ANNALS OF MEDICINE
2025, VOL. 57, NO. 1, 2542441
https://doi.org/10.1080/07853890.2025.2542441

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Effects of proprioceptive training intervention on knee function in patients with anterior cruciate ligament reconstruction: a systematic review and meta-analysis

Shiwei Chen, Jinfa Gu and Shazlin Shaharudin

Exercise & Sports Science Programme, School of Health Sciences, Universiti Sains Malaysia, Kota Bharu, Kelantan, Malaysia

ABSTRACT

Objective: This study aimed to systematically evaluate the impact of proprioceptive training on the rehabilitation of patients after anterior cruciate ligament reconstruction (ACLR) including subjective knee functional scores, knee proprioception, knee range of motion, flexion strength and single-leg hopping ability.

Methods: PubMed, Web of Science, Cochrane Library, Embase, and China National Knowledge Infrastructure were searched for randomized controlled trials (RCTs) on proprioceptive training for ACLR patients from the inception of the databases to December 2, 2024. The Cochrane Risk of Bias tool was used to assess, Grading of Recommendations Assessment, Development and Evaluation evaluated evidence levels, and the effect size combination, subgroup analysis, and sensitivity analysis were performed using Stata 17.

Results: Thirteen studies with a total of 529 patients were included. The meta-analysis indicated that proprioceptive training significantly improved subjective knee functional scores (Hedge's $g=0.58$, 95% CI: 0.26 to 0.9, $p=0.00$), single-leg hopping ability (Hedge's $g=0.44$, 95% CI: 0.15 to 0.72, $p=0.00$), and knee proprioception (Hedge's $g=-0.8$, 95% CI: −1.33 to −0.28, $p=0.00$) in ACLR patients. However, proprioceptive training did not have a significant effect on knee range of motion or flexion strength.

Conclusion: Proprioceptive training improves subjective knee functional scores, single-leg hopping ability and proprioception but does not significantly enhance knee range of motion or flexion strength in ACLR patients.

KEY POINTS

- Proprioceptive training enhanced subjective functional scores, and single-leg hopping ability, and knee proprioceptive function in ACLR patients.
- Proprioceptive training did not affect knee range of motion or knee flexion strength.
- The sample size significantly moderates the effects of proprioceptive training on improving knee proprioception. Future research should focus on the impact of sample size.

ARTICLE HISTORY
Received 21 March 2025
Revised 5 July 2025
Accepted 24 July 2025

KEYWORDS
Human health; knee biomechanics; rehabilitation; sports medicine

Introduction

Anterior cruciate ligament (ACL) rupture is a frequently occurring knee injury, constituting 50% of all knee injuries [1]. An ACL injury results in mechanical instability of the knee joint and has lifelong consequences on neuromuscular function and dynamic stability, significantly impairing the patient's athletic capability [2]. Epidemiological studies indicate approximately 200,000 annual incidences of ACL injuries, with a significant proportion occurring among secondary school students, university students, professional athletes, and military members [3,4]. The proportion of ACL patients who recover to their pre-operative exercise level after reconstruction surgery is about 45–50% [5].

ACL reconstruction (ACLR) is a widely performed surgical procedure. It improves the structural stability of the knee and restores the pre-injury status of knee function and dynamic neuromuscular control [6]. Although surgical treatment of ACL injury can restore knee stability, patients often exhibit functional

CONTACT Shazlin Shaharudin shazlin@usm.my Exercise & Sports Science Programme, School of Health Sciences, Universiti Sains Malaysia, Kota Bharu, Kelantan 16150, Malaysia.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/07853890.2025.2542441.

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (http://creativecommons.org/licenses/by-nc/4.0/), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

deficits such as decreased dynamic stability and impaired joint proprioception. This phenomenon is mainly related to the damage to proprioceptors in the ACL and the disturbance of the neuromuscular feedback system [7]. Therefore, the successful enhancement of knee joint stability during postoperative therapy has emerged as a significant focus of studies on ACL damage rehabilitation.

Proprioceptive training, aimed at restoring knee joint proprioception and stability, is widely used in rehabilitating patients following knee injury, and its clinical efficacy is established [8]. For example, it was found that innovative aquatic proprioceptive training coupled with a conventional rehabilitation program improved proprioception, pain, and knee joint function in patients with ACL reconstruction [9]. In addition, patients who performed proprioceptive training demonstrated improved knee function scores (e.g. Lysholm scores) [10]. Currently, only two meta-analyses have investigated the effects of proprioceptive training in ACL rehabilitation, but their conclusions remain inconsistent. One study reported significant improvements in knee joint proprioception and single-leg hop test performance, along with moderate improvements in subjective functional scores, but no effect on muscle strength [11]. The other found that proprioceptive training significantly improved knee range of motion (ROM) compared to conventional training, yet showed no significant differences in proprioception, subjective scores, or hop test performance [12].

These conflicting results indicate that the role of proprioceptive training in ACLR rehabilitation remains uncertain. Therefore, this study aims to conduct a more comprehensive meta-analysis focused specifically on ACL reconstruction (ACLR) patients, to clarify whether proprioceptive training can: (1) improve proprioception, (2) enhance single-leg hop performance, and (3) improve subjective functional scores. Additionally, it seeks to examine outcomes that have not been adequately assessed in previous reviews, such as ROM and knee flexion strength. Clarifying these effects will provide stronger evidence to support rehabilitation program design for patients following ACLR.

Methods

The review was conducted in alignment with the methodologies and stipulations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and the Cochrane Handbook [13], and the initial literature search was conducted on 2 December 2024 to assess feasibility and inform protocol development. The final protocol was subsequently registered with PROSPERO (CRD42025643822) on 7 February 2025, prior to full-text screening and data analysis.

Literature retrieval strategy

Two researchers (S.C. and J.G.) conducted independent searches across five databases, PubMed, Web of Science, Cochrane Library, Embase, and China National Knowledge Infrastructure, to investigate the effects of proprioceptive training on patients with ACLR. Furthermore, the China National Knowledge Infrastructure databases were confined to the Chinese Social Sciences Citation Index and Chinese Science Citation Database, both of which are esteemed journal databases in China. The search date was set from inception to December 2, 2024. The retrieval method involved a union of key words: keywords and MeSH terms. Boolean operators “AND” and “OR” were used for integration and connection, with the final strategy confirmed through multiple rounds of pre-checking. The English search terms included anterior cruciate ligament reconstruction, anterior cruciate ligament, ACL, ACLR, and proprioception, proprioceptive training. Equivalent Chinese search terms were used for the Chinese database to ensure accurate retrieval. The full list of terms is provided in Appendix A, which describes the detailed search strategy.

Inclusion and exclusion criteria

The selection criteria include studies that involved patients who underwent surgery to repair an ACL reconstruction and were already in the rehabilitation phase. The experimental group received proprioceptive training alone or in combination with conventional rehabilitation, or was implemented as an additional component in the training program of the control group. The control group underwent standard rehabilitation or comparable strength training. The outcome measures included proprioceptive and

knee function, with data presented as mean ± standard deviation. Only randomized controlled trials (RCTs) with the evaluation of participants carried out at least twice (pre- and post-intervention) were included. Outcome measures were assessed pre- and post-intervention based on the time points defined in the original trials; no uniform time interval was imposed across studies.

