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Review

Effect of strength training on knee proprioception in patients with knee osteoarthritis: A systematic review and meta-analysis

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A R T I C L E I N F O

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A B S T R A C T

Proprioception is significantly impaired in knee osteoarthritis (KOA), contributing to reduced functionality. Strength training (ST) is essential in KOA by improving muscle strength, although it may also be effective in improving proprioception. The purpose was to determine the effect of ST on knee proprioception in KOA patients. Pubmed, CINAHL, Scopus, WOS, and PEDro were searched for randomized controlled trials (RCTs) (inception to March 2023). Comparisons for ST were physical exercise different from ST, non-exercise-based interventions, and no intervention. Methodological quality was assessed using the PEDro scale, and risk of bias (RoB) using the Cochrane tool. Meta-analyses were performed by comparison groups using the standardized mean difference (SMD) (Hedge's g) with random effects models, also considering subgroups by proprioception tests. Finally, six RCTs were included. The mean PEDro score was 6.3, and the highest proportion of biases corresponds to performance, selection, and detection. The meta-analysis indicated that only when compared with non-intervention, ST significantly improved knee proprioception for the joint position sense (JPS) (active + passive), JPS (passive), and threshold to detect passive motion (TTDPM) subgroups ($g = -1.33$ [-2.33, −0.32], $g = -2.29$ [-2.82, −1.75] and $g = -2.40$ [-4.23, −0.58], respectively). However, in the knee JPS (active) subgroup, ST was not significant ($g = -0.72$ [-1.84, 0.40]). In conclusion, ST improves knee proprioception compared to non-intervention. However, due to the paucity of studies and diversity of interventions, more evidence is needed to support the effectiveness of ST. Future RCTs may address the limitations of this review to advance knowledge about proprioceptive responses to ST and contribute to clinical practice.

1. Introduction

Osteoarthritis is a chronic, degenerative joint disease characterized by articular cartilage loss, marginal bone hypertrophy, and inflammatory involvement of periarticular tissue.[1] It is the most prevalent chronic rheumatic disease worldwide, strongly impacting individual and population health.[1] The knee is the most frequently affected joint, so knee osteoarthritis (KOA) represents almost four-fifths of the global burden of osteoarthritis and increases with obesity and age.[2] Symptoms of KOA are pain, stiffness, reduced range of motion, and muscle weakness,[3] although proprioception may also be affected, contributing to the associated functional limitation.[4]

Proprioception is the afferent information arising from the internal peripheral areas of the body that contributes to postural control and dynamic joint stability.[5] This information is provided by joint, muscle, and skin mechanoreceptors, promoting motor planning and adaptive movement mechanisms.[6] Therefore, proprioceptive impairment compromises feedback and feedforward processes, affecting motor control and learning.[6] Some factors that can alter proprioception are pain, joint effusion, trauma, and muscle fatigue.[7]

Preserving proprioception is essential in patients with KOA because pain is associated with muscle weakness and impaired balance, increasing the risk of falls.[8] In addition, it has been reported that patients with KOA report knee instability and functional compromise in 63% and 44%, respectively.[9] Proprioceptive accuracy can be significantly affected

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List of abbreviations

ACR	American College of Rheumatology
AF	Adequate follow-up
AMEDA	Active movement extent discrimination assessment
BA	Blind assessors
BC	Baseline comparability
BGT	Between-group comparisons
BS	Blind subjects
BT	Blind therapists
CA	Concealed allocation
CI	Confidence interval
CKCE	Closed kinetic chain exercise
CPFE	Computerized proprioception facilitation exercise
EC	Eligibility criteria
ES	Effect size
G	Group
GRADE	Grading of Recommendations Assessment, Development and Evaluation
ITA	Intention-to-treat analysis
JPS	Joint position sense
KOA	Knee osteoarthritis
MeSH	Medical subheading
M/W	Men/Women
n	Sample size
NWB	Nonweight-bearing exercise
p	probability value
PEaV	Point estimates and variability
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRP	Passive repositioning
PrT	Proprioceptive training
RA	Random allocation
RCTs	Randomized controlled trials
RoB	Risk of bias
SD	Standard deviation
SE	Strength exercise
SMD	Standardized mean differences
ST	Strength training
Std	Standardized
TTDPM	Threshold to detect passive motion
WB	Weight-bearing exercise
WBV	Whole-body vibration
1 RM	One repetition maximum

in patients with unilateral KOA, both in the affected and unaffected knee, which is also associated with increased pain and reduced functionality.[10] Compared with healthy controls, KOA patients have higher odds of having proprioception deficits, lower muscle strength, and greater joint laxity.[11] On the other hand, although it is recognized that proprioceptive impairment in patients with KOA[10,11] and that proprioceptive deficits can alter knee biomechanics, favoring joint degeneration over time,[12] longitudinal studies have not found that proprioceptive impairment (position sense) is a causal factor for the onset or progression of radiographic KOA.[13,14]

The treatment of KOA includes surgery and pharmacological and non-pharmacological therapy.[15] Physical exercise is a fundamental and widely recommended component within non-pharmacological therapies.[15,16] Physical exercise has numerous local and systemic effects, some of which have been studied in patients with KOA. Fransen et al. reported that land-based therapeutic exercise significantly improves pain, physical function, and quality of life in patients with KOA.[17] More recently, Raposo et al. concluded that physical exercise programs appear to be safe and effective in patients with KOA, mainly referring to improving pain and muscle strength.[18]

Muscle weakness is a well-defined clinical feature in KOA, and compared to healthy controls, upper leg muscle strength is 20%–40% lower.[19] Muscle weakness influences the clinical course of the disease, being closely related to pain, functional limitation, and falls.[20] In addition, reduced strength is recognized as a risk factor for developing KOA itself and its radiographic progression, so muscle optimization may help prevent the disease.[21] Therefore, strength training (ST) has become a central component of rehabilitation programs in KOA.[22] ST has been performed under different exercise modalities and with various equipment, being generally effective for managing KOA.[23] The main objective of ST is to strengthen the muscles of the lower limbs, which can increase joint stability, reduce loads, and limit joint stress.[23] Functional capacity can only be maintained if sufficient muscle strength compensates for decreased proprioceptive accuracy and modulation of muscle activation so that functionality will be most affected in proprioceptive reduction and muscle weakness.[24]

