LITERATURE REVIEW

A SYSTEMATIC REVIEW OF THE EFFECTIVENESS OF ECCENTRIC STRENGTH TRAINING IN THE PREVENTION OF HAMSTRING MUSCLE STRAINS IN OTHERWISE HEALTHY INDIVIDUALS

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ABSTRACT

Background. Hamstring strains are the most common soft-tissue injury observed in recreational and athletic activities, yet no consensus exists regarding appropriate primary and secondary strategies to prevent these strains. Eccentric exercise has been reported to reduce the incidence of hamstring strains but its role has not been clearly defined.

Objective. The objective of this systematic review was to determine the effectiveness of eccentric exercise in preventing hamstring strains.

Data Sources. Online databases, including MEDLINE, PubMed, CINAHL, PEDro, SPORTDiscus, EMBASE, Cochrane Database of Systematic Reviews, Cochrane Central Register of Controlled Trials, and Web of Science were searched for relevant articles. Each database was searched from the earliest date to July 2007.

Study Selection. Selection criteria included diagnosis of hamstring strain, otherwise healthy individuals, and at least one group receiving an eccentric exercise intervention. Seven articles {three randomized controlled trials (RCTs) and four cohort studies} met the inclusion criteria.

Data Extraction. Data were extracted using a customized form. Methodological rigor of included studies was assessed using the PEDro scale and Oxford Centre for Evidence-based Medicine Levels of Evidence.

Data Synthesis. Studies were grouped by eccentric exercise intervention protocol: hamstring lowers, isokinetic strengthening, and other strengthening. A best-evidence synthesis of pooled data was qualitatively summarized.

Conclusions. Findings suggest that eccentric training is effective in primary and secondary prevention of hamstring strains. Study heterogeneity and poor methodological rigor limit the ability to provide clinical recommendations. Further RCTs are needed to support the use of eccentric training protocols in the prevention of hamstring strains.

Key Words: eccentric; hamstring strain; prevention

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INTRODUCTION

Hamstring strains are the most prevalent soft-tissue injury in recreational and sports activities that involve sprinting, jumping, and kicking.[1-3] Strains to this muscle group remain a primary concern for rehabilitation professionals as they result in a debilitating injury characterized by acute loss of functional performance, prolonged periods of recovery, and subsequent increased incidence of recurrence.[4] A recent review indicated hamstring injuries have the highest recurrence rates in sports, ranging from 12-31%.[4]

A muscle strain is defined as an excessive stretch, which leads to muscle fiber damage and disrupts the integrity of related vascular and connective tissue structures.[5,6] A muscle is commonly strained or torn during rapid acceleration or deceleration movements. A strain can be classified into grades from mild to severe to reflect injury severity. A mild (first degree) strain involves damage to a small number of muscle fibers and localized pain without loss of strength. A clear loss of strength coupled with pain reproduced on resistance is indicative of a moderate (second degree) strain. A severe (third degree) strain corresponds with complete rupture of the muscle and loss of strength and function.[7]

The hamstring muscle group is at increased risk for strains due to its anatomical configuration. The hamstrings are composed of three muscles - semitendinosus, semimembranosus, and biceps femoris - forming a triad in the posterior compartment of the thigh. The musculotendinous junction of the biceps femoris is the most common site of strain.[4,8] A rapid phase change of muscle contraction from eccentric to concentric has been suggested as the underlying mechanism for hamstring strains.[5] Eccentric contractions are characterized by active lengthening of muscle fibers, in which the force of contraction increases as the speed of contraction increases. Conversely, concentric contractions involve the shortening of muscle fibers and an inverse relationship between the force and speed of contraction. For example, during gait, the bi-articular arrangement of the hamstring muscles across the hip and knee allow the hamstrings to work eccentrically during late swing to decelerate the lower leg and control knee extension. A concentric contraction follows to initiate hip extension prior to heel strike. Hamstrings are maximally loaded and lengthened during this rapid phase change.[3]

