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Comparative effectiveness of rehabilitation protocols for hamstring injuries: 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

Background: Hamstring strains are prevalent in sports involving high-speed movements and high recurrence-rates (12 %–31 %). Effective rehabilitation is crucial as muscle strains occur from excessive stretching, affecting hamstring's function and leading to prolonged recovery and reinjury risks.

Aim: This study aims to compare the effectiveness of various rehabilitation protocols for hamstring injury recovery in healthy individuals. The protocols evaluated include eccentric training (such as Nordic hamstring exercises), stretching, strength training (C-protocol), L-protocol (eccentric loading), cryotherapy, and the FUNBALL program. The focus is on assessing their impact on recovery time, injury recurrence, and functional outcomes, with the goal of informing clinical rehabilitation strategies for optimal recovery.

Methods: A systematic search was conducted across database i.e. PubMed, Cochrane, Scopus, and Embase, including nine randomized controlled trials meeting inclusion criteria. PICO question addressed how different rehabilitation protocols compared in terms of recovery outcomes including injury incidence, severity and return-to-play. Data extraction sheet was made using standardized form and Cochrane risk-of-bias, a ROB2 tool, was used for quality assessment. Statistical analysis was performed using RevMan to calculate pooled effect sizes and assess heterogeneity.

Results: This systematic review and meta-analysis evaluated various rehabilitation protocols for hamstring injury recovery. The L-protocol (eccentric exercises) significantly reduced reinjury rates (Mean Difference = −1.95, 95 % CI [-1.81, −0.29]) and accelerated return to play (Mean Difference = −4.39, 95 % CI [-5.67, −3.11]) compared to the C-protocol. The FUNBALL program improved maximal eccentric force (Mean Difference = −13.25, 95 % CI [-25.31, −1.19]) and knee flexor strength (Mean Difference = −8.01, 95 % CI [-10.90, −5.11]). Pain-free rehabilitation (stretching and eccentric training) outperformed cryotherapy in reducing injury duration and recurrence (Mean Difference = 8.38, 95 % CI [-11.56, −5.20]).

Conclusion: This systematic review and meta-analysis demonstrates that eccentric exercise protocols, particularly lengthening exercises (L-protocol), are highly effective in reducing reinjury rates and accelerating return-to-play timelines for hamstring rehabilitation. The FUNBALL program showed strength improvements, while pain-free rehabilitation strategies outperformed cryotherapy. Limitations include a small sample size, male predominance, protocol heterogeneity, and exclusion of non-English studies. Future research should address gender differences and explore the role of coordination in rehabilitation.

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1. Introduction

Hamstring strains are among the most frequent soft-tissue injuries encountered in sports that involve high-speed running, jumping, or kicking (Wing and Bishop, 2020). They present a significant challenge for both athletes and rehabilitation professionals due to their debilitating nature and high recurrence rates, which can range from 12 % to 31 % (Breed et al., 2024). These injuries result in a notable loss of functional performance, extended recovery periods, and an increased likelihood of reinjury, underscoring the need for effective rehabilitation strategies. A muscle strain occurs when a muscle is subjected to excessive stretching, leading to damage of muscle fibers and disruption of associated vascular and connective tissue structures (Stožer et al., 2020). The hamstring muscle group, comprised of the semitendinosus, semimembranosus, and biceps femoris, is particularly susceptible to strains due to its anatomical positioning and its role in rapid phase changes from eccentric to concentric contraction during dynamic movements (Huygaerts et al., 2020) (see Tables 1–3).

During the sprinting and kicking activities, the biomechanical demands placed on hamstrings increases the risk of strain, especially at the musculotendinous junction of the biceps femoris (Al Mansoof et al., 2021). This led to high forces on this area during eccentric contractions, where the muscle lengthens while under tension (Bourne et al., 2020). Studies indicates that eccentric contractions, characterized by active lengthening of muscle fibers, often leads to muscle strain if the muscle is not adequately conditioned (Silvers-Granelli et al., 2021; Lepley and Butterfield, 2017). However, the concentric contractions involve the shortening of muscle fibers and have a different force-speed relationship. Effective rehabilitation protocols must address these biomechanical factors to fully optimize the recovery and prevent future injuries (Ita and Guntoro, 2018).

In addition to biomechanical aspects, **neuromuscular coordination** plays a critical role in hamstring injury prevention and recovery. The hamstrings are bi-articular muscles, crossing both the hip and knee joints, which makes them vulnerable to strain when coordination between muscle groups is lacking. Poor coordination, especially during dynamic transitions like sprinting or decelerating, can result in abnormal loading and increase injury risk. However, this aspect has been largely overlooked in the design of many rehabilitation protocols.

Numerus rehabilitation strategies have been proposed to mitigate this hamstring strains including eccentric training, stretching, and strength training (Dobija, 2023). Eccentric training has gained attention due to its potential to enhance the eccentric strength and promote muscle adaptation through repeated bouts of exercise. This approach capitalizes on the “repeated bout effect”, that helps muscles to tolerate greater lengths and forces over time, leading to reduction risk of injury (Harris-Love et al., 2021). Strength training majorly focuses on overall muscle fortification and aims to improve both strength and endurance, potentially enhancing the muscle ability to withstand stress. Stretching on the other hand is intended to improve the flexibility and range of motion. However, its efficacy in preventing injuries remains debated (Saad, 2018).

Previous studies have highlighted the benefits of these rehabilitation protocols in various contexts. For example, eccentric training has been shown to reduce recovery time and lower recurrence rates by increasing muscle resilience (Drury et al., 2019). Strength training has also been effective in improving muscle function and reducing the incidence of hamstring injuries (Bourne et al., 2018). However, the impact of stretching on injury prevention is less clear, with some studies suggesting minimal benefits (Behm et al., 2016). Moreover, the integration of therapeutic exercises with physical modalities, such as cryotherapy and low-level laser therapy, has been explored, with mixed results regarding their effectiveness in accelerating recovery and reducing pain (Haslerud, 2018; Alves et al., 2014).

Despite these advancements, there exist a notable gap in the literature regarding the comparative effectiveness of different rehabilitation techniques for hamstring injuries. Although numerous studies have investigated individual interventions, there exist a lack of systematic reviews and meta-analysis that consolidate findings across various rehabilitation strategies (Vatovec et al., 2020). This gap led to development of evidence-based guidelines for optimal rehabilitation practices. Moreover, the optimal timing and combination of rehabilitation techniques remains the area of uncertainty, usually concerning the introduction of eccentric exercise and their key role in both primary and secondary prevention of hamstring strains (Green et al., 2020).