Clinical studies have reported not only the effects of ST on muscle strength[25,26] but also knee proprioception in KOA patients.[25–28] For example, Jan et al. found that weight-bearing exercise (WB), but not nonweight-bearing exercise (NWB), improved proprioception compared to no intervention.[25] Lai et al. reported that squat training improves proprioception for knee flexion but not for knee extension compared with education.[27] For their part, Topp and Pifer reported that dynamic and isometric ST have favorable effects on different proprioceptive measures compared with no intervention.[28] The results of these studies are controversial; however, they suggest that proprioceptive improvement is a relevant outcome associated with ST, so it is interesting to know the combined effects of these types of interventions in this population.

Previous systematic reviews focused on strength-based interventions in KOA have reported results on muscle strength[29–32] and several outcomes relevant to the rehabilitation process, such as pain and functional disability,[29,30,32,33] biomechanical measurements,[31,32] and quality of life.[29,32] Additionally, a review that analyzed the effects of various physical exercise modalities (not specifically ST) concluded that improvement in muscle strength, knee extension impairment, and proprioception are possible mediators in the positive association between exercise and osteoarthritis symptoms such as pain and function.[34] Specifically in proprioception, a recent meta-analysis shows that the overall effect of physical exercise -but not individually the ST-favors the improvement of knee proprioception in patients with KOA.[35] Finally, recent emphasis has been placed on the knee proprioceptive and dynamic stability deficits in KOA, aspects that should be considered during exercise prescription[36] and that are demanded, for example, in proprioceptive training programs.[37] For this reason, it is clinically useful to dispose of other exercises that can improve proprioception when patients present difficulties in performing proprioceptive exercises. From this perspective, it is relevant to analyze whether ST by itself can improve various measures of knee proprioception in these patients, which, to the authors' knowledge, no previous review has done so. Therefore, the purpose of this review was to systematically analyze the available literature to determine the effect of ST on knee proprioception in patients with KOA.

2. Materials and methods

2.1. Protocol and registry

This systematic review with meta-analysis was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[38] The study protocol was prospectively registered in the International Platform of Registered Systematic Review and

Meta-analysis Protocols platform (inplasy.com) (registration number 202350102).

2.2. Eligibility criteria for the studies

2.2.1. Inclusion criteria

- Population: Patients with primary KOA (unilateral or bilateral).
- Intervention: Any modality of ST (oriented to the lower limbs generically or to specific muscle groups) administered without any other associated physical intervention. ST was considered a physical exercise involving voluntary muscle contraction against a graded external resistance through specially designed equipment or elements, free weights, or the patient's body weight. Interventions that do not meet this criterion, considering ST associated with another physical intervention or explicitly defined as another type of exercise, will not be considered an ST group.
- Comparison: (i) physical exercise different from ST (e.g., aerobic, balance, proprioceptive, or flexibility), (ii) no intervention, (iii) non-exercise-based interventions (e.g., education or physical agents).
- Outcome: Knee proprioception assessed by field or laboratory testing.
- Types of studies: Randomized controlled trials (RCTs), with no restriction on language.

2.2.2. Exclusion criteria

Studies conducted in patients with knee arthroplasty or osteoarthritis secondary to infectious, autoimmune, traumatic, congenital, or metabolic conditions were excluded.

2.3. Sources of information

The searches were performed in the electronic databases Pubmed, CINAHL, Scopus, Web of Science, and PEDro from inception to March 1st, 2023. No filters were applied, and a manual search was performed from the reference lists of the selected studies.

2.4. Search strategy

The strategy considered using Medical Subheading (MeSH) terms and common terms linked by boolean operators (OR and AND). The search terms were: (i) Population: Osteoarthritis, Knee [Mesh]; Osteoarthritis [Mesh], (ii) Intervention: Resistance Training [Mesh]; "strength training", (iii) Outcomes: Proprioception [Mesh]; Kinesthesis [Mesh]; "joint position sense"; propriocep*; kinesthe*; "position sense"; "sense of resistance". The full search strategy for Pubmed is presented in Supplementary Appendix A.

2.5. Selection of studies

Records obtained from the databases were imported into the Rayyan electronic platform.[39] After eliminating duplicates, records were screened by titles and abstracts to identify studies that potentially met the inclusion criteria. Then, the full texts of the remaining studies were retrieved to assess their eligibility. Two independent reviewers carried out this process, and discrepancies were resolved by a third author.

2.6. Data extraction

A standardized form was used to extract information from the selected studies. The form included information on (i) author and year of publication, (ii) characteristics of the studies and samples, (iii) intervention protocols, (iv) ST comparison groups, (v) measurement instruments, and (vi) Intergroup results in the post-test. Two reviewers independently performed the data extraction, and a third author intervened to homologate the information.

2.7. Methodological quality and risk of bias

Methodological quality was assessed with the PEDro scale, which consists of 11 items with a score from 0 to 10 (criterion 1 not considered).[40] A higher score is better quality, although the following classification has been recommended: 9–10 excellent; 6–8 good; 4–5 fair; < 4 poor.[41] Additionally, the risk of bias (RoB) was assessed through the Cochrane Collaboration tool for clinical trials.[42] Two reviewers independently applied these instruments, and the disagreements were consensual through the mediation of a third author.