The exclusion criteria were non-randomized controlled trial study designs, duplicate published papers, or conference proceedings. Outcome indicators that did not fit the study's standards or from which data could not be collected as well as intervention group materials that did not meet the requirements were also excluded.

Data extraction and coding

After the literature search was completed, two researchers (S.C. and J.G.) independently screened the records in a double-blind manner according to the predefined inclusion and exclusion criteria. The records were first imported into EndNote X9 software (Clarivate, Version X9, Philadelphia, PA, USA) to remove duplicates, followed by title and abstract screening. Subsequently, the full texts of potentially eligible studies were retrieved and thoroughly reviewed. Any disagreements between the two reviewers were resolved by a third researcher (S.S.) through discussion and consensus.

Two researchers (S.C. and J.G.) independently extracted the literature included in the analysis using a pre-designed form to extract and code pertinent information. If data were absent or could not be extracted, the authors of the literature were contacted to obtain the missing information. The extraction encompassed fundamental details (authors, publication year, country, sample size, population type, and age of patients), trial-based attributes (intervention details, duration of each session, frequency, and periodicity), and outcome metrics.

The coding was as follows: population type into general patients and athletes, geographical region into Asia and Europe, and sample size into groups of fewer than 30 and more than 30 individuals per group. Statistically, a sample size of less than 30 is considered small because the central limit theorem of normal distribution does not usually work with that many numbers, and precise analysis methods are needed [14]. Patients were categorized into two groups: those more than 6 months and those less than 6 months post-ACLR, based on restoring knee proprioception to normal within 6 months following the procedure [15].

Quality assessment

The quality of the selected studies was appraised using the Cochrane Risk of Bias Assessment Tool in this review [13], including random sequence generation, allocation concealment, participant and personnel blinding, outcome assessor blinding, incomplete data, selective reporting, and other sources of bias. The results of these analyses were classified into three categories of quality assessment: low-level, unclear, and high-level risks. This procedure was performed independently by two researchers (S.C. and J.G.). In cases of disagreement, another researcher (S.S.) participated in the discussion and made a decision.

Certainty of the evidence

Evidence quality was evaluated based on the Grading of Recommendations Assessment, Development and Evaluation (GRADE) system and rated as High, Moderate, Low, and Very Low [16]. The initial high-quality evidence derived from RCTs may diminish due to five different factors: (1) limitations of the study, (2) variability of outcomes, (3) indirectness of evidence, (4) lack of accuracy, and (5) publication bias.

Data analysis

A meta-analysis was conducted using the Stata 17 software (Stata Corp LLC, Version 17, College Station, TX, USA). Considering that the study's results included continuous variables and different testing

methods, the standardized mean difference (SMD) was used to calculate effect sizes [17]. According to Hedges' g effect size criteria, 0.2, 0.5 and 0.8 were the cut-off values for small, medium and large effect sizes [18]. Heterogeneity was calculated using Higgins' I^2 statistic, with 75%, 50% and 25% as the cut-off values for high, medium and low heterogeneity [13]. The data were analyzed using a fixed-effects model for $I^2<50\%$. In comparison, the random-effects model was used to analyze the data in the case of $I^2\geq50\%$, and if heterogeneity exceeded 50%, subgroup and sensitivity analyses were performed to explore the source of heterogeneity [19].

Results

Literature search results

A total of five databases were searched, including PubMed (702 articles), Embase (797 articles), The Cochrane Library (245 articles), Web of Science (1460 articles) and CNKI (108 articles), and a total of 3312 articles were searched, including 108 Chinese articles, 3201 English articles and 3 systematic review articles. After removing duplicates, 2234 articles remained. After initial screening based on titles and abstracts, 30 articles remained. Following full-text analysis and re-screening, another 17 articles were excluded because of mismatch of study design ($n=6$), non-RCTs ($n=8$), and duplicate publications ($n=3$). Finally, 13 RCTs were included in the review [9,10,20–30], as shown in Figure 1.

Characteristics of included literature

Thirteen articles were included in this study: ten in English and three in Chinese. These articles were published between 2002 and 2022. A total of 529 patients were aged 18 to 40 years. Interventions

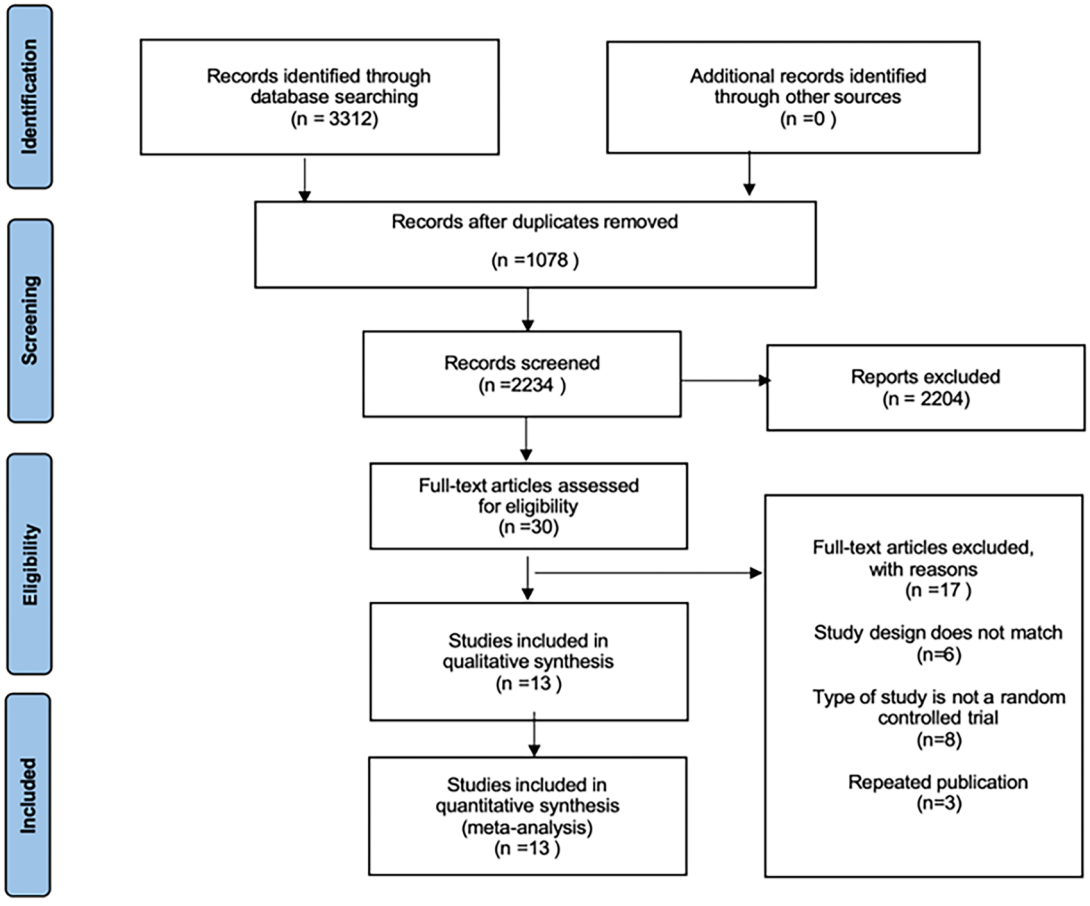


Figure 1. Flowchart of search results based on the PRISMA guidelines for systematic reviews and meta-analyses.

included various forms of proprioceptive training, such as balance training, neuromuscular training, and underwater proprioceptive training. The intervention duration ranged from 20 to 75 min per session, with a frequency of 2 to 5 times per week and a total period of 5 to 12 weeks. The primary modalities of outcome measures were single-leg hopping ability, subjective knee functional scores, knee mobility angle, knee proprioception, and knee flexion strength, as shown in Table 1.