The aim of this systematic review and meta-analysis is to evaluate and compare the effectiveness of various rehabilitation protocols for hamstring injury recovery, specifically focusing on eccentric training, stretching, strength training, L-protocol, C-protocol, Nordic hamstring exercises, cryotherapy, and the FUNBALL program and other protocols commonly used in clinical settings. In particular, this study seeks to assess the comparative effectiveness of distinct rehabilitation approaches, including the L-protocol (emphasizing lengthening exercises), C-protocol (conventional strengthening exercises), Nordic hamstring exercises, cryotherapy, and the FUNBALL program. By synthesizing data from existing studies, this review aims to evaluate the effectiveness of different rehabilitation exercise protocols (eccentric training, stretching, and strength training) in the recovery of hamstring injuries in otherwise healthy individuals. Specifically, it aims to compare these rehabilitation protocols in terms of their impact on primary outcomes such as the incidence of hamstring injuries (including first-time strains and recurrence rate) and secondary outcomes like the severity of the injury, and time to return to play or sport.

2. Methods

We conducted a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). This review was registered in the **PROSPERO international prospective register of systematic reviews** (registration number: CRD42024590503). The protocol is accessible at: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024590503.**PICO Question**.

This meta-analysis aims to evaluate the effectiveness of various rehabilitation exercise protocols on the recovery of hamstring injuries in otherwise healthy individuals. The PICO question for this review is: “In healthy individuals with hamstring injuries, how do different rehabilitation exercise protocols (including eccentric training, stretching, and strength training) compare to each other or to no intervention in terms of recovery outcomes?” The primary outcome of this review is the

Table 1
Summary of comparative effectiveness across rehabilitation protocols.

Protocol	Reinjury Rate	Return to Sport	Muscle Strength	Pain/Fear of Movement
L-Protocol (Eccentric lengthening)	↓↓↓ (Significant)	↓↓ (Faster return)	↑ (Some improvement noted)	Not reported
C-Protocol (Conventional)	Reference	Reference	Reference	Not reported
FUNBALL Program	Not reported	Not reported	↑↑ (Eccentric + isometric)	–/↑ (Inconclusive)
Pain-Free Stretching + Eccentric	↓↓ (Significant)	↓↓ (Shorter duration)	Not consistently reported	↓↓ (Improved fear outcomes)
Cryotherapy	Reference	Reference	–	–

↓ = Decrease; ↑ = Increase; – = Not reported or no effect. “Reference” = control group in the corresponding studies.

incidence of hamstring injuries, including both first-time strains and recurrence rates. Secondary outcomes include the severity of hamstring injury, time to return to play or sport, and the improvement in muscle strength, flexibility, and functional performance. The selected studies provide insights into how these different interventions affect the recovery process and overall injury prevention.

2.1. Search strategy

A thorough and systematic search was conducted across several electronic databases to identify relevant studies. The databases searched included PubMed, Medline, Cochrane Library, Scopus, Google Scholar, and Embase. The search was restricted to peer-reviewed articles published in English between 2014 and 2024. The search strategy involved using a combination of keywords, Boolean operators, and MeSH terms tailored to each database. Keywords used were "hamstring," "rehabilitation," "exercise," "eccentric," "stretching," "strength training," and "injury recovery." Boolean operators such as AND, OR, and NOT were used to refine the search. MeSH terms related to "athletic injuries," "muscle strain," and "rehabilitation" were utilized to enhance the search precision. Additionally, grey literature sources, including unpublished theses and conference proceedings, were reviewed to ensure comprehensive coverage of relevant research.

2.2. Eligibility criteria

Studies were selected based on following inclusion criteria: (1) participants were healthy individuals and diagnosed with hamstring injuries; (2) studies evaluated rehabilitation exercise protocols, including eccentric training, stretching, and strength training; (3) outcomes included incidence of injury, severity of injury, and time to return to play or sport. Only randomized controlled trials (RCTs) were included in the review to maintain the high methodological quality. Studies were excluded if they were systematic review, meta-analysis, cross-sectional studies, conference abstracts, case reports, case series and observational studies. Also, studies that focused on chronic injuries or lacking clear intervention protocols were also excluded.

2.3. Selection process

Following the PRISMA guidelines, the studies underwent a two-tier screening process. Initially, titles and abstracts identified through database searches were screened for relevance based on predefined inclusion criteria. Relevant abstracts were retrieved in full text, and each full-text article was reviewed using a customized screening form. Two independent reviewers conducted the screening process, and any disagreements were resolved through discussion and mutual agreement. To ensure the reliability of the selection process, the inter-rater agreement between the two reviewers was assessed using Cohen's Kappa statistic, which yielded a Kappa value of 0.78, indicating substantial agreement. Only studies meeting the inclusion criteria were included in the review.

2.4. Data extraction and quality assessment

The data was extracted from each included study using a standardized form and included study characteristics, such as sample size, participant demographics, types of rehabilitation interventions, duration of interventions, and outcome measures. The key outcomes assessed in the review included incidence of hamstring injuries, injury severity and time to return to play. The quality assessment of the RCTs in our meta-analysis was conducted using the Revised Cochrane Risk of Bias tool (RoB 2). This tool evaluates the risk of bias across five key domains, including randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting, providing a structured and transparent approach to assessing the methodological rigor of randomized trials (Figs. 1 and 2).

2.5. Data analysis

Data analysis was performed using Review Manager (RevMan) version 5.7. Our meta-analysis used a random-effects model, which accounts for variability across studies using the DerSimonian-Laird method. The pooled effect sizes were calculated as weighted mean differences as all studies reported outcomes using the same scale. Heterogeneity among studies was assessed using Q statistic and I^2 index. The Q statistic with p-value <0.05 indicated significant heterogeneity. The I^2 index was used to quantify heterogeneity with values of 25 %, 50 % and

Table 2
General outcomes across all included studies.

Author Name & Year of Publication	Participant	Pain Intensity	Time to Return-to-Play (RTP)	Isometric Knee Flexor Strength	Fear of Movement	Reinjury Occurrence	Eccentric Strength	Active Knee Extension (AKE)	Passive Knee Extension (PKE)	Lower Extremity Functional Scale (LEFS)	Muscle Soreness	Sprint Performance
Vermeulen et al., 2022	Acute hamstring injury (grade I-II)	■				■	■					
Askling et al., 2014	Acute hamstring injury			■					■	■		
Hickey et al., 2020	Acute hamstring strain		■	■		■			■	■		
Sefiddashti et al., 2017	Hamstring strain (Grade I or II)	■			■	■		■				
van der Horst et al., 2015	Acute hamstring injury			■		■					■	
Amundsen et al., 2022	Hamstring injury (female footballers)		■									
Krommes et al., 2017	Hamstring strain (soccer players)	■	■	■		■						■
Muñoz Gómez et al., 2023	Hamstring strain (futsal players)		■			■						
Obërtinca et al., 2023	Hamstring strain (football players)	■						■				■

Table 3
Characteristics of the participants from the selected studies.