2.8. Data synthesis and analysis

Studies were meta-analyzed (Review Manager® 5.4.1) according to the comparator, and subgroups were generated according to the type of proprioception measurement. Effect size (*ES*) was expressed as the standardized mean difference (*SMD*) using a random-effects model due to the diversity of measurement techniques and statistical heterogeneity. Heterogeneity was evaluated using the inconsistency index (I^2), classified as might not be important (0%–40%), moderate (30%–60%), substantial (50%–90%), and considerable heterogeneity (75%–100%).[42] For the calculation of *ES* (Hedges' *g*), the mean, standard deviation, and post-treatment sample size of the experimental and control groups were used and classified as: 0.20–0.49 small; 0.50–0.79 moderate; and ≥ 0.80 high.[42]

3. Results

3.1. Search results

A total of 1 458 records were found, of which 42 corresponded to Pubmed, 1 366 to Scopus, 21 to Web of Science, 6 to CINAHL, and 23 to PEDro. After the elimination of duplicates, 1 377 records remained, and after the screening, 16 records were selected for full-text review. Finally, six studies met all inclusion criteria.[25–28,43,44] Fig. 1 shows the selection process.

3.2. Characteristics of included studies

Five studies were from China,[25–27,43,44] and one was from the United States.[28] The publication intervals were from 2007[43] to 2021.[26] Regarding the diagnostic criteria for KOA, two studies used the Kellgren and Lawrence radiological evaluation scale,[43,44] two used the American College of Rheumatology (ACR) classification,[25,27] and two did not specify the diagnostic criteria.[26,28]

3.3. Methodological quality and risk of bias

The mean PEDro scale score was 6.3 (range 6–8 points). The six studies met the following criteria: Random allocation, baseline comparability, and between-group comparison. Only two studies had concealed allocation.[25,26] No study performed double blinding (subjects and therapists), and four used blinding for the assessors.[25–27,44] Five studies presented an adequate follow-up.[25,27,28,43,44] Finally, four studies analyzed their results by intention-to-treat.[25,26,28,44] The details of the scores are presented in Table 1.

Regarding the risk of selection bias, two studies presented low risk fulfilling the two criteria,[26,44] and the remaining studies presented at least one high-risk criterion and/or unclear risk.[25,27,28,43] Five studies had a high risk of performance bias.[25–28,44] Two studies were at high risk of detection bias because they did not describe blinding for outcome assessors.[28,43] Three studies were rated as having a low risk of attrition bias,[25,26,44] and two were unclear.[27,43] Finally, reporting bias and other biases were low in all studies. The summary of the RoB analysis is presented in Fig. 2.

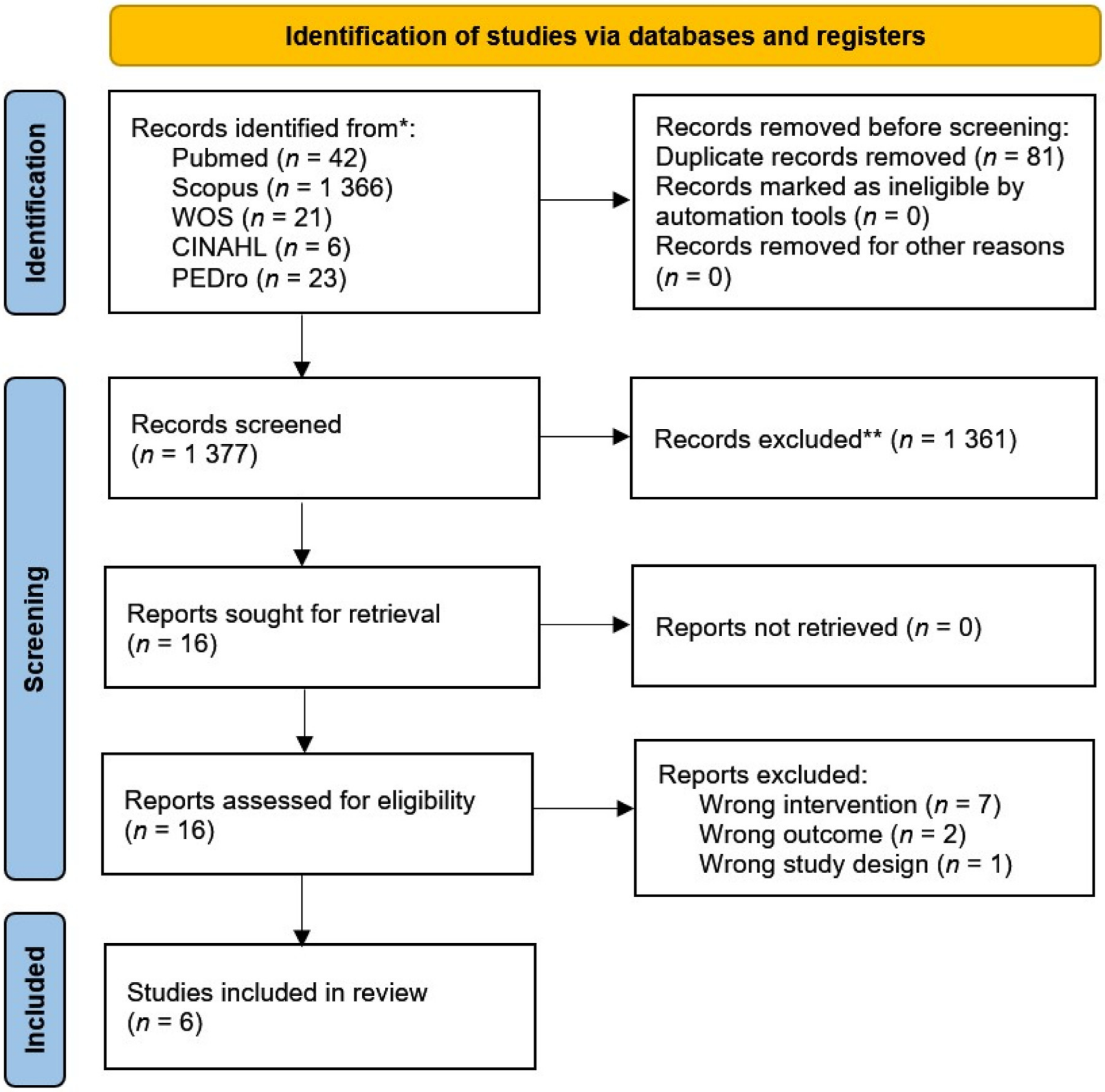

Fig. 1. Flowchart for study selection.