In addition to clinical investigations into the biomechanical predisposition of hamstring strains, retrospective studies have focused on the identification of other etiologic factors which may predict the occurrence of hamstring strains.[4] Intrinsic risk factors for hamstring muscle strains include older age,[9-11] ethnicity,[12] previous injury,[9,12,13] lumbopelvic instability,[14] decreased hamstring flexibility,[10,15] and reduced strength.[1,15,16] Other potential intrinsic risk factors include sex,[17,18] decreased angle of peak torque,[19] and agonist-antagonist muscle imbalance.[20] Extrinsic factors such as fatigue,[21] lack of warm-up,[22] and inadequate preseason training[23] have also been associated with increased risk of hamstring strains. However, research suggests the most significant predictor of hamstring injury is a history of previous strain to the muscle.[12,24] The direct influence of risk factors remains inconclusive as investigations do not provide strong evidence to support their individual or collective effect on development of hamstring strains.

Despite the high prevalence and subsequent high incidence of recurrent hamstring strains, there is a lack of consensus with respect to appropriate primary and secondary prevention strategies. Primary prevention is defined as an intervention that prevents the occurrence of an initial injury, while secondary prevention is an intervention that prevents the recurrence of subsequent or further injury.[25] Identification of valid and reliable prevention strategies is essential to reduce the incidence of injury and direct current rehabilitation efforts.[6]

The protective effect of muscle strengthening on the occurrence of hamstring strains has been reported in the literature;[3,6] however, the preventative role of eccentric exercise has not been clearly defined. Muscle adaptation is mode specific, with eccentric training increasing eccentric strength.[26] Hamstring strains commonly occur during the eccentric phase of a muscle contraction,[5,27-30] therefore, overloading these muscles with eccentric training could potentially serve to prevent hamstring strains.

Subsequent bouts of eccentric muscle overloading have demonstrated a cumulative protective effect against further exercise-induced damage.[31] This "repeated bout effect" causes a shift in the length-tension curve, such that peak tension is generated at longer muscle lengths.[27,32-34] Research suggests that sarcomeres are added in series following eccentric loading.[27] Given the length-dependent nature of muscle damage in hamstring strains near end range, this structural adaptation optimizes the angle of peak torque to reduce the risk for potential injury.[3,6]

Eccentric exercise has the potential to result in delayed onset muscle soreness (DOMS),[35] which needs to be differentiated from muscle strain. Delayed onset muscle soreness is clinically characterized by muscle soreness, stiffness, inflammation, and loss of function peaking one to three days after unaccustomed exercise.[36] With DOMS, repeated bouts of exercise result in progressively less tissue damage and soreness.[37] In comparison, muscle strain is characterized by immediate acute pain, and exercise too soon after strain can lead to a more disabling injury.[7]

A preliminary search of the literature found that no systematic reviews currently exist investigating the benefit of eccentric training on the primary and secondary prevention of hamstring strains. Thus, the objective of this systematic review is to evaluate the existing evidence to determine effectiveness of eccentric exercise on primary and secondary prevention of hamstring muscle strains.

Movement of the ankle may result in a reduction in foot volume secondary to a muscle pumping action moving fluid out of the area.[26] Results of this study may help health care practitioners prescribe a more appropriate exercise mode when addressing the cardiovascular health of the active geriatric individuals.

METHODS

The Question

This systematic review was undertaken to determine if eccentric strength training was effective in the prevention of hamstring strains in otherwise healthy individuals. Studies included were those in which the subjects underwent an eccentric strength training intervention for the primary or secondary prevention of hamstring strains. When appropriate, comparisons were made between groups receiving eccentric strength training and groups receiving alternative interventions. The primary outcome measure of interest was incidence of hamstring strains, which included first-time muscle strains and strain recurrences. The secondary outcome measure was the severity of hamstring strain.

Search Strategy

Electronic databases searched for the purpose of this systematic review included: MEDLINE, PubMed, EMBASE, CINAHL, the Cochrane Central Register of Controlled Trials, the Cochrane Database of Systematic Reviews, SPORTDiscus, PEDro, and Web of Science. In addition, reference lists of all studies included in the review, additional articles published by leading authors in this area of research, and other relevant academic journals were hand searched. Grey literature resources were also hand searched, including: CIRRIE Database of International Rehabilitation Research, NARIC's REHABDATA Literature Databases, and Critically Appraised Topics. Grey literature materials are not formally published in regularly accessible, peer-reviewed journals or indexed in major electronic databases. Common formats of grey literature include: works in progress, unpublished theses, statistical reports, and conference proceedings. All databases were searched from the earliest date to March 2007 to ensure the comprehensive identification of all relevant publications. The search was limited to articles in English or French.