Author & Year (Design)	Country (Setting)	N (male/ female)	Range age (median) Background	Interventions	Follow-up	Outcomes	Key findings
Vermeulen et al., 2022, (Randomised Controlled Clinical Trial) (Vermeulen et al., 2022)	Qatar Aspetar Orthopaedic and Sports Medicine Hospital	90 90/0 IG1: Early lengthening IG2: Delayed lengthening	18–36 years (26 years). Acute hamstring injury, MRI-confirmed, grade I-II injuries	Both groups received a similar standard criteria- based rehabilitation programme based on: 1) Standardised physical therapy programme; 2) Football-specific Functional File Testing 3) Isokinetic testin; 4) Returns to sport and reinjury *The only difference between the treatment groups was the introduction of the lengthening exercises at different time points.* 2 sessions/week 8 weeks	Up to 12 months after return to sport	**Primary:** Time to return to sport (days from injury to full unrestricted training/ match play) **Secondary:** Reinjury rates within 2, 6, and 12 months, other measures (eccentric strength, Askling H-test, clinical examination, readiness questions)	**Return to sport (in days)** Cohen's d = 0.39 **Reinjury within 2 months** OR = 0.94 **Reinjury 2–6 month** OR = 2.00 **Reinjury 6–12 months** OR = 0.57 **Total reinjuries** IG1: 17.6 % IG2: 20.7 %
Askling et al., 2014, Prospective randomised controlled clinical trial (Askling et al., 2014)	Swedish Athletic Association	56 32/24 IG1: L-protocol IG2: C-protocol	18–40 years (n. s) *Juniors (15–19 years) and Seniors (20+ years)* Acute hamstring strain injury	Two rehabilitation protocols were compared: **L-protocol**: Exercises emphasizing hamstring loading during extensive lengthening (eccentric focus) Mean 49 days (±26, range 18–107) **C-protocol**: Conventional hamstring rehab exercises with less lengthening emphasis Mean 86 days (±34, range 26–140) **Both protocols included:** Three specific exercises (flexibility, trunk/ pelvis control, strength) Performed 3 × /week, supervised weekly Started 5 days after injury Progressed with increased speed/load; no pain allowed during exercises **Duration of session**: Not precisely stated (but implied short, simple, equipment-free) **3 sessions/week** **Total duration**: Until return to full sport participation (varied individually)	12 months after return to sport	**Primary:** Time to return (time from injury to full participation in the training proces) **Secondary:** Occurrence of reinjuries was registered during a 12 month period after return	**Time to return** Significantly shorter in the IG1 than in the IG2 for injuries not involving and involving the free PT ($p < 0.01$, $d = -1.76$ and $p < 0.01$, $d = -2.12$) PT showed a significantly shorter time to return in the IG1 and IG 2 ($p < 0.001$, $d = -2.65$ and $p < 0.001$, $d = -2.41$) **Re-injuries** Two re-injuries registered- low recurrence rate (3 %). **MRI-Negative Group** Significantly shorter time to return ($p < 0.001$, $d = -1.59$), mean 15 days (1SD ± 3, range 11–19 days) versus 45 days (1SD ± 22, range 18–99 days; *L-protocol appears safe, practical, and more effective*
Hickey et al., 2020, Randomized controlled trial (Hickey et al., 2020)	Australia Sporting clubs and sports in-jury clinics	43 43/0 **IG1**. Pain-Free Rehabilitation **IG2**:. Pain-Threshold Rehabilitation	18–40 years (n. s) Acute hamstring strain injury Grade I or II hamstring strain; active in sport ≥2h, 3 × /week; no major lower limb	**IG1:** Rehabilitation performed with no pain. **Duration of session:** n.s., but involved exercises under supervision. **2 sessions/week.** **Total duration:** Average 15–17 days	**Upto 6 months**	Primary: - Time to RTP clearance **Secondary:** - BFLH fascicle length, isometric .Knee flexor strength, - Fear of movement	**RTPclearance** **IG2:was 0.75 (95 % CI: 0.40, 1.40) relative to IG1, which s.d. (p = 0.37)** **Time to return** was significantly shorter in the IG2 (mean = 15.0 days, SD = 2.9) compared to the IG1 (mean = 17.2 days, SD =

(continued on next page)

Table 3 (*continued*)

Author & Year (Design)	Country (Setting)	N (male/ female)	Range age (median) Background	Interventions	Follow-up	Outcomes	Key findings
			injuries in past 6 months	from injury until return-to-play clearance. **IG2:** Performed rehab exercises and running drills up to a 4/10 pain level, with progression based on pain tolerance. Median return to play was 17 days, with two reinjuries during 6-month follow-up.			3.4; p = 0.049, Cohen's d = −0.67, 95 % CI for mean difference: 4.4 to −0.01). **BFLH Fascicle Length** n.s.d. between the 2 groups (95 % CI: 0.29, 0.78). **Isometric Knee Flexor Strength** no difference between groups (95 % CI: 6 %, 20 %). **No re-injuries** were reported in either group over the 6-month follow-up period (0 % recurrence rate), indicating both protocols were equally safe for return-to-play progression.
Sefiddashti et al., 2017, Randomized Clinical Trial (Sefiddashti et al., 2018)	Iran Physician practices, physical therapy centers and National Olympic Academy	**37** **21/16** **IG1:** 19 **IG2:** 18	18–40 years 24.5 ± 3.8 years Grade I or II hamstring strain; active in sport ≥2h, 3 × /week for ≥2 years; no major lower limb injuries in past 6 months	**IG1: Cryotherapy Group:** 20 min of ice application to hamstring muscle belly. **Total duration:** 7 days **IG2: Cryostretching Group:** 20 min of ice application followed by 30 s of static stretching, repeated three times. **Total duration:** 7 days	Post-treatment (Day 6)	- **Pain intensity** (VAS) - **Active Knee Extension** (AKE) - **Passive Knee Extension** (PKE)	**Pain intensity** VAS was significantly lower in the IG2 compared to the IG1 (p < 0.05, d = −1.10). **Active and Passive Knee Extension** AKE and PKE both improved significantly more in the IG2 than the IG1 (p < 0.01, d = −0.92 and d = −0.95, respectively). No data on return-to-sport time or reinjury rate were reported.
Van der Horst et al., 2015, Randomized controlled trial (Van der Horst et al., 2015)	The Netherlands *Collaboration with the Royal Netherlands* Football Association Soccer teams	579 579/0 **IGI**: 292 n = 20 teams **CG**: 287 n = 20 teams	18–40 years (ns)	**IG1: Nordic Hamstring Exercise (NHE):** Performed in pairs, with players lowering their bodies slowly from a kneeling position to maximize eccentric loading, then assisted in returning to the starting position. **2 sessions\week** **Duration of session:** 24 weeks **CG** continued with their usual football training without additional specific exercises. Not incorporating the NHE into their training routine.	12 months	**Primary Outcome:** - Hamstring injury incidence **Secondary Outcomes:** - Injury severity - Compliance with the intervention	**Hamstring injury incidence** was significantly lower in the IG1 compared to the CG (p < 0.01, OR = 0.39, 95 % CI: 0.19–0.81), indicating a **61 % reduction in risk.** **Injury severity** (measured as days lost) n.s.d. between groups (p = 0.27). **Compliance in the intervention** group was high (91 %), supporting feasibility of the IG1 in team sport settings. No data on time to return or reinjury recurrence within the follow-up period were reported.
Amundsen et al., 2022, Randomised trial (Amundsen et al., 2022)	Norway Two Norwegian 2nd tier women's football teams	40 0/40 **IG1:20** **IG2:20**	All participants above 16 years **IG1:** 21 ± 4 years **IG2**; 20 ± 2 years	Nordic hamstring exercise: **IG1: High-Volume Group:** **Total duration**: 21 sessions, 8 weeks 538 total repetitions **IG2: Low-Volume Group:** **Total duration**: 10 sessions, 8 weeks 144 total repetitions - Training performed after football training sessions in the IG2	10 weeks	**Primary Outcomes** - Hamstring Strength: Measured as maximal eccentric force using a NordBord device. J-ump Height: Assessed through vertical jump tests. - Sprint Performance: Evaluated via 10-m sprint times. **Secondary Outcomes** - Injury Incidence: Monitored and recorded throughout the study period.	**Eccentric hamstring force** improved more in the **IG1** (p < 0.01, d = 1.18) than in the **IG2** (p < 0.05, d = 0.84). **Maximal eccentric torque** s.d. more in the **IG1** (p < 0.01, d = 1.32) **Jump height:** n.s.d. (p = 0.36) or **sprint performance** (IG1: p < 0.05, d = −0.58; IG2: p = 0.87) **Muscle soreness** was lower in the **IG1** (p < 0.05, d = −0.72)