Table 1
PEDro scale scores.

Author	EC[a]	RA	CA	BC	BS	BT	BA	AF	ITA	BGC	PEaV	Total
Lin et al. 2007[43]	✓	✓	X	✓	X	X	X	✓	X	✓	X	4
Jan et al. 2009[25]	X	✓	X	✓	X	X	✓	✓	✓	✓	✓	7
Lin et al. 2009[44]	✓	✓	✓	✓	X	X	✓	✓	✓	✓	✓	8
Topp and Pifer 2017[28]	✓	✓	X	✓	X	X	X	✓	✓	✓	✓	6
Lai et al. 2018[27]	✓	✓	X	✓	X	X	✓	✓	X	✓	✓	6
Lai et al. 2021[26]	✓	✓	✓	✓	X	X	✓	X	✓	✓	✓	7

[a] EC not included in the total score. EC Eligibility criteria; RA Random allocation; CA Concealed allocation; BC Baseline comparability; BS Blind subjects; BT Blind therapists; BA Blind assessors; AF Adequate follow-up; ITA Intention-to-treat analysis; BGT Between-group comparisons; PEaV Point estimates and variability.

3.4. Characteristics of the population

A total of 479 subjects with KOA participated in the studies, of whom 316 were included in some physical exercise program ($n = 224$ for ST only; $n = 92$ for other therapeutic modalities) and 163 were non-physically intervened controls (non-intervention or education). The sample size per exercise group ranged from a minimum of 18 subjects[27] to a maximum of 36 subjects.[25,44] The sample size per control group (non-intervened or education) ranged from a minimum of 16 subjects[27] to a maximum of 36 subjects.[44] The mean age was 62 years (range 58–64 years).

3.5. Characteristics of interventions and proprioception measures

The groups analyzed were those that performed ST as a single intervention. Four studies used one group of ST,[26,27,43,44] and two studies used two groups of ST.[25,28] The STs were isometric[26–28] and dynamic (concentric and eccentric).[25,28,43,44] The ST load was set according to the

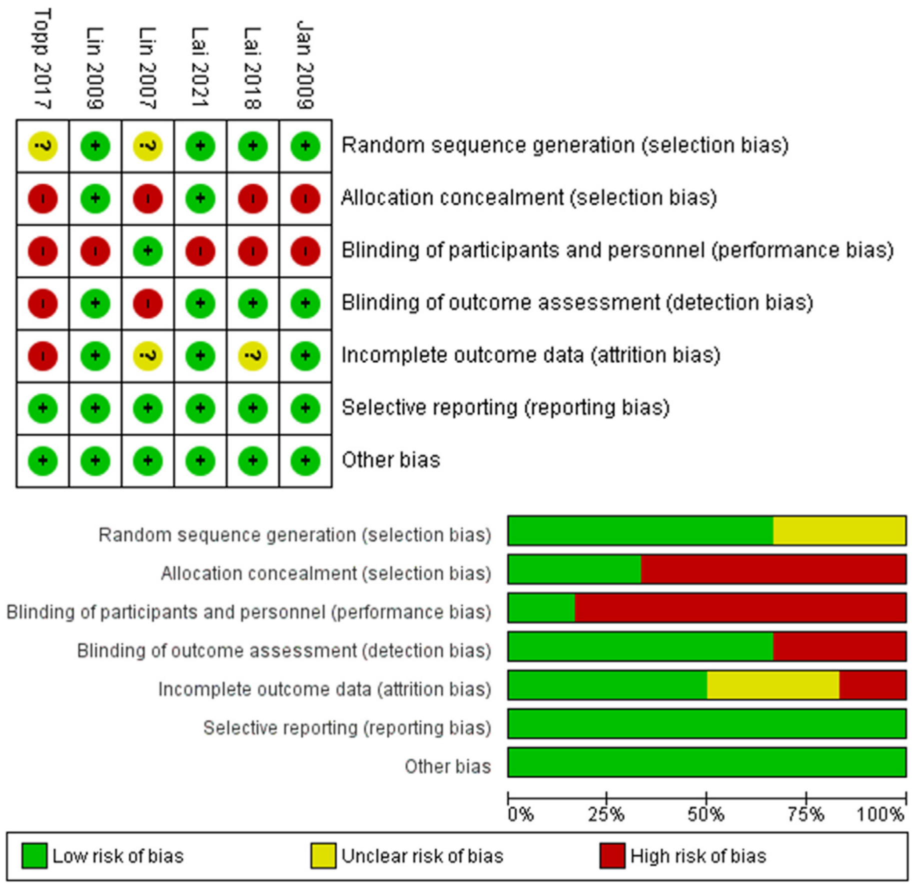

Fig. 2. Analysis of risk of bias.

percentage of body weight,[43] one repetition maximum (1 RM),[25,44] elastic band tension,[28] and isometric contraction time.[26,27] The implementation used considered various resistance devices such as Shuttle Mini Clinic,[43] EN-Tree, EN-Dynamic,[25,44] and elastic bands.[28] Two studies used only own body weight.[26,27] The ST was compared with proprioceptive training (computerized proprioceptive facilitation

Table 2
Summary of included studies.