Evaluation of the quality of the included literature

This study included 13 papers, all detailing the creation of randomized sequences; seven outlined the allocation concealment process, five were blinded to the investigators and subjects, and three were blinded to the raters. All the studies had comprehensive data and did not engage in selective reporting, as shown in Figure 2.

Meta-analysis results on the effect of proprioceptive training on ACLR

Knee range of motion

In three investigations [10,20,21], involving 83 patients who underwent ACLR, knee ROM was assessed using measures of limited range of motion, knee abduction (valgus) angles, and knee flexion angles. The heterogeneity test results (I^2=0.64%; $p=0.37$) demonstrated the absence of significant heterogeneity in the different studies. Hence, the fixed-effects model was employed for the analysis. The outcome indicated that proprioceptive training could not enhance knee ROM in individuals with ACLR (Hedge's $g=0.12$, 95% CI: −0.3 − 0.54, p=.57), as displayed in Figure 3(A).

Knee flexion strength

In three studies [23,26,27] involving 124 patients who underwent ACLR, knee flexion strength was assessed through hamstring peak torque timing, the work ratio performed by the quadriceps and hamstrings relative to the healthy leg, and the similarity coefficients of the electrical activity amplitude of the muscles compared with healthy subjects. The heterogeneity test results (I^2=6.56%; $p=0.34$) demonstrated an absence of statistical heterogeneity among the studies. Consequently, a fixed effects model was used in the analysis. The meta-analysis indicated that proprioceptive training did not enhance knee flexion strength in individuals with ACLR (Hedge's g= −0.02, 95% CI: −0.37 − 0.32, $p=0.9$), as demonstrated in Figure 3(B).

Subjective knee functionality score

In four investigations [9,10,29,30], 150 patients who underwent ACLR were evaluated for knee function using the IKDC scale. The heterogeneity assessment showed low heterogeneity (I^2 = 33.85%, $p=0.21$). The studies exhibited low heterogeneity. Therefore, the effect sizes were aggregated using a fixed-effects model. Meta-analysis indicated that proprioceptive training enhanced subjective knee functional scores in patients who underwent ACLR (Hedge's $g=0.58$, 95% CI:0.26 − 0.9, $p<0.05$), as shown in Figure 4(B).

Single-Leg hopping ability

Three studies [10,25,27] used hop distances, with 154 patients with ACLR, to assess single-leg hopping ability. Outcomes of the heterogeneity assessment: (I^2= 20.58%, $p=0.28$). These studies exhibited low heterogeneity. Hence, a fixed effects model was used in the analysis. The meta-analysis revealed that proprioceptive training improved the single-legged hopping ability in patients with ACLR (Hedge's $g=0.44$, 95% CI: 0.15 − 0.72, $p=0.00$), as shown in Figure 4(C).

Knee proprioception

Knee proprioception was assessed in six studies [9,22,24,27–29] involving 346 ACLR patients using knee position sense errors and balance and stability indices. The heterogeneity test results (I^2=80.57%; $p=0.00$) revealed significant heterogeneity across studies. Consequently, a random effects model was

Table 1. Characteristics of included literature.

Study	Country	Age(E/C)	Sex(E/C)	N(E/C)	Activity level	Intervention	Duration & frequency	Outcome
Cooper (2005)	Australia	E:31.3 ± 7.8 C:24.7 ± 5.1	E:12M,5F C: 8 M,7F	14/15	General patients	Proprioceptive and balance exercise	6 weeks 1 h each time, 5 times per week	CKRS, PSFS, KROM, Hop Tests
Hajouj (2020)	Iran	E:23.79 ± 3.04 C:24.68 ± 3.78	E:19M C:19M	19/19	Athletes	Innovative Aquatic Proprioceptive Training	6 weeks 40–60 min 2 times a week	JPS, VAS, IKDC
Hajouj (2021)	Iran	E:23.7 ± 2.66 C:24.4 ± 3.59	E:20M C:20M	20/20	Athletes	Innovative Aquatic Proprioceptive Training	10 weeks 60–75 min 2 times a week	MAG, SI
Lisi (2022)	China	18–40 (only interval)	E: 10 M,10F C: 8 M,12F	20/20	General patients	Proprioceptive training	8 weeks 20–30 min twice/day	Lysholm, HopTests, knee angles.
Khalid (2022)	Pakistan	E:31.13 ± 5.03 C:29.92 ± 5.71	E: 18 M,20F C: 25 M,13F	38/38	General patients	Neuromuscular training for proprioception	6 months 3 times per week	CKRS, Hop Tests, NPRS.
T. Liu (2002)	Canada	E:25 ± 3.7 C:24.7 ± 2.7	N/A	5/5	General patients	Proprioceptive training	12 weeks 3 times a week	PeakTT, AIT, Lysholm, Tegner and Gillquist, Hop Tests
Vathrakokilis (2008)	Greece	28.6 ± 6(only interval)	E: 8 M,4F C: 9 M,3F	12/12	General patients	Balance-training for proprioception	8 weeks 3 times per week, 20 min per session	BSS, BB
Mohammad (2020)	Iran	E:27.2 ± 3.4 C:26.9 ± 4.1	N/A	12/12	Athletes	Neuromuscular training for proprioception	8 weeks 2–3 sessions per week,22 total sessions	Position sense errors
Yu (2015)	China	E:35.9 ± 12.2 C:37.0 ± 11.5	E: 23 M,8F C: 26 M,5F	31/31	General patients	Proprioceptive strengthening exercise combined with motor imagery therap	6months 20–40 min, 2–3 times per week	Positional awareness, knee function
Zhang (2014)	China	24.1 ± 1.2(only interval)	E: 2 M,3F C: 2 M,3F	5/5	Athletes	Neuromuscular training for proprioception	12months 2–3 times per week	IKDC, Lysholm
Jiang (2011)	China	E:29.4 ± 2.9 C:30.2 ± 3.5	E: 48 M,14F C: 44 M,18F	62/62	General patients	Balance training for proprioception	5 weeks 5–20 min each time, seven times a week	SBFA, LFS
Cappellino (2012)	Italy	E:27 ± 6 C:28 ± 4	E: 7 M C: 7 M	7/7	General patients	Neurocognitive treatment for proprioception	6months 1–5 times per week for 1 h	Knee angle
Risberg (2007)	Norway	28.4(Only the average)	47M,27F (total)	39/35	General patients	Neuromuscular training for proprioception	6months 2 to 3 times a week	Single hop, position sense, VAS, QHP

Abbreviations: E = Experimental group; C = Control group; CKRS, Cincinnati Knee Rating System; PSFS, Patient Specific Functional Scale; KROM, Knee Range of Motion Testing; JPS, Joint Position Sense; VAS, Visual Analog Scale; IKDC, International Knee Documentation Committee Questionnaire; SI, Similarity Coefficient of Total Electrical Activity; MAG, Electromyographic Activity Patterns of Muscles; PeakTT, Time to reach peak torque of the hamstring muscles; AIT, Mean isokinetic torque values of the quadriceps and hamstring muscles; BSS, Biodex Stability System; BB, Balance Boards; SBFA, Static Balance Function Assessment; LFS, Length in Function of Surface; QHP, Quadriceps and Hamstring Power; NPRS, Numeric Pain Rating Scale.
All control groups received a conventional rehabilitation training program.