The search began with the identification of MeSH terms referring to hamstring strains. These MeSH terms were "exploded" in all databases in order to tailor the search terms to each specific database. Databases were searched using MeSH terms and keywords such as: "athletic injuries," "sprains and strains," "leg injuries," AND "hamstring," "semimembranosus," "semitendinosus," 'biceps femoris," AND "eccentric."

Study Selection

A list of citations was accrued from the database searches and assessed for eligibility by two independent reviewers. Citations must have included: 1) "strain" or "injury" AND 2) one of "hamstring," "eccentric," "prevention," "exercise," or "training," or some variation thereof. Reviewers selected citations they deemed eligible, and abstracts were obtained for any citations selected by at least one reviewer. Abstracts were evaluated for eligibility by two independent reviewers based on predetermined selection criteria. Study selection criteria included: diagnosis of hamstring strain (any grade), otherwise healthy individuals, and at least one group receiving eccentric exercise intervention. Full text articles were retrieved for all abstracts deemed eligible by at least one reviewer. When an abstract was not available, the full text article was retrieved. Finally, full text articles were evaluated by two independent reviewers using a customized article screening form. Reviewers discussed their decisions and reached a consensus regarding whether or not to include each full text article. If two reviewers were unable to reach a consensus, a third reviewer evaluated the full text article and made a final tie-break decision.

Search Results

Results of the overall search strategy are summarized in Figure 1. An initial 354 primary articles were identified for potential inclusion. Of these articles, 259 were excluded after citation screening, leaving 95 citations. For the remaining 95 citations, abstracts were obtained and screened for eligibility. Seventy-four abstracts were excluded in the second phase of screening, leaving 21 eligible full text articles. Some reasons for abstract exclusion included: lack of eccentric training intervention, no report of hamstring strains, and limitation in study design (i.e., a review article). Of the 21 full text articles included in the final phase of screening, a further 16 were excluded. Reasons for exclusion included: lack of specified eccentric exercise intervention (n = 12) and lack of reported hamstring strain incidence or severity (n = 4). Studies were not excluded on the basis of study design. In total, five full text articles were included after the systematic review of the literature. Following hand searching of relevant journals and recent grey literature searches, two additional articles were subjected to the same process and deemed eligible for inclusion, for a total of seven included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs). The RCTs are prospective trials in which eligible participants are randomly assigned to one or more treatment groups or a control group. The remaining four articles were cohort studies which followed groups of individuals and examined the relationship between an intervention (eccentric strengthening) and the incidence of the outcome of interest (hamstring strain) in study participants.

Table 1. *PEDro scores and inter-rater reliability*

Article	Rater	2	3	4	5	6	7	8	9	10	11	Consensus Score	Kappa Value
Arnason et al.[28]	Rater 1	n	n	n	n	n	n	n	n	y	n*	2	.615
	Rater 2	n	n	n	n	n	n	n	n	y	y		
Askling et al.[30]	Rater 1	y	n	y	n	n	n	y	y	y	y	6	.800
	Rater 2	y	n	y	n	n	n	y	y	y	n*		
Brooks et al.[2]	Rater 1	n	n	y	n	n	n	y	y	y	y	5	.800
	Rater 2	n	n	y	n	n	n	y	y	n*	y		
Croisier et al.[1]	Rater 1	n	n	n	n	n	n	y	n	n	y	2	1.000
	Rater 2	n	n	n	n	n	n	y	n	n	y		
Gabbe et al.[29]	Rater 1	y	y	y	n	n	y	n	y	y	y	7	1.000
	Rater 2	y	y	y	n	n	y	n	y	y	y		
Queiros Da Silva et al.[40]	Rater 1	n	n	n	n	n	n	y	y	n	n	2	1.000
	Rater 2	n	n	n	n	n	n	y	y	n	n		
Sherry and Best.[14]	Rater 1	y	y	y	n	n	n	y	y	y	y	7	1.000
	Rater 2	y	y	y	n	n	n	y	y	y	y		

* = consensus reached by changing this score

Data Extraction and Synthesis

Using a customized data extraction form, two independent reviewers extracted data regarding subject characteristics, type of eccentric intervention and controls, study design, and results. Discrepancies were resolved by discussion between the two reviewers. If additional study information was required prior to determining eligibility, the primary author was contacted via e-mail. Pertinent data were qualitatively summarized in both text and tabular forms.