Author	Subjects			Intervention		
	Total; *n*	M/W; *n*	Age, mean (*SD*); *n*	Type	Frequency	Post-test results (*p* value)
Lin et al. 2007[43]	81	19/62	G1: 61.0 (7.7); $n = 26$ G2: 61.6 (8.1); $n = 29$ G3: 62.8 (6.3); $n = 26$	G1: Strength (CKCE) G2: Proprioception (CPFE) G3: Education (control)	8 weeks, 3 sessions/week	JPS active G1 vs. G2 ($p > 0.05$) G1 vs. G3 ($p < 0.05^{\dagger}$)
Jan et al. 2009[25]	106	33/73	G1: 62.0 (6.7); $n = 36$ G2: 63.2 (6.8); $n = 35$ G3: 62.2 (6.7); $n = 35$	G1: Strength (WB) G2: Strength (NWB) G3: No intervention (control)	8 weeks, 3 sessions/week	JPS active G1 vs. G3 ($p < 0.05^{\dagger}$) G2 vs. G3 ($p > 0.05$)
Lin et al. 2009[44]	108	33/75	G1: 61.6 (7.2); $n = 36$ G2: 63.7 (8.2); $n = 36$ G3: 62.6 (6.7); $n = 36$	G1: Strength (ST) G2: Proprioception (PrT) G3: No intervention (control)	8 weeks, 3 sessions/week	JPS active G1 vs. G2 ($p < 0.05^{\ddagger}$) G1 vs. G3 ($p > 0.05$)
Topp and Pifer 2017[28]	69	18/51	G1: 65.22 (2.34); $n = 23$ G2: 63.48 (2.19); $n = 23$ G3: 58.83 (2.81); $n = 23$	G1: Strength (Dynamic) G2: Strength (Isometric) G3: No intervention (control)	16 weeks, 3 sessions/week, 50 min/session	JPS passive: G1 vs. G3 ($p < 0.05^{\dagger}$) G2 vs. G3 ($p > 0.05$) TTPDM extension: G1 vs. G3 ($p > 0.05$) G2 vs. G3 ($p < 0.05^{\dagger}$)
Lai et al. 2018[27]	34	2/32	G1: 64.07 (4.45); $n = 18$ G2: 63.20 (3.69); $n = 16$	G1: Strength (SE) G2: Education (control)	8 weeks, 3 sessions/week, 12–39 min/session	TTPDM extension: G1 vs. G2 ($p > 0.05$) TTPDM flexion: G1 vs. G2 ($p < 0.05^{\dagger}$)
Lai et al. 2021[26]	81	11/70	G1: 64.81 (4.04); $n = 27$ G2: 63.52 (4.98); $n = 27$ G3: 63.67 (4.84); $n = 27$	G1: Strength (ST) G2: Strength/Vibration (WBV) G3: Education (control)	8 weeks, 3 sessions/week, 12–39 min/session	TTDPM extension/flexion: G1 vs. G3 ($p > 0.05$)

M/W Men/Women; G Group; *n* Sample size; *SD* Standard deviation; *p* probability value; JPS Joint position sense; TTDPM Threshold to detect passive motion; CKCE Closed kinetic chain exercise; CPFE Computerized proprioception facilitation exercise; WB Weight-bearing exercise; NWB Nonweight-bearing exercise; PrT Proprioception training; ST Strength training; SE Strength exercise; WBV Whole-body vibration; † Difference in favor of strength training; ‡ Difference in favor of other intervention.

system),[43,44] ST plus whole-body vibration (WBV) (i-vib5050 platform),[26] educational programs,[26,27,43] as well as with non-interventional controls.[25,28,44] The educational programs included lectures on KOA without physical activity outside the daily routine. No specific indications are described in the non-intervention groups.

The duration of the intervention was eight weeks in five studies[25–27,43,44] and 16 weeks in one study.[28] All interventions were performed at a frequency of 3 times per week, with a duration of 50 min per session in one study[28] and 12–39 min in two studies.[26,27] Three studies did not indicate session duration.[25,43,44]

Proprioception measurement was performed using an electrogoniometer[25,43,44] and custom-designed devices,[26–28] which were described previously.[45–47] The proprioception techniques used were based on active joint position sense (JPS),[25,43,44] passive JPS or passive repositioning (PRP),[28] and threshold to detect passive motion (TTDPM).[26–28] The characteristics of the studies are summarized in Table 2.

3.6. Effects of interventions

The strength interventions performed were described as Closed kinetic chain exercise (CKCE),[43] WB,[25] NWB,[25] Dynamic,[28] Isometric,[28] Strength exercise (SE)[27] and ST.[26,44] Table 2 presents the intergroup effects of the interventions on the post-tests. For active JPS, two studies presented greater effectiveness of ST (CKCE and WB) concerning education[43] and a non-intervention group,[25] respectively. In addition, ST (CKCE and ST) was not superior to proprioceptive training.[43,44] For passive JPS, one study demonstrated greater ST (Dynamic) effectiveness when compared to a non-intervention group.[28] For TTDPM, two studies demonstrated greater effectiveness of ST (Isometric) compared to education[27] and a non-intervened group,[28] respectively.

For the meta-analysis, the studies were grouped into three categories: (i) ST vs. other physical exercise interventions,[43,44] (ii) ST vs. no intervention,[25,28,44] and (iii) ST vs. other non-exercise-based interventions,[26,27,43] In addition, in each category, subgroups were generated according to the type of proprioception test (JPS active, JPS passive, and TTDPM).

In the first category, for knee JPS (active), *SMD* ($g = 0.64$ [-0.63, 1.91]) was not significant (Fig. 3). In the second category, for the knee JPS (active + passive) subgroup, *SMD* ($g = -1.33$ [-2.33, -0.32]) was significant (large *ES*). In the knee JPS (active) subgroup, *SMD* ($g = -0.72$ [-1.84, 0.40]) was not significant. In the knee JPS (passive) subgroup, *SMD* ($g = -2.29$ [-2.82, -1.75]) was significant (large *ES*). In the knee TTDPM subgroup, *SMD* ($g = -2.40$ [-4.23, -0.58]) was significant (large *ES*) (Fig. 4). In the third category, for the knee TTDPM subgroup, *SMD* ($g = 0.17$ [-0.15, 0.50]) was not significant (Fig. 5).

4. Discussion

This systematic review and meta-analysis aimed to analyze the effect of ST on knee proprioception in patients with KOA. Six RCTs were included, and the assessment of knee proprioception was performed using JPS and TTDPM tests. The results of the meta-analysis indicate that only in the second category (ST vs. no intervention) ST achieves a significant overall improvement in proprioception. Furthermore, the subgroups corresponding to JPS (active + passive), JPS (passive), and TTDPM show statistical significance in this same category. However, except for JPS (passive), the heterogeneity is significant, suggesting that the effectiveness of ST should be interpreted with caution. Although these findings are interesting, the low number of included studies implies that the interest of the clinical community in analyzing the behavior of proprioception associated with ST is still incipient, which may at least partially explain the low effectiveness observed.