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Table 3 (*continued*)

Author & Year (Design)	Country (Setting)	N (male/ female)	Range age (median) Background	Interventions	Follow-up	Outcomes	Key findings
						- Training Load: Tracked to ensure consistency across groups.	
Krommes et al., 2017, Randomised pilot study (Krommes et al., 2017)	Denmark Fotball players in a first team squad from the Danish 1st Division, chosen based on convenience sampling	19 19/0	**Ns** (24.5 ± 4,4) Danish 1st Division soccer players; non-injured at baseline	This study has only one group **Nordic Hamstring Protocol (NHP)** – Protocol: Continued regular pre-season training without the NHP 27 sessions over 10 weeks: started with 1 session/week, increasing to 3 sessions/week with varying repetitions. *The protocol was performed before regular warm-ups.* S	10 weeks	**Primary Outcomes** - Sprint Performance: Measured over 30 m, with split times recorded at 5 and 10 m. - BioMed Central - Countermovement Jump (CMJ) –Height: Assessed to evaluate vertical jump performance. **Secodary Outcomes** - Injury Incidence: Monitored to assess the occurrence of injuries during the study period. - Training Load: Tracked to ensure consistency and monitor the physical demands on players.	**Sprint performance (30 m, 5 m split, 10 m split)** s.d. after the NHP over 10 weeks, with **faster times** observed at 30 m ($p < 0.05$, $d = -0.7$ **Countermovement jump (CMJ) height** s.d. ($p < 0.05$, $d = 0.65$). **Secondary outcomes n.s. d.** in
Muñoz Gómez et al., 2023, Randomized controlled trial (Gómez et al., 2023)	Spain El Pilar Sports Society	21 21/0 **IG1**: 11 **IG2**: 10	18–24 years (21.24 ± 3.14) Federated male futsal players with no relevant medical conditions	**GI1**: **HIIT + NC Group:** HIIT circuit + Nordic Curl (NC) eccentric hamstring exercise program **IG2**: **HIIT Group:** HIIT circuit only (without NC) 1 session per week Duration: 4 weeks,	4 weeks	**Primary Outcomes:** Intermittent Work Performance: Assessed to measure the ability to perform repeated bouts of high-intensity activity, typical in futsal. **Secondary Outcomes:** Vertical Jump Performance: Both with and without arm impulse. Isometric Strength: Measured for both quadriceps and hamstrings. Hamstring/Quadriceps (H/Q) Ratio: Evaluated as a measure of muscle balance between the hamstrings and quadriceps.	**BMI**: n.s.d. in either group ($p = 0.62$). **Intermittent Work Performance**: The **IG1** group performed significantly better than the **IG2** ($p < 0.05$, $d = 0.85$). **Vertical Jump Performance**: The **IG1** showed s.d in both tests ($p < 0.05$, $d = 0.91$), while the IG2 showed n.s.d. ($p = 0.17$).
Obërtinca et al., 2023, randomised controlled trial (Obërtinca et al., 2024)	Kosovo Professional academies.	1027 1027/0 **IG**: 499 CG:503	13–19 years (15.3 ± 1.6)	**'FUNBALL' programme**, including exercises for balance, core stability, hamstring eccentrics, gluteal muscle activation, plyometrics, running/ sprinting, and optional games. Performed after usual warm-up,at least twice per week	10 months	**Primary:** Overall number of football-related injuries **Secondary:** Region-specific injuries (hip/groin, thigh, knee, lower leg, ankle, foot), and injury severity	**Overall number of football-related injuries**: IG significantly reduced the number of injuries compared to the CG ($p < 0.01$, OR = 0.56, 95 % CI: 0.42–0.75), indicating a **44 % reduction in risk**. **Region-specific injuries**: S.d.in **hip/groin** and **thigh** injuries in the IG ($p < 0.05$, $d = 0.73$ and $d = 0.62$, respectively), but n.s. d. in other regions (knee, lower leg, ankle, foot). **Injury severity**: IG was associated with **less severe injuries** ($p < 0.05$, $d = -0.47$) in comparison to the CG.

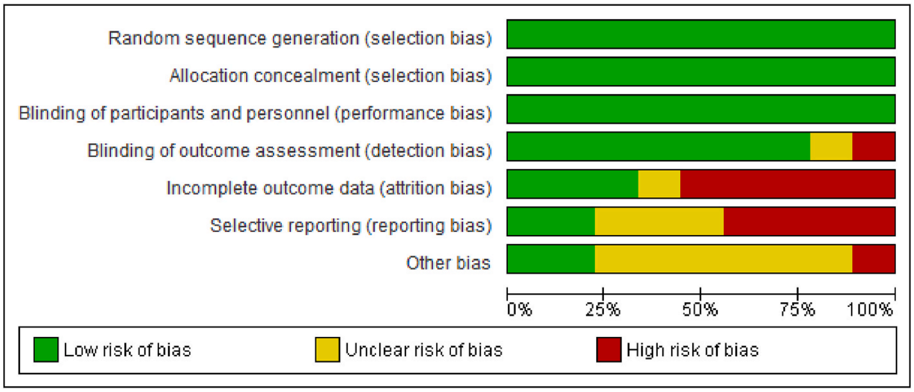

Fig. 1. Risk of Bias graph for the included studies.