Quality Assessment

The Physiotherapy Evidence Database (PEDro) Scale was used by two independent reviewers to assess the methodological quality of each included full text article.[38] A third reviewer acted as a tie-breaker when necessary. The PEDro Scale is scored out of ten with a single point awarded when a specified criterion is met.[38] Criteria evaluated include: random allocation, concealed allocation, baseline similarity, blinding, reported outcome measures, intention to treat analysis, statistical comparisons, and measures of variability.[38] Table 1 summarizes the quality assessment scores of included full text articles. Of the seven included full text articles, three were randomized controlled trials (RCTs) with PEDro scores ranging from 6 to 7. Scores greater than 6 are considered strong evidence.[38] The remaining four articles were cohort studies and achieved PEDro scores ranging from 2 to 5. The average kappa value for inter-rater reliability of PEDro scores was 0.89 (range 0.62 to 1.00), indicating strong agreement between reviewers.

Methodological rigor of included articles was also evaluated using Oxford Centre for Evidence-based Medicine Levels of Evidence.[39] Levels of evidence categorizations ranged from 2b to 4, where 2b represented individual cohort studies or low quality RCTs and 4 represented case-series, poor quality cohort, and case-control studies.[39] Results of this analysis are summarized in Table 2.

RESULTS

A summary of included studies is displayed in Table 3. A concise summary of results is available in Table 4. A lack of similar methodologies negated a quantitative meta-analysis of results. The seven included studies were grouped by eccentric intervention type: "hamstring lowers" protocol (n = 3), isokinetic strengthening protocol (n = 2), and other strengthening protocols (n = 2). A best-evidence synthesis of pooled data is qualitatively described below.

Table 2. *Oxford centre for evidence-based medicine levels of evidence*

Article	Level of Evidence
Arnason et al[28]	4
Askling et al[30]	2b
Brooks et al[2]	4
Croisier et al[1]	4
Gabbe et al[29]	2b
Queiros Da Silva et al[40]	4
Sherry and Best[14]	2b

Effect of Eccentric Exercise - "Hamstring Lowers" Protocol

Three studies (two cohorts, one RCT) examined the effects of eccentric exercise, using a "hamstring lowers" protocol, on the prevention of hamstring muscle strain injuries and their severity.[2,28,29] The "hamstring lowers" protocol involved participants kneeling on the floor with upright trunk perpendicular to floor *(Figure 2)*. Feet were supported under a low bench or held by a partner. Arms were kept folded across chest and body was lowered forward. Participants lowered their body until they were no longer able to hold the position, at which point the participant was allowed to relax and use their arms to catch themselves as they reached the floor.[26,27] This protocol was employed in conjunction with other conservative treatments including stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine.

Arnason et al[9] examined the effect of eccentric "hamstring lowers" and contract-relax proprioceptive neuromuscular facilitation (PNF) stretching on incidence (i.e., number of hamstring strains) and severity (i.e., duration of absence from play) of hamstring strains in male soccer players from top Icelandic and Norwegian soccer leagues during the 1999 to 2002 soccer seasons. Participants completed one of three interventions, which included combinations of warm-up PNF stretching, PNF flexibility exercises, and eccentric strength training. Results from the intervention teams were compared to results from baseline seasons (1999 and 2000) and to control teams. Control teams did not partake in the intervention programs during the 2001 and 2002 soccer seasons. Incidence of hamstring strains in the "hamstring lowers" group was less compared to baseline seasons among intervention teams. Differences in injury severity and re-injury rates, however, were not statistically significant between baseline seasons amongst intervention teams. When compared to control teams (0.62 $\pm$ 0.05 hamstring strains per 1000 player hours), the overall incidence of hamstring strains was 65% lower in the "hamstring lowers" group (0.22 $\pm$ 0.6 hamstring strains per 1000 player hours). However, the severity of injury and re-injury rates were not significantly different between "hamstring lowers" and control groups.