Four studies used JPS tests.[25,28,43,44] During this test, a body segment is moved passively or actively to a target angle and then returned to its initial position. Then, subjects without visual feedback attempt to replicate that angle actively or with passive assistance, thus assessing reproducibility accuracy.[48,49] The JPS test has been shown to be reliable in healthy subjects and in various knee conditions,[50] and particularly in KOA, an inverse relationship has been observed between JPS performance and quadriceps muscle endurance, as well as lower performance in these patients compared to asymptomatic subjects.[51] In this review, although ST (CKCE and WB) significantly improves active JPS when compared to non-physically intervened controls,[25,43] it is also found that ST (NWB and ST) does not generate differences.[25,44] In addition, the ST (CKCE) compared to proprioceptive training (CPFE) does not show significant differences,[43] and even the ST turns out to be inferior to proprioceptive training (PrT) for the performance of this test.[44] On the other hand, a study that evaluated the JPS passively reports that dynamic ST performed with elastic bands significantly improves this test compared to non-intervened controls but not isometric ST with elastic bands.[28] The results of the meta-analysis indicate that there is no clear trend in favor of ST on knee JPS. In this regard, although the result of the second category shows a favorable trend towards ST on active JPS, the effect is not significant. Moreover, in the first category (ST vs. other physical exercise interventions), there is a trend in favor of proprioceptive exercise over JPS active. Interestingly, a significant effect in favor of ST over JPS passive is observed in the second category without heterogeneity. However, the combination of studies using active and passive JPS, although significant in favor of ST, the high heterogeneity, and the presence of only one study evaluating JPS passive[28] suggest that this result should be considered cautiously.

The TTDPM knee test was used in three studies.[26–28] This test consists of passively mobilizing a joint slowly, and then without sensory feedback, subjects must detect the onset of movement as early as possible.[4,49] The TTDPM has been shown to be reliable,[52,53] and in patients with KOA, the performance is inferior compared to unaffected knees of persons of the same age.[10] Furthermore, the greater the severity of KOA, the lower the proprioceptive accuracy.[10] In the studies included in this review, it is observed that ST (Isometric) with elastic bands[28] or ST based only on body weight resistance[27] produce a significant improvement in TTDPM compared to non-physically intervened controls. However, it is also found that various modalities of ST do not generate differences compared to non-intervened controls,[28] education,[26,27] or vibration training.[26] Similar to the JPS test, no clear trend in favor of the ST is observed for the TTDPM test. In the second category, the ST reaches a significant effect

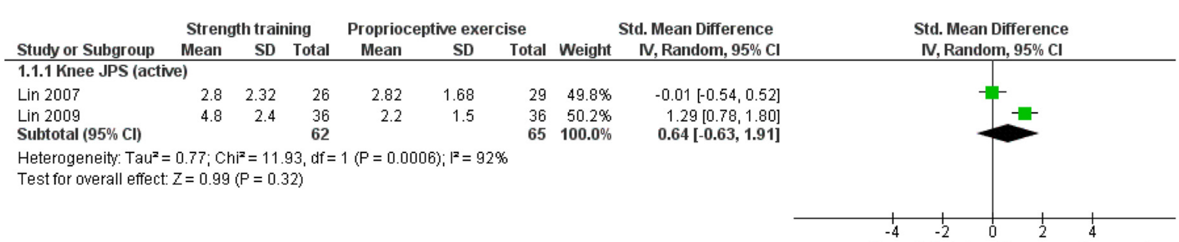

Fig. 3. Forest plot of strength training (ST) vs. other physical exercise interventions (proprioceptive exercise). *SD* Standard deviation; JPS Joint position sense; *CI* Confidence interval; Std Standardized.