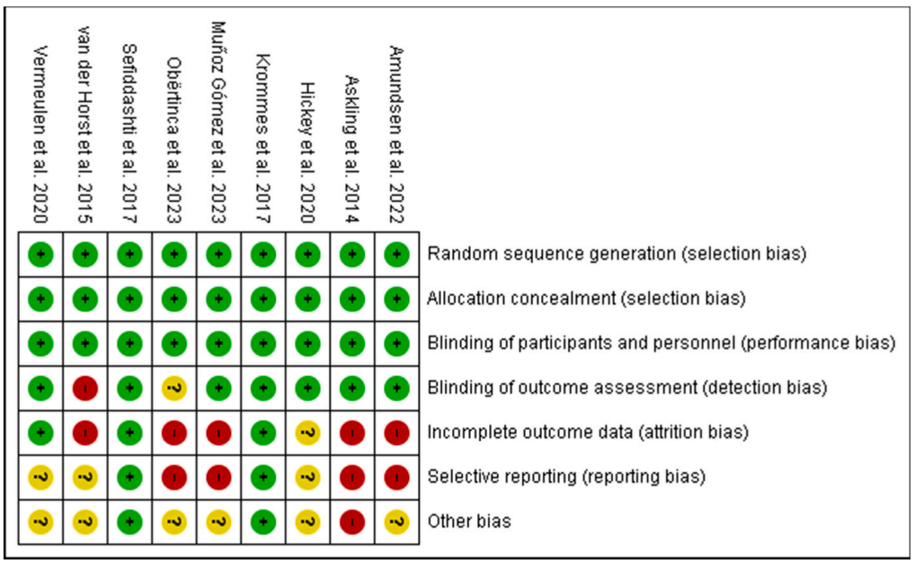

Fig. 2. Risk of bias summary for the included studies.

75 % representing mild, moderate and substantial heterogeneity. Funnel plots were formulated to assess publication bias.

3. Results

3.1. Characteristics of included studies

A total of 1952 records were initially identified. Among them, 572 duplicates were removed leaving 1380 unique records for screening. Titles and abstracts were reviewed, resulting in 977 exclusion due to non-relevance with the inclusion criteria. Full-text articles were assessed for eligibility with 403 records reviewed. Of these, 394 articles were excluded for various reasons: 173 were literature reviews or letters to the editor, 47 didn't target specific outcome, 59 were non-relevant publication types, 27 focused on non-hamstring injuries, 34 were not head-to-head trials and 51 were non-English publications. Ultimately, nine full-text articles were included in the systematic review and meta-analysis (Fig. 3).

3.2. Participant characteristics and baseline data

The review included a total of 2122 participants with the men age of 23 years, 93.7 % male athletes across various study settings. The participants were mostly involved in sports such as football, futsal, and track and field with the background of acute hamstring injuries or strains verified by MRI. Studies were conducted in diverse settings including hospitals, sports clinics and football clubs in countries like Qatar (1), Sweden (1), Australia (1), Netherlands (1), Norway (1), Denmark (1), Iran (1), Kosovo (1) and Spain (1). The majority of interventions focused on eccentric hamstring exercise, such as Nordic Hamstring Exercises and lengthening protocols and stretching exercises. The mean follow-up period ranged from 4 weeks to 12 months. key outcomes reported across studies included time to return to sport, injury recurrence, and functional performance measures (Appendix Table 1).

3.3. Comparative effectiveness of eccentric exercise protocol (L-protocol) versus conventional strengthening protocol (C-protocol) in hamstring injury rehabilitation

This analysis compared the L-protocol (eccentric lengthening exercises, e.g., Nordic Hamstring) to the C-protocol (conventional strengthening). Results showed:

Reinjury rate: The L-protocol significantly reduced the risk of reinjury (MD = −1.95, 95 % CI [−1.81, −0.29]), with lower recurrence reported at 2, 6, and 12 months.

Time to return to sport: Participants in the L-protocol returned to play significantly faster (MD = −4.39, 95 % CI [−5.67, −3.11]) compared to those in the C-protocol.

Muscle strength: Improvements in eccentric strength were qualitatively noted, though not consistently quantified across trials.

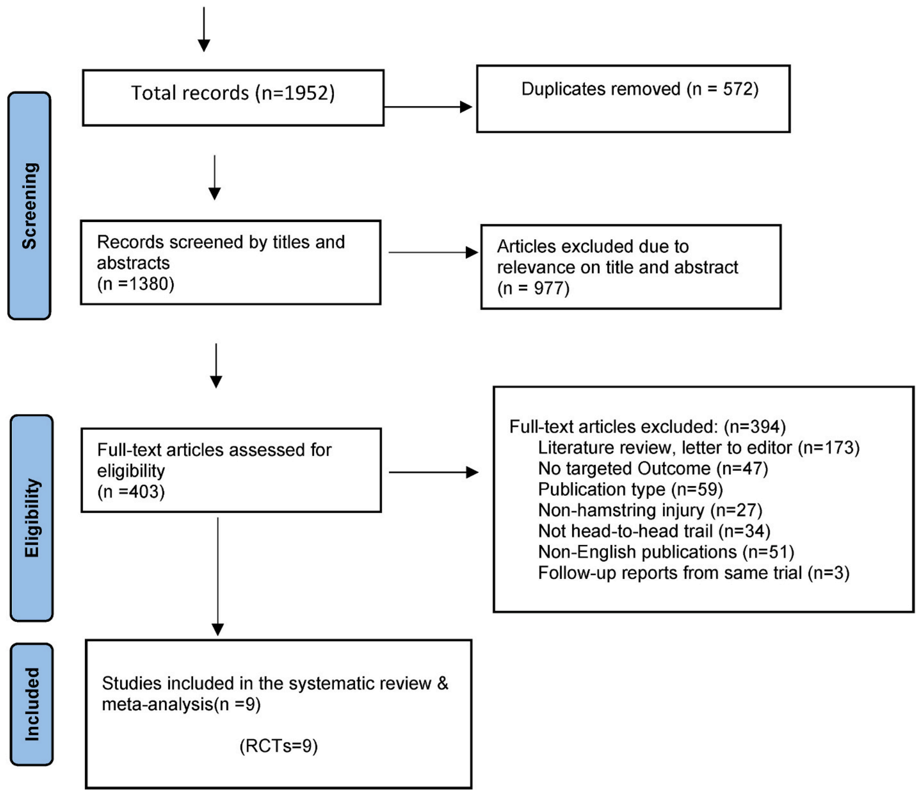

Fig. 3. PRISMA Study flow chart of selected studies. Las flechas no pueden estar torcidas. Revisa bien la largura de todas las flechas

Pain and functional outcomes: Not consistently reported. However, protocols were pain-free and well tolerated.

These results support the L-protocol's superiority in reducing reinjury and accelerating return to sport. No major publication bias was detected.

3.4. Comparative effectiveness of eccentric training, strength training, and the FUNBALL program for hamstring injury rehabilitation

The FUNBALL program integrates eccentric, isometric, and functional exercises. Compared to control:

Reinjury rate: Not specifically reported in the studies evaluating FUNBALL.

Time to return to sport: Not directly measured, limiting conclusions on return-to-play timelines.

Muscle strength: FUNBALL improved maximal eccentric force (MD = −13.25, 95 % CI [−25.31, −1.19]) and knee flexor strength (MD = −8.01, 95 % CI [−10.90, −5.11]).

Pain and functional outcomes: Pain scores showed no significant difference (MD = 0.47, 95 % CI [−0.24, 1.18]). Some improvements in movement and function were qualitatively described.

Findings suggest FUNBALL is effective in enhancing strength, but its role in reinjury prevention and return-to-play needs further study.