Brooks et al[2] examined the effectiveness of "hamstring lowers" and hamstring stretching on

Table 3. *Summary of included studies*

Author & Study Design	Prevention	Participants	Groups	Intervention	Results
Arnason et al. [28] Cohort (prospective)	Combined 1° & 2° Prevention	Icelandic and Norwegian elite league male soccer teams (elite)	Warm-up stretching, flexibility, strength training n=8 teams (age: not reported)	Warm-up stretching of hamstrings using contract-relax Warm-up: throughout entire season before each training session and game Flexibility for hamstrings based on partner contract-relax stretching Flexibility: after training 3x/week during preseason, 1-2x/week during competitive season Eccentric strength training using "hamstring lowers" Eccentric: 5-week intro period, 3 sets of 12, 10, 8 reps; during preseason 3x/week, during competitive season 1-2x/week	Incidence of hamstring muscle strain Eccentric training: Overall incidence of hamstring strains was 65% lower compared to control* (0.22 ± 0.06 vs. 0.62 ± 0.05; RR 0.35; 95% CI 0.19-0.62, p<0.001). Incidence of hamstring strains was lower compared to baseline (RR 0.42 [0.21-0.84], p=0.009). Flexibility training: No significant difference was found in the incidence of hamstring strains between intervention and control (0.54 ± 0.12 vs. 0.35 ± 0.10; relative risk 1.53; 95% CI 0.76-3.08, p=0.22) No difference in re-injury rates between "hamstring lowers" group compared to control and baseline. Severity of hamstring muscle strain No difference in injury severity between "hamstring lowers" group compared to control. Injuries in the "hamstring lowers" group were less severe compared to baseline.
			Warm-up stretching, strength training n=11 teams (age: not reported)		
			Warm-up stretching, flexibility n=7 teams (age: not reported)		
Askling et al. [30] RCT	Combined 1° & 2° Prevention	Premier league male soccer players from Sweden (elite)	Training group n=15 (age: 24±2.6 yrs)	General training & eccentric hamstring strength training using YoYo Flywheel ergometer General training not described Eccentric: 4 sets x 8 reps; 16 sessions over 10 weeks	Incidence of hamstring muscle strain Incidence of hamstring strains decreased in trained group (3/15) when compared to control group (10/15).
			Control group n=15 (age: 26±3.6 yrs)	General training General training not described	
Brooks et al. [2] Cohort (prospective)	Combined 1° & 2° Prevention	Professional male rugby players in the English Premiership rugby union club (elite)	Strengthening (S) n=148 (age: 25.5±4.1 yrs)	Regular concentric & eccentric hamstring strengthening Strength: 1.2 sessions/wk; 3.6 sets x 8.2 reps (Exercises not described)	Incidence of hamstring muscle strain S: 1.1 (95% CI 0.74-1.4) injuries/1000 player hours; 26% proportion of recurrences SS: 0.59 (95% CI 0.34-0.84) injuries/1000 player hours; 28%