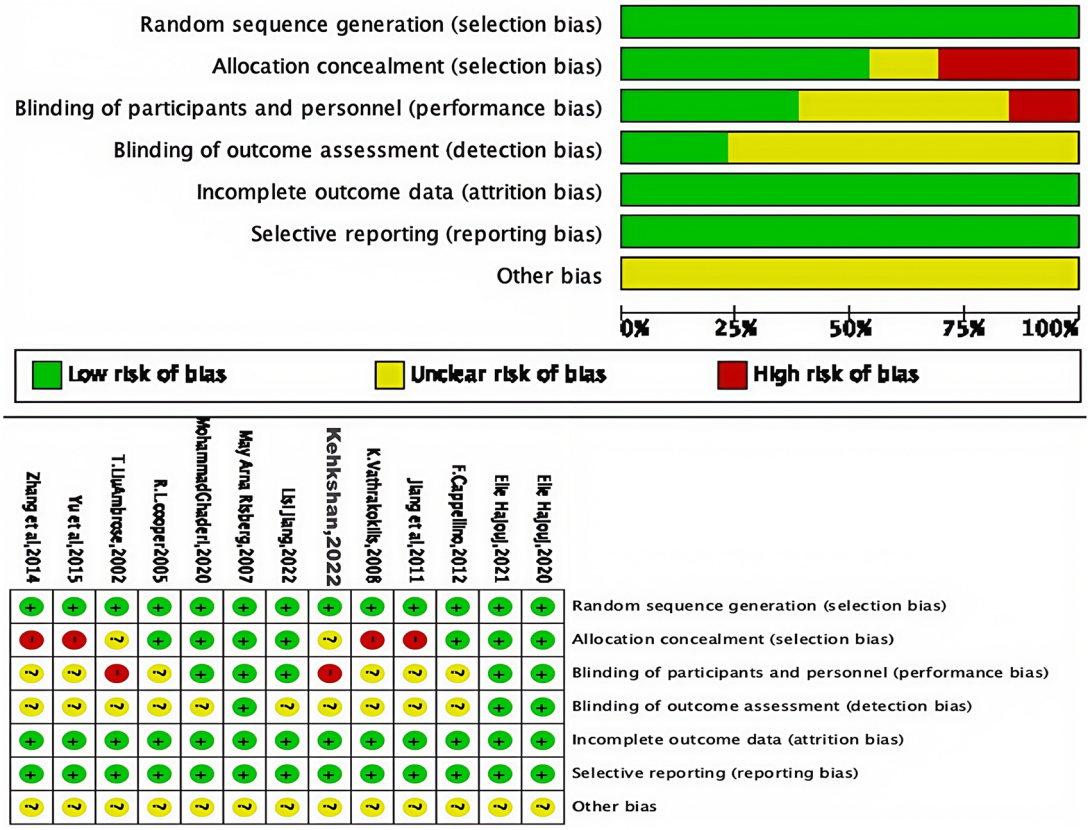


Figure 2. Risk of bias assessment following the cochrane collaboration guidelines.

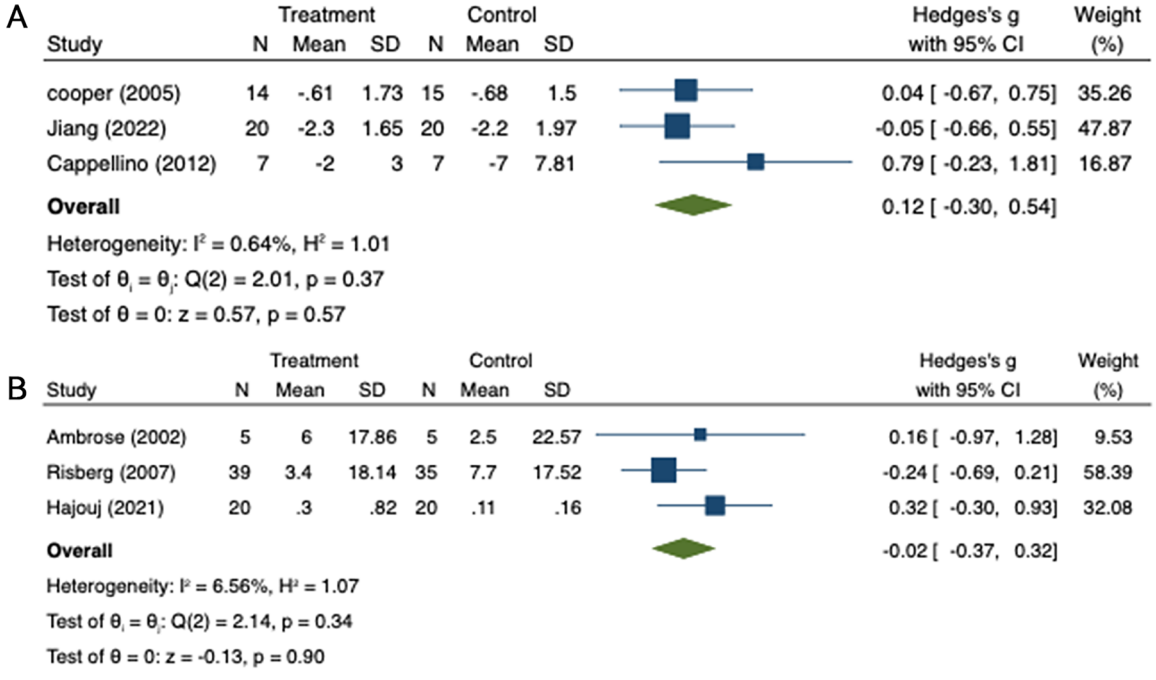


Figure 3. Forest Plot-based evaluation of the effect of proprioceptive training on the outcome measures of knee range of motion and knee flexion strength.