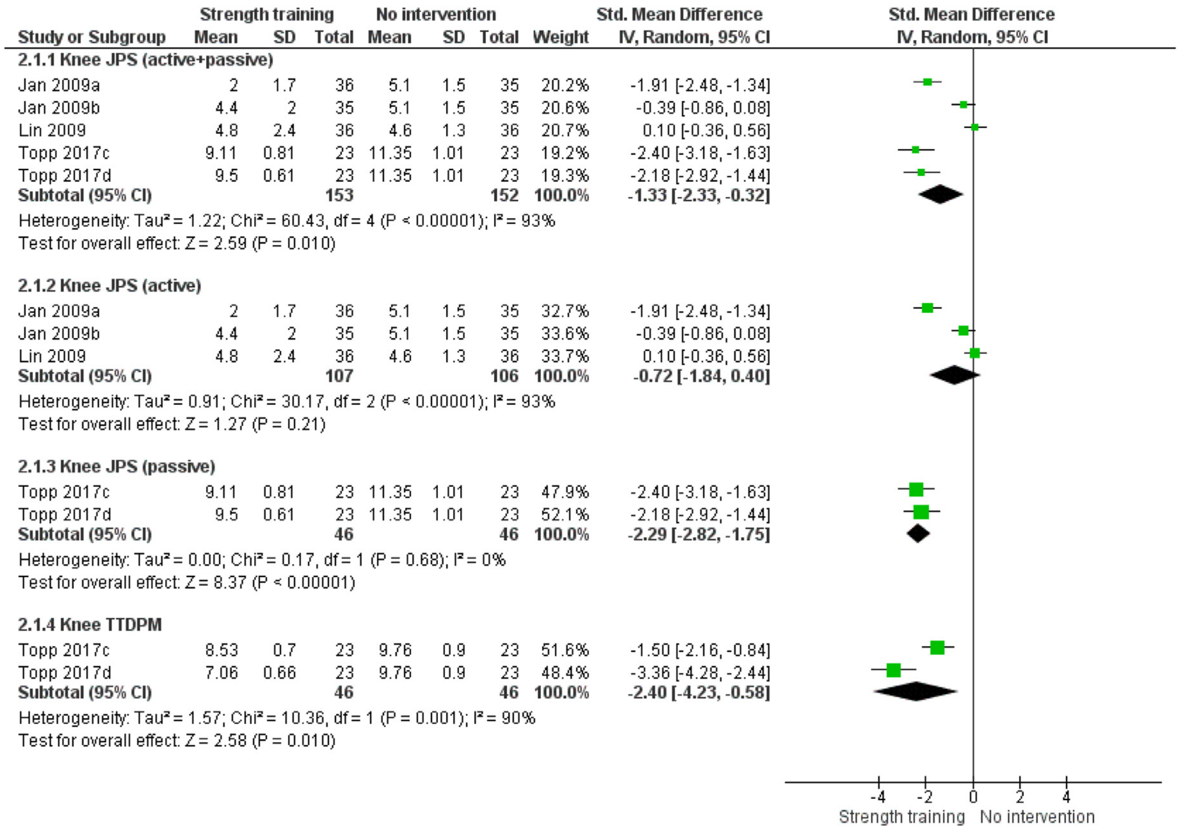

Fig. 4. Forest plot of strength training (ST) vs. no intervention. a ST-Weight-bearing exercise; b ST-Nonweight-bearing exercise; c ST-Dynamic; d ST-Isometric; *SD* Standard deviation; JPS Joint position sense; *CI* Confidence interval; Std Standardized; TTDPM Threshold to detect passive motion.

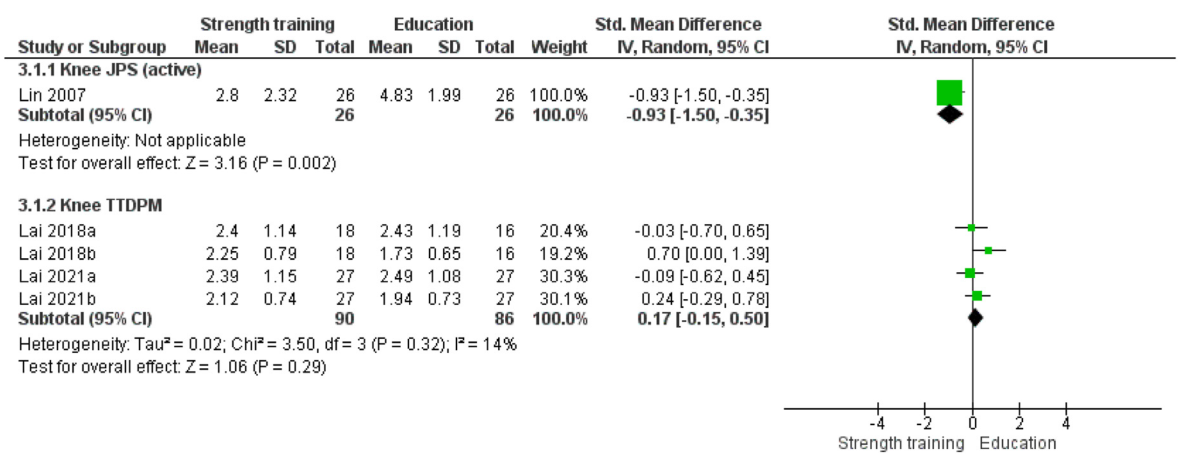

Fig. 5. Forest plot of strength training (ST) vs. other non-exercise-based interventions (education). a TTDPM for knee extension; b TTDPM for knee flexion; *SD* Standard deviation; JPS Joint position sense; *CI* Confidence interval; Std Standardized; TTDPM Threshold to detect passive motion.

with high heterogeneity. In the third category (ST vs. other non-exercise-based interventions), there is a slight trend in favor of education, although it is not significant.

The ST interventions were diverse. Lin et al. applied a CKCE protocol where supine patients placed one foot in the center of the pedal of a resistance device (Shuttle Mini Clinic), and the exercise consisted of flexion-extension of the knee with a 1-s rhythm for each movement.[43] Jan et al. considered two ST groups (WB and NWB).[25] For WB, subjects in seated posture fixed one foot in the center of the pedal of a resistance device (EN-Dynamic), and the exercise consisted of knee flexion-extension with a 90°/2s rate. For NWB, subjects were seated with their backs to a resistance device (EN-Tree) with the knee free. The device cable was attached to the distal end of the leg, and subjects performed extension (concentric) and flexion (eccentric) with a speed of 90°/2s. Lin et al. applied an NWB protocol similar to that described by Jan et al.[25,44] Topp and Pifer considered two ST groups (Dynamic and Isometric). Both groups were given a booklet with six ankle, knee, and hip exercises using TheraBand® elastic bands performed dynamically and isometrically.[28] Lai et al. applied a protocol based on isometric squats with knee flexion at 30° and 60°, maintaining a time between 30 and 70 s.[27] Finally, Lai et al.[26] formed two ST groups (ST and WBV), which carried out the same strengthening protocol described by Lai et al.,[27] with the difference that the WBV group performed the exercises on a vibrating platform. Then, because WBV was a mixed intervention

(ST associated with vibration), we could not consider it in the meta-analysis. This variability in strengthening protocols may also help explain the low effectiveness of ST on proprioceptive improvement in patients with KOA. Consequently, further efforts should be made to protocolize the interventions.

The average methodological quality is good according to the PEDro scale, representing, in general, an adequate internal validity of the RCTs.[40,41] The main methodological limitation is associated with the non-blinding of subjects and therapists; however, it should be taken into account that under the applied rehabilitation context of the studies, these criteria are often complex to implement. According to the RoB tool, the highest proportion of biases corresponds to performance, selection, and detection, which could also influence the results. These analyses should be considered by the community of researchers and health professionals for the proper interpretation of results and their transfer to clinical practice.