			Strengthening & stretching (SS) n=144 (age: 25.8±4.0 yrs)	Regular concentric & eccentric hamstring strengthening and static stretching Strength: 1.8 sessions/wk; 3.3 sets x 7.5 reps Flexibility: 2.6 sessions/wk; 2.8 sets held 25 seconds (Exercises not described)	injuries/1000 player hours; 28% proportion of recurrences SSN: 0.39 (95% CI 0.25-0.54) injuries/1000 player hours; 15% proportion of recurrences Severity of hamstring muscle strain S: Mean 17 (95% CI 13-23) days lost per injury SS: Mean 21 (95% CI 12-30) days lost per injury SSN: Mean 14 (95% CI 9-19) days lost per injury
			Strengthening, stretching and Nordic† strengthening n=200 (age: 25.4±4.1 yrs)	Regular concentric & eccentric hamstring strengthening, static stretching and eccentric strength training using "hamstring lowers" Strength: 1.3 sessions/wk; 3.0 sets x 7.5 reps Flexibility: 1.8 sessions/wk; 2.6 sets x 28 reps Eccentric: 1.3 sessions/wk; 2.8 sets x 6.7 reps (Exercises not described)	
Croisier et al. [1] Cohort (prospective)	2° Prevention	National or international male soccer, track & field, martial arts athletes (elite)	n=18 (age: 25±8 yrs)	Initial individualized isokinetic concentric, eccentric, or combined eccentric and concentric programs 10-30 sessions; 3x/week, 4-8 reps at 30° or 120°s^{-1} Followed by 12-month standardized maintenance program, including manual muscle strengthening and static stretching	Incidence of hamstring muscle strain No participants sustained a hamstring strain after return to their respective sports for 12 months. Pain of initial hamstring muscle strain Before rehabilitation, pain VAS was 5.9 ± 1.1. On return to activity pain VAS was 0.9 ± 0.6. Intervention significantly reduced pain at $P < 0.001$.
Gabbe et al. [29] RCT	Combined 1° & 2° Prevention	Senior or reserve grade male team from VAFA 2004 (competitive)	Eccentric strengthening n=114 (age: 23.4; range 18.0-35.0 yrs)	Controlled hamstring lowers 5 sessions/12 weeks; 12 sets x 6 reps	Incidence of hamstring muscle strain Intervention group not at decreased risk for hamstring injury when intention to treat was analyzed (RR 1.2, 95% CI 0.5-2.8) Of participants who completed at least two training sessions, 4% of the eccentric strengthening group and 13.2% of stretching and ROM exercise group sustained a hamstring strain (RR 0.3, 95% CI 0.1-1.4; p=0.098)
			Stretching and ROM exercises n=106 (age: 23.9; range 17.4-36.0 yrs)	Static stretching Gastrocnemius, hip flexors, hamstrings stretches held for 30 seconds; lumbar spine stretch held for 15 seconds.	

Queiros Da Silva et al.[40] Cohort (prospective)	2° Prevention	Male athletes with previous hamstring strain (unspecified level of competition)	n=8 (age: 25±8 yrs)	Eccentric hamstrings using a Cybex® isokinetic dynamometer and classical kinesiotherapy Isokinetic training: 10-14 sessions over 38-52 days, 2x/wk minimum 4 sets x 8 reps (5°/xec); 5 sets x 8 reps (10°/xec); 6 sets x 8 reps (15°/xec)	Incidence of hamstring muscle strain recurrence During the 8-month follow-up, there were no recurrent hamstring injuries reported.
Sherry and Best[14] RCT (prospective)	2° Prevention	Male and female athletes with acute hamstring strain (unspecified level of competition)	Stretch and Strength (STST) n=11(9 male, 2 female) (age: 24.3±12.4 yrs) 1° strain (n=7) 2° strain (n=4)	Static stretching, isolated progressive hamstring resistance exercise (including eccentric "foot catches"), and icing Mean duration=33.3 days	Incidence of hamstring muscle strain STST: 6/11 injured within 2 weeks PATS: 0/13 injured within 2 weeks STST: 7/11 injured within 1 year PATS: 1/13 injured within 1 year
			Progressive agility and trunk stabilization (PATS) n=13(9 male, 4 female) (age: 23.2±11.1 yrs) 1° strain (n=5) 2° strain (n=8)	Progressive agility and trunk stabilization exercises and icing Mean duration=18.8 days	

reducing incidence (i.e., number of injuries per player hours) and severity (i.e., number of days lost per injury) of hamstring muscle strains in 546 professional rugby players. One hundred and forty-eight players were in the strengthening group, 144 players in the conventional strengthening and stretching group, and 200 players in the intervention group, which combined conventional strengthening and stretching with "hamstring lowers." The incidence of hamstring strains in the intervention group (0.39 injuries per 1000 player hours) was reported as significantly lower than in the strengthening group (1.1 injuries per 1000 player hours) and the conventional strengthening and stretching group (0.59 injuries per 1000 players). Although a difference in hamstring strain severity existed across the three training groups, this difference was not significant.