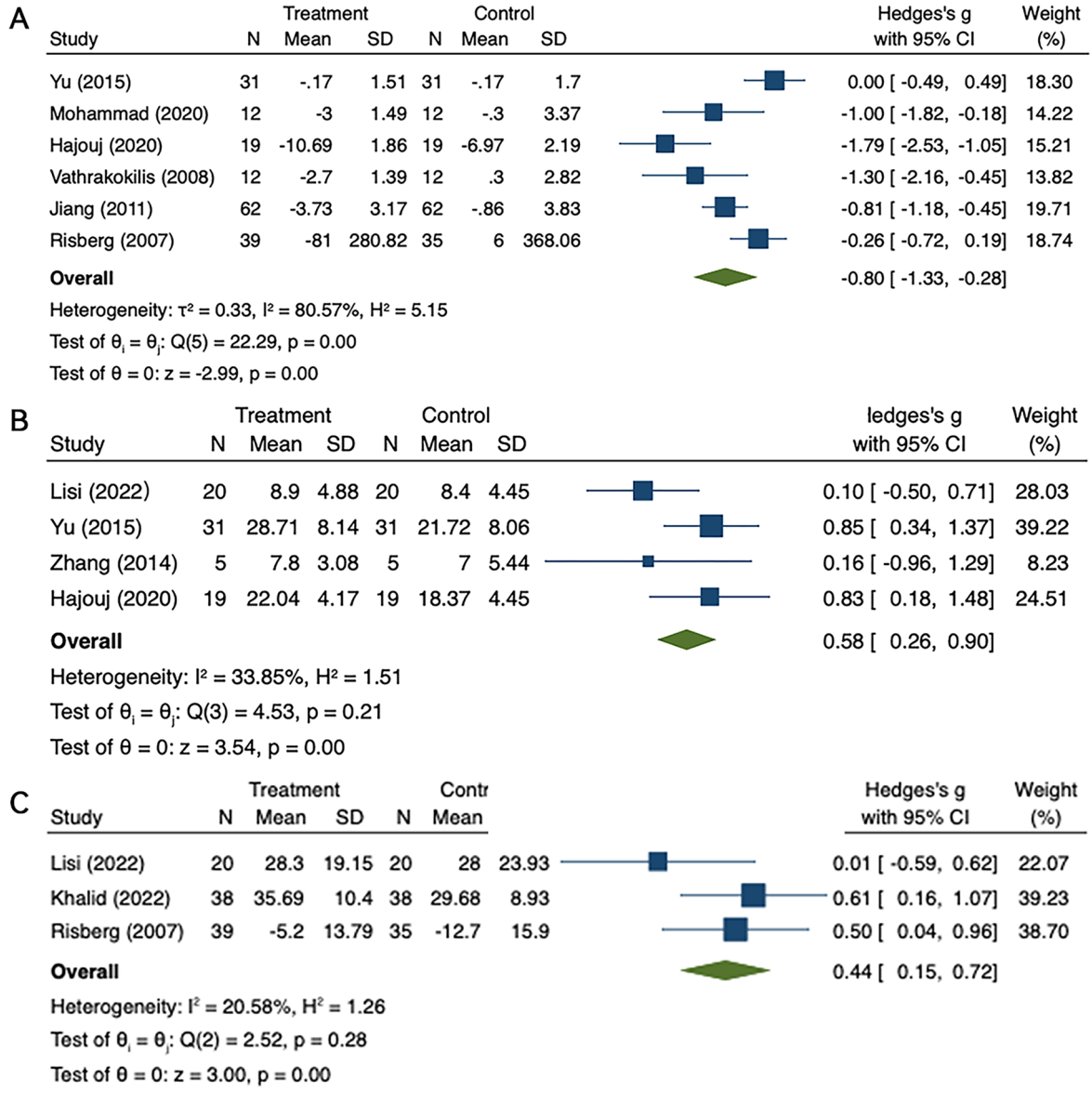


Figure 4. Forest Plot-based evaluation of the effect of proprioceptive training on the outcome measures of subjective functional scores, single-legged hopping ability, and knee proprioception.

Table 2. Combined effects of removing individual studies on proprioceptive function of the knee.

Study eliminated	Hedge's g (95% CI)	*p* value (combined effect)	I^2 (%)	*p* value (heterogeneity)
Yu (2015)	−0.97(−1.49 to −0.46)	0	73.1	0.01
Mohammad (2020)	−0.78(−1.41 to −0.16)	0.01	85.31	0
Hajouj (2020)	−0.6(−1.05 to −0.16)	0.01	69.44	0.01
Vathrakokilis (2008)	−0.73(−1.32 to −0.14)	0.02	83.68	0
Jiang (2011)	−0.82(−1.48 to −0.15)	0.02	81.68	0
Risberg (2007)	−0.93(−1.53 to −0.33)	0	79.54	0

All models are random effects models.

used for the analysis. The meta-analysis revealed that proprioceptive training improved knee proprioception in individuals with ACLR (Hedge's g= −0.8, 95% CI: −1.33 – −0.28, $p = 0.00$), as shown in Figure 4(A).

Sensitivity analyses were conducted to investigate the source of heterogeneity, and the elimination of individual studies did not result in substantial changes to heterogeneity, indicating that it was not derived from any particular study, as shown in Table 2.

Table 3. Subgroup analysis of the impacts of proprioceptive training for knee proprioceptive functions.

Moderator variable	*Q*, *p*	Included studies	I^2 (%)	Effect size (95% CI)	*P* value
Sample size	8.54,0.003	6			
<30		3	7.41	−1.395(−1.877 to −0.914)	0
≥30		3	72.71	−0.381(−0.861 to 0.099)	0.119
Type of population	3.48,0.062	6			
general		4	75.21	−0.537(−1.042 to −0.031)	0.037
athletes		2	49.08	−1.417(−2.192 to −0.642)	0
Geography	0.05,0.82	6			
Asian		4	84.46	−0.862 (−1.580 to −0.144)	0.019
European		2	77.33	−0.718 (−1.727 to 0.291)	0.163
Postoperative time	0.94,0.332	6			
<6 months		4	88.74	−0.681 (−1.408 to 0.045)	0.066
≥ 6 months		2	0	−1.146(−1.739 to −0.553)	0

All models are random effects models (except for the first one). All four subgroups were derived from the six studies: (Yu (2015); Mohammad (2020); Hajouj (2020); Vathrakokilis (2008); Jiang (2011); Risberg (2007).

As the sensitivity analysis did not lead to substantial changes in heterogeneity, this study conducted additional subgroup analysis to investigate the factors of heterogeneity. Subgroup analyses were based on the sample size, population type, geography, and postoperative time, As shown in Table 3.

Subgroup analyses based on sample size indicated that sample size influenced the effect of the intervention ($Q = 8.54$, $p = 0.003$). Statistical significance was found (Hedge's g = −0.381, 95% CI: −0.861 − 0.099; p = .0119) for groups ≥ 30. Fewer than 30 in each group showed statistical significance (Hedge's g=-1.395, 95% CI: −1.877 − −0.914; p=.000).

Subgroup analyses based on population type indicated that the type of population did not influence the effect of the intervention ($Q = 3.48$, $p = 0.062$). It was statistically significant in both the general patient population and the athlete population (Hedge's g= −0.537, 95% CI: −1.042 − −0.031; p=.037), (Hedge's g= −1.417, 95% CI: −2.192 − −0.642; p=.000).

Subgroup analyses based on patient geography revealed that geography did not influence the effects of the intervention ($Q = 0.05$, $p = 0.82$). Asian geography showed a statistically significant result (Hedge's g= −0.862, 95% CI: −1.580 − −0.144; p=.019). European geography did not show statistically significance (Hedge's g=-0.718, 95%CI: −1.727 − 0.291; p=.163).

Subgroup analyses based on postoperative time indicated that the timing did not influence the effect of the intervention ($Q = 0.94$, $p = 0.332$). A postoperative time of < 6 months was not statistically significant (Hedges' g= −0.681, 95% CI: −1.408 − 0.045; p=.066). A postoperative duration of ≥ 6 months showed statistical significant (Hedge's g= −1.146, 95% CI: −1.739 − −0.553; p = .000).

Evaluation of outcome evidence

The grade of evidence associated with the subjective functional score was rated low owing to study limitations and publication bias. The quality of evidence for knee proprioception was rated as intermediate, which was also affected by the study limitations. The quality of evidence for knee range of motion was assessed as low and downgraded owing to methodological limitations, imprecise estimates, and concerns about publication bias. Knee flexion strength was rated low and downgraded for imprecise estimates, and concerns regarding publication bias. Finally, the grade of evidence for single-leg hopping distance was rated low and downgraded for imprecise estimates, and concerns about publication bias. The assessments based on GRADE are presented in Table 4.