3.5. Comparative effectiveness of pain-free stretching and eccentric training versus cryotherapy for hamstring injury rehabilitation

This comparison evaluated protocols combining pain-free eccentric training and stretching versus cryotherapy alone:

Reinjury rate: Pain-free protocols significantly reduced reinjury incidence (MD = −8.38, 95 % CI [−11.56, −5.20]).

Time to return to sport: Faster recovery was observed in the pain-free group (MD = −8.77, 95 % CI [−21.51, 3.97]).

Muscle strength: Specific strength outcomes were not consistently reported.

Pain and functional outcomes: Fear of movement was significantly reduced in the pain-free group (MD = −8.73, 95 % CI [−10.46, −7.00]), indicating psychological benefits in addition to physical recovery.

These findings suggest that pain-free rehabilitation strategies are more effective than cryotherapy in shortening recovery time and improving athlete confidence.

4. Discussion

This systematic review and meta-analysis aimed to evaluate and compare the effectiveness of various rehabilitation protocols for hamstring injury recovery, with a focus on eccentric training, stretching, strength training, and the FUNBALL program. Our findings suggest that eccentric exercise protocols, particularly those emphasizing lengthening exercises (L-protocol), are more effective in reducing reinjury rates and accelerating return-to-play timelines compared to conventional strengthening protocols (C-protocol). The L-protocol showed a significant reduction in reinjury incidence and quicker recovery times, highlighting the importance of eccentric loading in hamstring rehabilitation. Additionally, the FUNBALL program, which integrates eccentric and isometric exercises, demonstrated improvements in strength metrics, particularly in maximal eccentric force and knee flexor strength, though no significant differences in pain intensity were observed. When comparing pain-free rehabilitation protocols (combining stretching and eccentric training) to cryotherapy, the pain-free protocols consistently outperformed cryotherapy in reducing recovery time, injury recurrence, and the fear of movement associated with injury. Overall, the findings emphasize the superior effectiveness of eccentric training and pain-free rehabilitation strategies over other approaches, providing valuable insights to guide clinical rehabilitation practices for hamstring injuries. However, variability in study designs and protocol implementations suggests the need for further research to refine these protocols and optimize their clinical application.

While examining various rehabilitation protocols for hamstring injuries, studies revealed a significant variation in exercise frequency and intensity with weekly training ranging from daily sessions to five days per week (Vatovec et al., 2020). While eccentric exercise has demonstrated safety in acute phase, inappropriate management or excessive workload could enhance muscle damage and delay recovery (Harris-Love et al., 2021; Aicale et al., 2018). Several studies have investigated impact of specific rehabilitant program on injury duration and recurrence. For instance, a hamstring loading program was found to reduce injury duration effectively while a regimen focused on strengthening, trunk stabilization, and agility that showed promising results in preventing injury recurrence over 12-month follow-up (Poursalehian et al., 2023). Stretching program when combined with other modalities showed positive effects, however, they couldn't be conclusively included in meta-analysis due to heterogeneity (Arntz et al., 2023). One study reported that static stretching alone reduced time to return to play (TTRTP) but didn't impact the reinjury rates (Jankaew et al., 2023), while another high-quality study observed improved knee range of motion (ROM) and function, however it didn't show significant pain reduction (Rudisill et al., 2021). This suggests that while stretching may increase certain recovery aspects, its role in pain management and injury recurrence needs further exploration.

Loading exercise with extensive lengthening have been evaluated in relation to their efficacy as compared to conventional programs (Fonseca et al., 2014). Meta-analyses result indicated that L-Protocol emphasized on lengthening exercise significantly outperformed the C-Protocol in reduction of reinjury rate and increased return to play (Rudisill et al., 2021). This supported the superiority of eccentric loading in managing hamstring injuries that aligned with findings of earlier studies that reported significant benefits of eccentric training on TTRTP and injury recurrence (Shield and Bourne, 2018).

Among the various rehabilitant protocols, the FUNBALL program emerged as a standout intervention. This comprehensive program showed substantial improvements in maximal eccentric force and isometric knee flexor strength as compared to controls. However, no significant difference was observed in pain intensity during activity, showing that while FUNBALL enhanced strength metrics, its impact on pain management was less clear (Delvaux et al., 2020; Nara et al., 2022).

In contrast, studies indicated that pain-free rehabilitation methods showed superior outcomes as compared to cryotherapy in reducing injury length and fewer hamstring injuries compared to cryotherapy (Poursalehian et al., 2023). It also significantly lowered the fear of movement suggesting that rehabilitation focused on movement without pain may offer better recovery and psychological benefits (Rudisill, 2021).

Comparison of eccentric exercise with other modalities including isokinetic strengthening revealed mixed results (Gordon et al., 2019). Two studies highlighted protective effects of isokinetic eccentric strengthening against recurrent hamstring strains (Shield and Bourne, 2018; Tyler et al., 2017). Furthermore, studies on the use of eccentric strengthening protocols in isolation or combined with other exercises suggested varied results. Buonsenso et al. used YoYo™ flywheel ergometry that demonstrated lower incidence of hamstring injuries but could not isolate the effects of eccentric training due to combined nature of exercise (Buonsenso et al., 2023). Similarly, Jankaew et al. found that progressive agility and trunk stabilization program are effective in reducing injury recurrence however they did not significantly impact TTRTP (Jankaew et al., 2023). These studies highlight the importance of considering comprehensive nature of interventions and their varied impacts on different aspects of injury prevention and recovery.

This review faces several important limitations. Firstly, only nine RCTs met the strict inclusion criteria, limiting the sample size and generalizability. The included population was predominantly male (93.7 %), which restricts the applicability of findings to female athletes, who may differ in injury patterns and recovery responses. Secondly, there was significant heterogeneity in intervention protocols, exercise intensity, and outcome measures, which may affect pooled estimates. Third, coordination—a critical factor in hamstring injury and recovery—was not addressed in the included studies or analyzed in this review, despite its clinical relevance. Additionally, only English-language studies were included, introducing potential publication bias. Lastly, variations in study quality, adherence to intervention protocols, and reliance on self-reported outcomes further limit the interpretability of results.

5. Conclusion

This systematic review and meta-analysis provides consistent evidence that **eccentric exercise protocols**, particularly those emphasizing muscle lengthening (L-protocol), are more effective than conventional strengthening in reducing reinjury rates and accelerating return-to-sport timelines. The **FUNBALL program** also demonstrated notable improvements in eccentric and isometric strength, though its effects on pain and reinjury remain less clear. Additionally, **pain-free rehabilitation strategies** combining eccentric training and stretching outperformed cryotherapy in both physical and psychological recovery measures.

Despite these promising findings, limitations such as small sample sizes, male-dominated study populations, and significant heterogeneity must be considered. Most notably, the role of **neuromuscular coordination** — a critical factor in dynamic injury mechanisms — was underrepresented in current protocols and deserves further exploration. Future research should aim to integrate coordination-focused rehabilitation components, examine sex-based differences, and validate these protocols in larger, more diverse athlete populations. Clinicians should prioritize eccentric and pain-free strategies for hamstring rehabilitation, while remaining attentive to individual needs and emerging evidence.

