, and details on randomization, concealment, and pre-specified analysis plans were often inadequately reported. While double-blinding is challenging in exercise trials, researchers should pre-register analysis plans and report randomization procedures transparently to mitigate bias. Although our sensitivity analysis (after excluding studies at high risk of bias) indicates that the primary conclusions remain stable (Figure S3), this does not entirely eliminate the potential impact of bias on the overall body of evidence. Furthermore, the relatively small number of included studies and sample sizes limit the confidence in our conclusions. Particularly in this network meta-analysis, the sample size included for CST was relatively small. While the Bayesian framework can handle this uncertainty to some extent, small sample sizes may lead to imprecise effect estimates and reduce our statistical power to detect true differences in these comparisons. Therefore, caution is warranted when interpreting the results of direct comparisons between CST and other interventions. Furthermore, the primary outcome measures in this network meta-analysis were patient-reported questionnaires assessing pain and functional improvement. This inherently limits the precision of our findings. However, it is noteworthy that studies indicate patients may achieve substantial functional recovery and quality-of-life improvements even when imaging shows incomplete tendon healing. Pain relief and functional restoration do not necessarily depend on tendon morphology normalization [34, 35]. Therefore, when evaluating the success of exercise therapy, greater emphasis should be placed on patient-reported functional improvement and quality of life enhancement rather than solely pursuing radiographic "perfect healing". Future research should include more homogeneous and larger trials to confirm these findings.

Conclusion

This NMA pooled data from RCTs of seven exercise interventions for RCRSP. Among exercise interventions for improving shoulder dysfunction, CST has demonstrated the greatest potential. The ECT and TT programs

also had significant advantages over the other exercise interventions and are likely to be the second- and third-ranked exercise interventions, which could be used as a second-choice program for short- and medium-term improvement of shoulder dysfunction. For shoulder pain relief, CST may still be the optimal choice, with no significant differences among other interventions. Guideline developers and practitioners should encourage the use of the CST program because of its superiority in improving both shoulder disability and pain in patients with rotator cuff-related shoulder pain. For the other six exercise interventions, this NMA provides a hierarchy of their efficacy for improving shoulder disability, although the differences between them for pain relief were generally not significant. Further research is needed to confirm their specific roles in clinical practice.

Abbreviations

RCRSP	Rotator cuff-related shoulder pain
TT	Traditional Training
SFT	Scapula-Focused Training
CST	Concentric Strengthening Training
ECT	Eccentric Strengthening Training
MCE	Motor Control Exercise
HLT	High-load Training
LLT	Low-load Training
SPADI	The Shoulder Pain and Disability Index (SPADI) is valid and reliable for the assessment of individuals with shoulder disorders
DASH	The DASH questionnaire is a 30-item self-reported questionnaire measuring symptoms and disabilities caused by a nonspecific upper-limb disorder. The questionnaire is scored on a 100-point scale, where 0 represents no disabilities and 100 represents extreme disabilities
NPRS	The numerical pain rating scale (0–10 on an analog scale) was used to measure the intensity of pain during evaluation
WORC	The WORC index was also used to assess functional limitations. It is a disease specific questionnaire developed to measure health-related function and quality of life of individuals with rotator cuff disorders. It contains 21 items and is scored out of 100, with 0 representing extreme function loss and 100 no function loss
SDQ	The Shoulder Disability Questionnaire (SDQ), a self-reported questionnaire. The SDQ has previously been used in patients with shoulder impingement syndrome and covers 16 items to evaluate functional status disability in patients with shoulder disorders. The 16 items describe a possible pain provocation during the last 24 h of the patient's daily activities. The questionnaire is completed with yes, no, or not applicable
VAS	Pain at rest and during movement was evaluated using a 100-mm VAS, where 0 mm corresponds to no pain and 100 mm corresponds to the worst imaginable pain
NPA	The NPA questionnaire (least, worst, and average pain of the former week). NPA was scored on a numeric scale from 0 (no pain) to 10 (worst imaginable pain)
CM	The CM score has four subscales: pain (15 points), activities of daily living (20 points), range of motion (ROM) (40 points) and strength (25 points). The maximum CM score is 100 points, indicating excellent shoulder function. Research has shown that the CM score can be used in clinical and research settings and has acceptable reliability
BPI	Short form of Brief Pain Inventory
Constant	The Constant scale is a validated instrument that includes four parameters: pain; activities of daily living, joint mobility, and strength. The maximal total sum is 100 points, and the higher the score, the better the functionality. The Constant scale is universally used to evaluate the functionality of the shoulder

Supplementary Information

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Supplementary Material 1.

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Author contributions

W. Zhang and M. Tian contributed to the initial study conception and topic selection. The literature search and screening were performed by W. Zhang and M. Du, with F. Hao acting as an arbiter to resolve any discrepancies. Data extraction was then conducted by L. Xia and W. Zhang. M. Du provided methodological guidance throughout these processes to ensure adherence to the standard procedures for meta-analysis. W. Zhang performed the data analysis and drafted the initial manuscript. F. Hao assisted. W. Zhang in revising and editing the article. F. Hao and M. Tian supervised all aspects of the work and were responsible for securing funding.

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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.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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