Discussion

Knee proprioception, subjective functional scores and single-leg hopping ability

This review and meta-analysis revealed that proprioceptive training significantly enhanced knee proprioception in patients undergoing ACLR rehabilitation. A previous study assessed the impact of a proprioceptive rehabilitation program on postoperative proprioception and functional status, revealing notable changes in proprioceptive measurements in ACLR after six months compared to a control group [31]. Another study evaluated patients' knee proprioception by measuring single-leg balance for 25 s on a strain-gauge force

Table 4. Level of evidence for outcome indicators.

Outcome indicator	Studies (Sample size)	Evaluation of the quality of evidence					Quality of evidence
		Limitations	Inconsistency	Indirectness	Inaccuracy	Publication bias	
subjective functional score	4(150)	Downgrade	No Downgrade	No Downgrade	No Downgrade	Down grade	Low
knee proprioception	6(346)	No Downgrade	No Downgrade	No Downgrade	No Downgrade	Down grade	Moderate
knee mobility angle	3(83)	Downgrade	No Downgrade	No Downgrade	Downgrade	Down grade	Low
knee flexion strength	3(124)	No Downgrade	No Downgrade	No Downgrade	Downgrade	Down grade	Low
single-leg hopping distance	3(154)	No Downgrade	No Downgrade	No Downgrade	Downgrade	Down grade	Low

plate, focusing on the center of pressure (COP) amplitude and mean velocity. At follow-up, both neuromuscular proprioception training and traditional rehabilitation training groups improved proprioceptive function. However, there were no significant differences [32]. The differences may be due to the variations in measurement techniques. Currently, there is no consistent standard for proprioceptive measurement methods, and the tools used for proprioceptive assessment do not exhibit clear characteristics, particularly for individuals following ACLR [33]. Some studies have demonstrated this by assessing position sense, while others do so by evaluating balance. Moreover, different studies may vary in the content of proprioceptive training, intervention periods, and measured outcomes. This study's inclusion criteria for proprioceptive measurements differed from those in previous studies, and this study incorporated multiple forms of proprioceptive measurements together for analysis to reduce single-indicator limitations.

This study found that proprioceptive training improved the subjective functional scores in patients with ACLR. A previous study compared the influence of proprioceptive training in patients with ACLR, assessing the patients' subjective knee function through a knee score test, and found that proprioceptive training enhanced the mean knee score by 50.4% [31]. Another study evaluated subjective knee function using the Lysholm and Gillquist Knee Score and found no difference between the proprioceptive training subjects and the control subjects [26]. The differences could be due to the variety of subjective functional knee scales. Currently, different studies may utilize various subjective knee functional scales, including the Lysholm Knee Scoring Scale, the International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, the Cincinnati Knee Rating System, and the Visual Analogue Scale (VAS). Moreover, different studies may vary according to the timing of the intervention. At three months, a notable improvement was observed in the neuromuscular training group compared to the control group, but this was not observed at 12 months [34]. The inclusion criteria for subjective knee function scores in this study differed from those in previous studies. Only similar assessments of the same type (e.g. Lysholm and IKDC) were included to enhance the comparability and reliability of the results.

This study revealed that proprioceptive training improved the single-leg hopping ability in patients who underwent ACLR. Previous studies utilized a vibrating platform for 8 weeks of proprioceptive training and evaluated single-leg hopping ability 6 months post-surgery. Single-legged jumping and agility improved results compared to conventional rehabilitation [35], which aligns with the findings of this study. On the other hand, the single-legged jump and timed jump tests were used to assess proprioception levels in patients following ACLR. Following the intervention period, no marked difference was observed between the proprioceptive training group and control subjects [26]. The differences could be attributed to the testing method. The varying technical requirements of single-legged jump tests (such as distance and time tests) across studies may influence the sensitivity of the results. Moreover, different studies may vary in sample characteristics, including the stage of postoperative rehabilitation or patients' baseline single-legged jumping ability, contributing to variations in results.

Knee range of motion and knee flexion strength

This study found that proprioceptive training had no effect on the knee ROM in the patients who underwent ACLR. A previous study evaluated knee ROM with a standard goniometer at the time points of

3 months and 12 months after ACL injury, the knee ROM showed no difference between the neuromuscular training for proprioception and self-monitoring groups across the two assessments [34], aligning with the findings of this study. Conversely, another study found that proprioceptive training could enhance knee ROM [12]. The differences may be due to variations in the time after the patient's surgery. The postoperative period after ACL surgery significantly influences the range of motion of the knee. Initially, the range of motion was limited, but by six months, 89% of patients achieved near-full knee ROM of approximately 146° [36]. The previous study included subjects selected during the postoperative period of 8 weeks and the immediate postoperative period, but fewer people were selected 6 months after surgery. Moreover, different studies may vary in the measurement tools used. Knee activity measurement is typically performed using a handheld protractor, electronic protractor, and knee isometric instrument. Each tool varied in accuracy, potentially resulting in differences between the studies.

The study concluded that proprioceptive training did not enhance the knee flexion strength in patients who underwent ACLR. A previous study evaluated knee extension and flexion strength through isometric muscle strength testing, and the findings indicated that proprioceptive training did not result in a significant difference compared to the control group [11], consistent with the results of the current study. In contrast, another study indicated that after six months of proprioceptive training, muscle strength in the quadriceps and hamstrings could be enhanced [37]. The differences could be due to variations in training design. Some studies have used proprioceptive training alone, emphasizing the enhancement of joint position sense and balance function. In other studies, conventional rehabilitation training incorporated proprioceptive training, including muscle strength training. This may explain the observed differences in muscle strength measurements. Moreover, different studies have different patient characteristics. Variations in patient characteristics, particularly initial knee strength and stages of postoperative recovery, led to notable differences in muscle strength among patients and may have significantly affected the outcomes.

Subgroup: sample size

Subgroup analyses revealed that the sample size significantly moderated the impact of proprioception training on improving knee proprioception. The effect was more pronounced in studies with fewer than 30 participants, and less evident in those with larger sample sizes. A previous study indicated that the effect of neuromuscular proprioception training on knee proprioception was insignificant compared to conventional training, with a sample size of 30 or more participants [27]. A different study indicated that knee proprioception improved when engaging in neuromuscular training for proprioception with a sample size of fewer than 30 participants [22]. Future studies should further examine the moderating role of sample size on intervention efficacy.

Strengths and limitations of the study

This study clarified conflicting evidence in previous research by systematically evaluating the effects of proprioceptive training on knee proprioception, single-leg hopping ability, and subjective functional scores in patients with ACLR. Additionally, it further examined uncertain aspects, including their impact on range of motion (ROM) and flexion strength, offering a more comprehensive understanding of their role in ACLR rehabilitation. All 13 papers in this meta-analysis were RCTs, and the majority exhibited minimal heterogeneity, augmenting the stability and applicability of the findings. These studies included various outcome indicators, such as subjective knee functional scores, proprioception, ROM, flexion strength, and single-leg hopping ability, providing comprehensive data to evaluate the multifaceted impact of proprioceptive training. This study included subgroup analyses to investigate the potential influence of characteristics, such as sample size, postoperative time, population type, and geographic region, on intervention effects, thereby revealing sources of heterogeneity.