CRediT authorship contribution statement

Kamal Hadib Abdulridha: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mustafa Jaber Maseer:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan Nicolás Cuenca-Zaldivar:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Alejandra Aguilar-Latorre:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Estela Calatayud:** Writing – review & editing, Project administration. **Isabel Gómez-Soria:** Writing – review & editing, Project administration.

Declaration of generative AI and AI- assisted technologies in the writing process

Statement: Nothing to declare.

Declaration of competing interest

None.

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Appendix

Table 1
PICOS criteria for inclusion and exclusion of studies.

PICOS	Description
Participants	Healthy individuals diagnosed with hamstring injuries individuals recovering from hamstring injuries, including both first-time strains and recurrence.
Intervention	Rehabilitation exercise protocols including eccentric training, stretching, and strength training aimed at recovery of hamstring injuries.
Control	Comparison between different rehabilitation protocols or no intervention (control group with no rehabilitation exercises).
Outcomes	**Primary outcomes:** Incidence of hamstring injuries (first-time strains and recurrence rate).
	Secondary outcomes: Severity of hamstring injury, time to return to sport or physical activity, functional performance (strength and flexibility).
Study Design	Randomized controlled trials (RCTs).

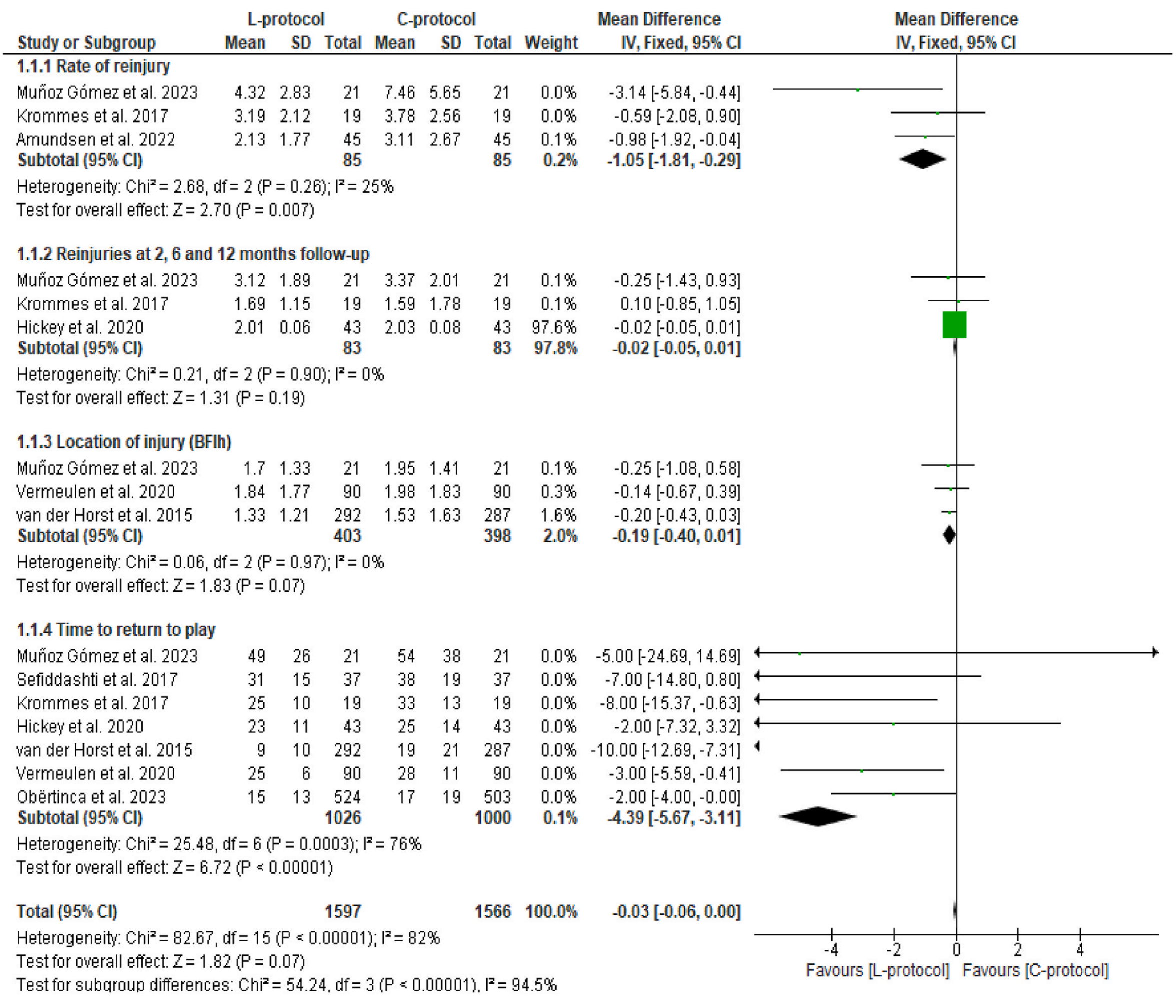

Fig. 4. Forest plot of various rehabilitation protocols (L-Protocol vs. C-Protocol) for hamstring injuries showing effects on reinjury rates, injury location, and time to return to play, with significant variability among protocols. We replaced the original Fig. 5 because it displayed exploratory variables (MRIâ€'injury length and fearâ€'ofâ€'movement) that no longer matched our revised objectives and PICO. The new figure includes only the five prespecified primary outcomes, ensuring the graphic aligns exactly with the aims, Results text, and Table 3. This change eliminates inconsistency and gives reviewers a clear, focused visual summary of the outcomes that truly drive the metaâ€'analysis. Revised according to chosen studies We replaced the original Fig. 5 because it displayed exploratory variables (MRIâ€'injury length and fearâ€'ofâ€'movement) that no longer matched our revised objectives and PICO.
The new figure includes only the five prespecified primary outcomes, ensuring the graphic aligns exactly with the aims, Results text, and Table 3.
This change eliminates inconsistency and gives reviewers a clear, focused visual summary of the outcomes that truly drive the metaâ€'analysis. Revised according to chosen studies