To our knowledge, this is the first literature review to evaluate ST's effects on proprioception in patients with KOA. However, previous systematic reviews have analyzed the effects of ST on various clinical outcomes in this population. For example, Li et al. report that ST improves gait speed,[31] and Turner et al. find that ST improves pain and physical function.[33] For their part, Kus et al. show that specific quadriceps strengthening improves muscle strength, pain, and physical function.[30] In addition, it is important to note that in a recent meta-analysis, Hua et al. states that high-intensity ST can have similar effects on pain, functionality, and quality of life, with comparable safety to that of low-intensity ST and habitual routines.[54] This interesting finding opens the possibility of exploring ST intensity's influence on proprioception.

From the clinical perspective, physical exercise is considered the core therapeutic management of KOA patients, being recommended in various clinical practice guidelines regardless of age and severity.[15,16,55] The present review focused specifically on muscle strengthening since it has also been recommended in its various modalities.[23,55] However, the guidelines do not express details regarding the characteristics, parameters, and dosage of this type of training, probably due to the heterogeneity of the studies, which is consistent with the intervention protocols used by the RCTs included in this review. It is also interesting to mention that although the guidelines consistently express the benefits of ST on pain, functional performance, and quality of life,[16,23] they do not include the analysis of other relevant outcomes in physical therapy, such as proprioception, despite the evidence of its affectation in patients with KOA.[4]

On the other hand, systematic reviews focused on physical exercise have considered greater clinical outcomes, including proprioception.[34,35] In this regard, Sheikhhoseini et al., in a 2023 meta-analysis that included 17 RCTs, analyzed the effect of exercise on knee proprioception in KOA.[35] The results indicated that patients who participated in different types of exercise achieved a lower knee repositioning error (mean difference: 1.14° [95% *CI*: 1.51, −0.77]) compared to control patients (no treatment or conventional treatments).[35] This is a promising result; however, it cannot be deduced whether ST alone favors this proprioception measure or another. For this reason, our results complement this study by discarding the potential influence of other interventions adjunctive to ST and by analyzing the groups differentiated according to the type of comparator.

Raizah et al. recently emphasized that KOA patients have impaired proprioception and limits of stability (reaction time, maximum excursion, and directional control) compared to asymptomatic individuals, so these factors should be considered in developing intervention strategies.[36] Proprioceptive and postural control abilities are demanded in proprioceptive training programs,[37,56] thus underlining the need for other therapeutic modalities to improve proprioception in patients with KOA who lack sufficient postural balance to perform proprioceptive exercises. In this sense, our results highlight that ST could be effective in inducing improvements in knee proprioception, so from this, we propose: (i) provide a new rationale for possible recommendations in favor of ST in clinical guidelines for the management of KOA; (ii) confirm the diversity of ST allowing, in turn, greater versatility in the planning of therapeutic interventions in KOA; and (iii) identify an alternative for proprioceptive training when this cannot be adequately performed or puts at risk the integrity of KOA patients, especially in those with severe symptomatology.

The strengths of this review lie in (i) focus on knee proprioception as a relevant clinical outcome associated with ST in KOA patients, (ii) conducting a quantitative analysis for the effectiveness of ST considering the comparator (other intervention, non-intervention, and education) and subgroups by proprioception test, (iii) the review was comprehensive covering five electronic databases, (iv) studies were critically analyzed for their methodological quality and RoB using valid scales. In turn, the main limitations are (i) due to the few studies found, an analysis grouped by type of ST that considers intensity, type of contraction, muscle groups, and load control, among others, was not performed. Considering these aspects can contribute to further discriminating the potential effects of ST, (ii) for the same reason, more robust statistical analyses were not performed to assess sensitivity and publication bias, (iii) other non-conventional sources of information (gray literature) that could have complemented the results were not considered, (iv) the quality of the evidence was not analyzed, so the Grading of Recommendations Assessment, Development and Evaluation (GRADE) criteria can be adopted for a more comprehensive report, (v) the few studies included in this meta-analysis imply that heterogeneity is not reliable. Determining heterogeneity is still debatable; however, more robust statistical methods are recommended for better estimation.[57]

As a future perspective, it is proposed that (i) more randomized studies with adequate bias control should be generated to analyze the effectiveness of ST on proprioception in KOA, (ii) studies can expand the proprioceptive assessment batteries, including in addition to JPS and TTDPM, active movement extent discrimination assessment (AMEDA) techniques[49] or other specific tests of kinesthesia and force sensation,[58] (iii) upcoming clinical studies can analyze the influence of ST intensity on proprioceptive accuracy, (iv) studies can also categorize interventions according to the clinical profile of patients and the severity of KOA, and (v) due to differences in the risk of KOA, researchers should analyze possible proprioceptive differences by gender associated with ST.

5. Conclusion

Although current evidence is insufficient to support that the effectiveness of ST on proprioception in KOA is superior to other therapeutic modalities, the present systematic review and meta-analysis show promising results when ST is compared to non-interventional controls. Thus, ST may provide a versatile clinical alternative for the proprioception approach in people with KOA. Nevertheless, due to the paucity of studies, statistical heterogeneity, and diversity of interventions, these results should be taken with caution. Future RCTs may address the limitations of this review to advance knowledge about proprioceptive responses to ST.

Submission statement

This manuscript is an original work that has not been previously published, nor will it be under consideration for publication by any other journal before a decision has been made by Sports Medicine and Health Science. If accepted, this manuscript will not be published elsewhere. All authors have read and agree with the manuscript content.

Protocol and registry

This systematic review with meta-analysis was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The study protocol was prospectively registered in the International Platform of Registered Systematic Review and Meta-analysis Protocols platform (inplasy.com) (registration number 202350102).

Authors' contributions

Francisco Guede-Rojas: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Alexis Benavides-Villanueva:** Data curation, Investigation, Validation, Writing – original draft, Writing – review & editing. **Sergio Salgado-González:** Data curation, Investigation, Validation, Writing – original draft, Writing – review & editing. **Cristhian Mendoza:** Writing – review & editing. **Gonzalo Arias-Álvarez:** Writing – review & editing. **Adolfo Soto-Martínez:** Formal analysis, Visualization. **Claudio Carvajal-Parodi:** Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2023.10.005.

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