The restricted amount of research incorporated in this meta-analysis for some outcome variables (e.g. flexion strength and single-leg hopping capability) may constrain the statistical accuracy of the findings. Simultaneously, there was considerable variability in several variables (e.g. knee proprioception), which may have the potential to influence the stability and consistency of the results, even after conducting subgroup and sensitivity analyses. Additionally, a limitation of this study is that publication bias (funnel

plot) was not assessed because of the small number of studies included per outcome (3–6 studies), which may affect the reliability of the findings.

Recommendations for future studies

For future research, it is advisable to increase the sample size to further investigate the impact of various patient demographics (e.g. age, gender, or mobility levels) on proprioceptive training, thus enhancing the generalizability of the findings. It is advisable to conduct extended long-term follow-up studies to monitor the durability of proprioceptive training effects and evaluate their enduring influence on quality of daily life and motor performance, thereby offering more thorough theoretical and practical support for postoperative ACL rehabilitation.

Conclusion

Proprioceptive training enhanced subjective functional scores, single-leg hopping ability, and knee proprioceptive function in ACLR patients, but did not affect knee mobility or knee flexion strength. These results should be considered when developing future ACLR rehabilitation programmes.

Acknowledgements

The authors would like to express their gratitude to all individuals who contributed to this study, including those who provided valuable insights and the research staff for their technical support. Their contributions have been instrumental in improving the quality of this study.

Author contribution statement

CRediT: **Shiwei Chen**: Conceptualization, Methodology, Writing – original draft, Writing – review & editing; **Jinfa Gu**: Conceptualization, Data curation, Writing – review & editing; **Shazlin Shaharudin**: Formal analysis, Methodology, Supervision, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The study received no external funding.

ORCID

Shiwei Chen http://orcid.org/0009-0005-2919-4667
Jinfa Gu http://orcid.org/0009-0006-8260-2145
Shazlin Shaharudin http://orcid.org/0000-0001-5583-7631

Data availability statement

The datasets used in this study can be obtained from the corresponding author upon reasonable request.

References

[1] Olsson O, Isacsson A, Englund M, et al. Epidemiology of intra- and peri-articular structural injuries in traumatic knee joint hemarthrosis – data from 1145 consecutive knees with subacute MRI. Osteoarthritis Cartilage. 2016;24(11):1890–1897. doi:10.1016/j.joca.2016.06.006.

[2] Hewett TE, Ford KR, Hoogenboom BJ, et al. Understanding and preventing acl injuries: current biomechanical and epidemiologic considerations - update 2010. N Am J Sports Phys Ther. 2010;5(4):234–251.
[3] Prodromos CC, Han Y, Rogowski J, et al. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. Arthroscopy. 2007;23(12):1320–1325.e6. doi:10.1016/j.arthro.2007.07.003.
[4] Paterno MV, Rauh MJ, Schmitt LC, et al. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. Am J Sports Med. 2014;42(7):1567–1573. doi:10.1177/0363546514530088.
[5] Ardern CL, Taylor NF, Feller JA, et al. Return-to-sport outcomes at 2 to 7 years after anterior cruciate ligament reconstruction surgery. Am J Sports Med. 2012;40(1):41–48. Jan. doi:10.1136/bjsports-2013-093398.
[6] Beasley LS, Weiland DE, Vidal AF, et al. Anterior cruciate ligament reconstruction: a literature review of the anatomy, biomechanics, surgical considerations, and clinical outcomes. Oper Tech Orthop. 2005;15(1):5–19. doi:10.1053/j.oto.2004.11.003.
[7] Chmielewski TL, Rudolph KS, Snyder-Mackler L. Development of dynamic knee stability after acute ACL injury. J Electromyogr Kinesiol. 2002;12(4):267–274. doi:10.1016/s1050-6411(02)00013-5.
[8] Jeong HS, Lee SC, Jee H, et al. Proprioceptive training and outcomes of patients with knee osteoarthritis: a meta-analysis of randomized controlled trials. J Athl Train. 2019;54(4):418–428. doi:10.4085/1062-6050-329-17.
[9] Hajouj E, Hadian MR, Mir SM, et al. Effects of innovative aquatic proprioceptive training on knee proprioception in athletes with anterior cruciate ligament reconstruction: a randomized controlled trial. Arch Bone Jt Surg. 2021;9(5):519–526. doi:10.22038/abjs.2020.50106.2485.
[10] Jiang L, Zhang L, Huang W, et al. The effect of proprioception training on knee kinematics after anterior cruciate ligament reconstruction: a randomized control trial. J Back Musculoskelet Rehabil. 2022;35(5):1085–1095. doi:10.3233/BMR-210201.
[11] Huang L, You G, Li M, et al. Outcomes of proprioceptive training on recovery after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Am J Phys Med Rehabil. 2025;104(5):436–444. doi:10.1097/PHM.0000000000002639.
[12] Ma J, Zhang D, Zhao T, et al. The effects of proprioceptive training on anterior cruciate ligament reconstruction rehabilitation: a systematic review and meta-analysis. Clin Rehabil. 2021;35(4):506–521. doi:10.1177/0269215520970737.
[13] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71.
[14] Indrayan A, Mishra A. The importance of small samples in medical research. J Postgrad Med. 2021;67(4):219–223. doi:10.4103/jpgm.JPGM_230_21.
[15] Angoules AG, Mavrogenis AF, Dimitriou R, et al. Knee proprioception following ACL reconstruction; a prospective trial comparing hamstrings with bone-patellar tendon-bone autograft. Knee. 2011;18(2):76–82. doi:10.1016/j.knee.2010.01.009.
[16] Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924–926. doi:10.1136/bmj.39489.470347.AD.
[17] Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol. 2005;5(1):13. doi:10.1186/1471-2288-5-13.
[18] Brydges CR. Effect size guidelines, sample size calculations, and statistical power in gerontology. Innov Aging. 2019;3(4):igz036. doi:10.1093/geroni/igz036.
[19] Armijo-Olivo S, Stiles CR, Hagen NA, et al. Assessment of study quality for systematic reviews: a comparison of the Cochrane Collaboration Risk of Bias Tool and the Effective Public Health Practice Project Quality Assessment Tool: methodological research. J Eval Clin Pract. 2012;18(1):12–18. doi:10.1111/j.1365-2753.2010.01516.x.
[20] Cappellino F, Paolucci T, Zangrando F, et al. Neurocognitive rehabilitative approach effectiveness after anterior cruciate ligament reconstruction with patellar tendon. A randomized controlled trial. Eur J Phys Rehabil Med. 2012;48(1):17–30.
[21] Cooper RL, Taylor NF, Feller JA. A randomised controlled trial of proprioceptive and balance training after surgical reconstruction of the anterior cruciate ligament. Res Sports Med. 2005;13(3):217–230. doi:10.1080/15438620500222547.
[22] Ghaderi M, Letafatkar A, Almonroeder TG, et al. Neuromuscular training improves knee proprioception in athletes with a history of anterior cruciate ligament reconstruction: a randomized controlled trial. Clin Biomech (Bristol). 2020;80:105157. doi:10.1016/j.clinbiomech.2020.105157.
[23] Hajouj E, Hadian MR, Mir SM, et al. Motor control changes after innovative aquatic proprioceptive training in athletes with anterior cruciate ligament reconstruction: voluntary response index analysis. Arch Neurosci. 2021;8(2):e112185. doi:10.5812/ans.112185.
[24] Jiang YL, Wang K. X. Effect of balance promotion training on knee proprioception after reconstruction of knee anterior cruciate ligament injury. Chin J Rehabil Med. 2011;26(03):251–253+267. doi:10.3969/j.issn.1001-1242.2011.03.011.
[25] Khalid K, Anwar N, Saqulain G, et al. Neuromuscular training following anterior cruciate ligament reconstruction - pain, function, strength, power & quality of life perspective: a randomized control trial. Pak J Med Sci. 2022;38(8):2175–2181. doi:10.12669/pjms.38.8.5730.