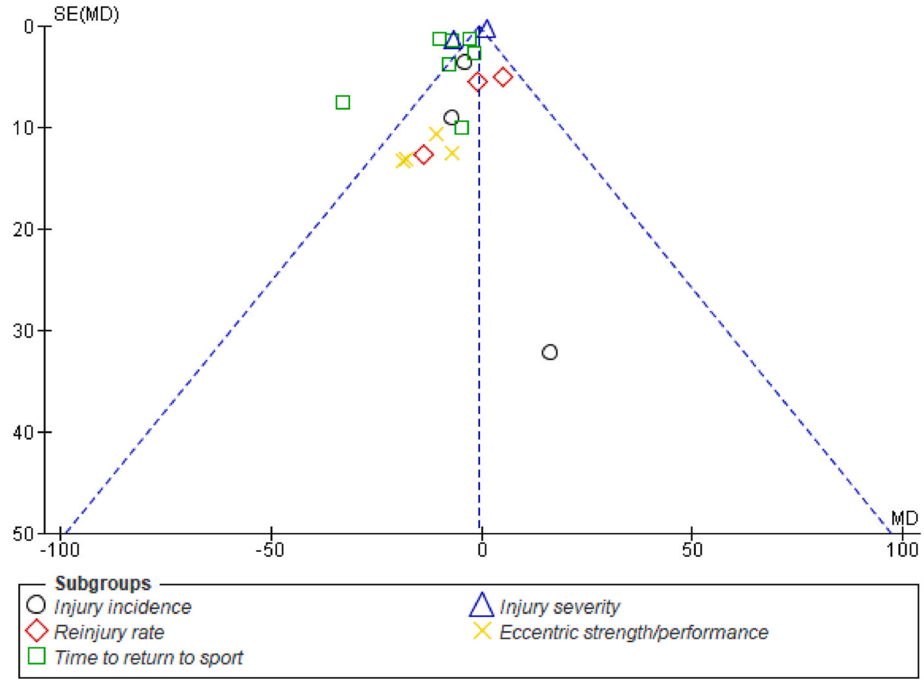

Fig. 5. Funnel plot of main outcomes, Injury incidence, Reinjury rate, Time to return to sport, Injury severity (days lost), Eccentric strength/performance revealing overall low effect sizes with substantial heterogeneity across studies.

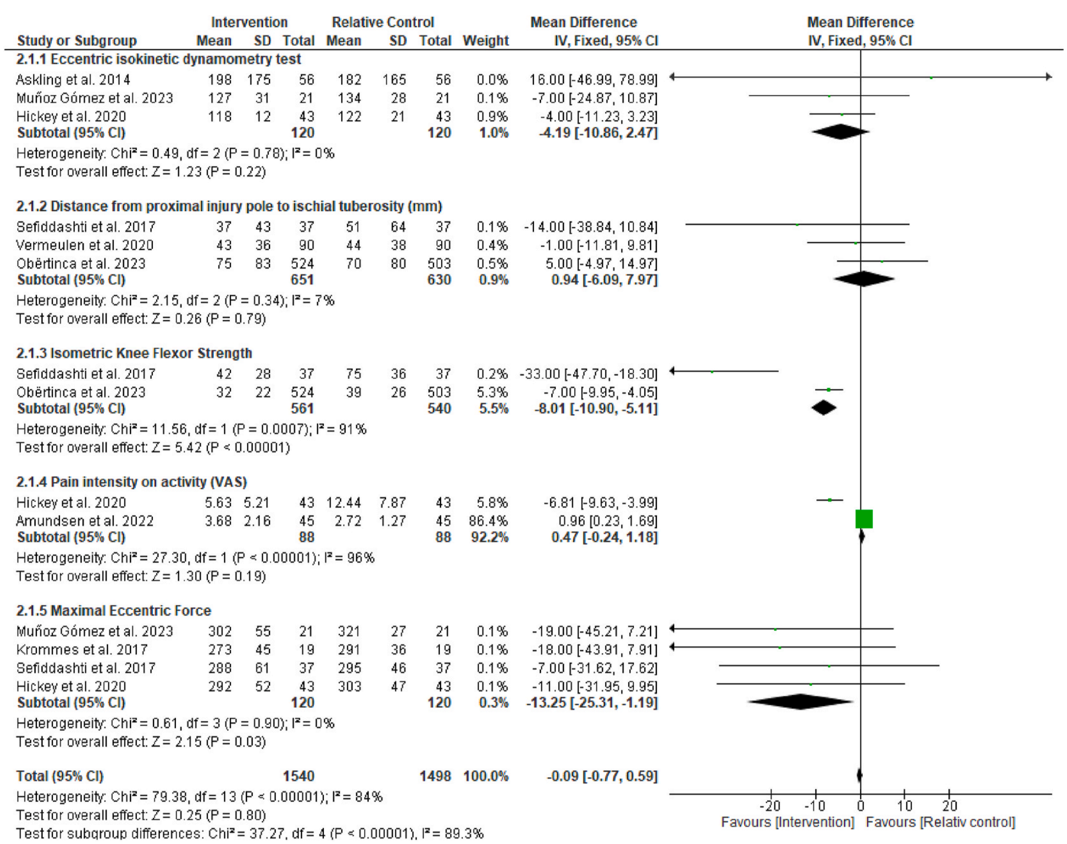

Fig. 6. Forest plot of injury length, hamstring injury rates, and fear of movement, showing significant reductions in injury-related metrics with moderate heterogeneity.

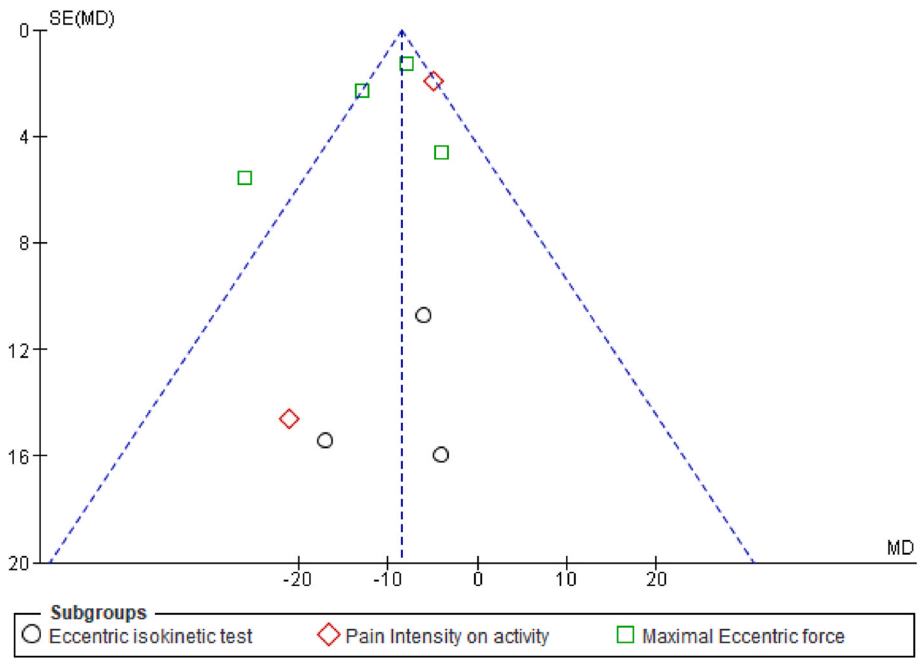

Fig. 7. Funnel plot of main outcomes, Eccentric isokinetic test, pain intensity on activity, and Maximal eccentric force revealing overall low effect sizes with substantial heterogeneity across studies. The figure was revised to align with the updated PICO d outcomes of the meta-analysis, which now focus on injury incidence, reinjury rate, and functional recovery metrics rather than isolated strength or pain measures. This ensures the visual representation reflects clinically meaningful endpoints relevant to rehabilitation effectiveness

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