[26] Liu-Ambrose T, Taunton JE, MacIntyre D, et al. The effects of proprioceptive or strength training on the neuromuscular function of the ACL reconstructed knee: a randomized clinical trial. Scand J Med Sci Sports. 2003; 13(2):115–123. doi:10.1034/j.1600-0838.2003.02113.x.
[27] Risberg MA, Holm I, Myklebust G, et al. Neuromuscular training versus strength training during first 6 months after anterior cruciate ligament reconstruction: A randomized clinical trial. Phys Ther. 2007;87(6):737–750. doi:10.2522/ptj.20060041.
[28] Vathrakokilis K, Malliou P, Gioftsidou A, et al. Effects of a balance training protocol on knee joint proprioception after anterior cruciate ligament reconstruction. BMR. 2008;21(4):233–237. doi:10.3233/BMR-2008-21403.
[29] Yu BJ, Ye JK, Hong JY. Effect of proprioception strengthening training combined with motor imagery therapy on recovery in patients with double-bundle reconstruction of the anterior cruciate ligament. Chin J Mod Med. 2015;25(30):89–94. doi:10.3969/j.issn.1005-8982.2015.30.021.
[30] Zhang X, Liao B, Chen S, et al. Effect of neuromuscular training on the rehabilitation outcome after ACL reconstruction in athletes. Chin J Sports Med. 2014;33(8):772–776. doi:10.16038/j.1000-6710.2014.08.005.
[31] Ordahan B, Küçükşen S, Tuncay İ, et al. The effect of proprioception exercises on functional status in patients with anterior cruciate ligament reconstruction. J Back Musculoskelet Rehabil. 2015 2015;28(3):531–537. doi:10.3233/BMR-140553.
[32] Ageberg E, Zätterström R, Moritz U, et al. Influence of supervised and nonsupervised training on postural control after an acute anterior cruciate ligament rupture: a three-year longitudinal prospective study. J Orthop Sports Phys Ther. 2001;31(11):632–644. doi:10.2519/jospt.2001.31.11.632.
[33] Jebreen M, Maffulli N, Migliorini F, et al. Known-group validity of passive knee joint position sense: a comparison between individuals with unilateral anterior cruciate ligament reconstruction and healthy controls. J Orthop Surg Res. 2023;18(1):525. doi:10.1186/s13018-023-03996-y.
[34] Zätterström R, Fridén T, Lindstrand A, et al. Rehabilitation following acute anterior cruciate ligament injuries—a 12-month follow-up of a randomized clinical trial. Scand J Med Sci Sports. 2000;10(3):156–163. doi:10.1034/j.1600-0838.2000.010003156.x.
[35] Fu CL, Yung SH, Law KY, et al. The effect of early whole-body vibration therapy on neuromuscular control after anterior cruciate ligament reconstruction: a randomized controlled trial. Am J Sports Med. 2013;41(4):804–814. doi:10.1177/0363546513476473.
[36] Shelbourne KD, Benner R, Gray T, et al. Range of motion, strength, and function after ACL reconstruction using a contralateral patellar tendon graft. Orthop J Sports Med. 2022;10(11):23259671221138103. doi:10.1177/23259671221138103.
[37] Kaya D, Guney-Deniz H, Sayaca C, et al. Effects on lower extremity neuromuscular control exercises on knee proprioception, muscle strength, and functional level in patients with ACL reconstruction. Biomed Res Int. 2019;2019:1694695–1694697. doi:10.1155/2019/1694695.

Appendix

Appendix 1: search strategy

Database	Retrieval strategy
Cochrane	**#1** MeSH descriptor: [Anterior Cruciate Ligament Reconstruction] explode all trees #2 ("cranial cruciate ligament reconstruction" or "anterior cranial cruciate ligament reconstruction" or "anterior cruciate ligaments reconstruction" or "anterior cruciate ligament" or "ACL" or "ACLR"):ti,ab, kw #3 MeSH descriptor: [Proprioception] explode all trees #4 (proprioceptive or "proprioceptive training" or "Proprioceptive Neuromuscular Facilitation" or PNF or "sensorimotor" or "sensorimotor training" or "balance training" or "knee joint position sense"):ti, ab, kw #5 #1 or #2; #6 #3 or #4 ; #7 #5 and #6
Embase	**#1** ('anterior cruciate ligament reconstruction'exp OR 'cranial cruciate ligament reconstruction':ti, ab OR 'anterior cranial cruciate ligament reconstruction':ti,ab OR 'anterior cruciate ligaments reconstruction':ti, ab OR 'anterior cruciate ligament':ti, ab OR 'acl':ti,ab OR'aclr' ti,ab) #2 (*proprioception/exp OR 'proprioceptive' ti, ab OR 'proprioceptive training' ti, ab OR 'proprioceptive neuromuscular facilitation':ti, ab OR 'pnf:ti,ab OR 'sensorimotor'ti, ab OR 'sensorimotor training':ti,ab OR 'balance training' ti,ab OR 'knee joint position sense :ti,ab) #3 #1 AND #2
Web of Science	**#1** TS= ("Anterior cruciate ligament reconstruction" or "cranial cruciate ligament reconstruction" or "anterior cranial cruciate ligament reconstruction" or "anterior cruciate ligaments reconstruction" or "anterior cruciate ligament" or "ACL" or"ACLR") #2 TS=(Proprioception or proprioceptive or "proprioceptive training" or"Proprioceptive Neuromuscular Facilitation" or PNF or sensorimotor or"sensorimotor training" or "balance training" or "knee joint position sense") #3 #2 AND #1
PubMed	**#1** ("Anterior Cruciate Ligament Reconstruction"[Mesh]) OR ("cranial cruciate ligament reconstruction"[Title/Abstract] OR "anterior cranial cruciate ligament reconstruction"[Title/Abstract] OR "anterior cruciate ligaments reconstruction"[Title/Abstract] OR "anterior cruciate ligament"[Title/Abstract] OR "ACL"[Title/Abstract] OR "ACLR"[Title/Abstract]) #2 ("Proprioception"[Mesh]) OR ("proprioceptive"[Title/Abstract] OR "proprioceptive training"[Title/Abstract] OR "Proprioceptive Neuromuscular Facilitation"[Title/Abstract] OR PNF[Title/Abstract] OR sensorimotor[Title/Abstract] OR "sensorimotor training"[Title/Abstract] OR "balance training"[Title/Abstract] OR "knee joint position sense"[Title/Abstract]) #3 #1 AND #2
CNKI	**#1** 本体感觉训练+本体感觉 (Proprioceptive training + proprioception) #2 前交叉韧带+前交叉韧带重建+前交叉韧带损伤 (ACL + ACLR + ACL injury) #3 #1 AND #2