Gabbe et al[29] examined the effect of eccentric muscle strengthening on the prevention of hamstring strains in 220 male football players from the Victorian Amateur Football Association. Participants in this Oxford level 2b RCT were divided into two groups: eccentric strengthening ("hamstring lowers"), and stretching and range of motion. A high number of dropouts were reported in this study. Results of the intention to treat analysis suggested the eccentric strengthening group was not at decreased risk for hamstring strains. However, amongst players who completed at least two training sessions, a trend existed towards a protective effect from eccentric strengthening. Incidence of hamstring strains in the eccentric strengthening group and in the stretching and range of motion group was 4% and 13.2%, respectively.

Effect of Eccentric Exercise - Isokinetic Strengthening Protocol

Two prospective cohort studies investigated the incidence of hamstring strains following eccentric exercise using isokinetic strengthening protocols. Croisier et al[1] observed the recurrence of hamstring muscle strains in 26 male athletes with pre-existing unilateral strains. Participants' baseline isokinetic profiles of hamstring and quadriceps muscle function were assessed on a Kintrex 500® dynamometer (Puidoux, Switzerland) before individualized rehabilitation programs were prescribed. Rehabilitation programs involved isokinetic eccentric exercise using the same dynamometer. During the 12-month follow-up period, no participants sustained a clinically diagnosed recurrent hamstring strain. Initial injury severity (i.e., rating of muscle pain and discomfort on a 10-point visual analogue scale) decreased from 5.9 ± 1.1 points pre-intervention to 0.9 ± 0.6 post-intervention ($p < 0.001$) and remained constant for 12 months.

A more recent study by Queiros Da Silva et al[40] explored the use of eccentric exercise using an isokinetic strengthening protocol with a Cybex® Medway, MA isokinetic dynamometer coupled with "classical kinesiotherapy" (i.e., cryotherapy, "physiotherapy," non-steroidal anti-inflammatories, deep transverse massage, progressive passive musculotendinous stretching, manual eccentric exercise, and proprioception exercises) for the secondary prevention of thigh muscle injuries. Of the eight participants with hamstring strains, none sustained a recurrent strain during the 8-month follow-up period post-intervention.

Effect of Eccentric Exercise - Other Strengthening Protocols

Two RCTs investigated the use of other eccentric exercise strengthening protocols on the incidence of hamstring strains. Askling et al[30] examined the effects of pre-season overloading using a YoYo™ flywheel ergometer (Stockholm, Germany) on incidence of hamstring muscle strains in 30 Swedish elite male soccer players. As described in Askling et al,[3] rotation of the flywheel was initiated with a concentric contraction of the hamstrings. An eccentric contraction of the hamstring muscle group was subsequently required to decelerate the movement of the flywheel. Eccentric overloading of the hamstrings required the performance of an eccentric contraction over a smaller angular displacement. The training group completed general training combined with concentric and eccentric hamstring strength training using a YoYo™ flywheel ergometer, while the control group completed general training only. Results showed a decreased incidence of hamstring strains in trained (n = 3) compared to control (n = 10) groups. Six of the 13 participants who sustained a hamstring strain reported a previous hamstring injury. Of these participants, two were in the training group and four in the control group.

Table 4. *Summary of results*

AUTHOR (YEAR)	PREVENTION	INCIDENCE	SEVERITY
"Hamstring Lowers"			
Arnason et al. [28]	1° and 2°	↓*	No difference
Gabbe et al. [29]	1° and 2°	↓	
Brooks et al. [2]	1° and 2°	↓	No difference
Isokinetic Strengthening			
Croisier et al. [1]	2°	Ø†	
Queiros Da Silva et al. [40]	2°	Ø	
Other Strengthening			
Askling et al. [30]	1° and 2°	↓	
Sherry Best [14]	2°	↑‡	

*↓ decreased incidence of hamstring strain in eccentric group(s) vs. other intervention groups

†Ø no recurrent hamstring strains after eccentric intervention

‡↑ increased incidence of hamstring strain recurrence in eccentric group vs. other intervention

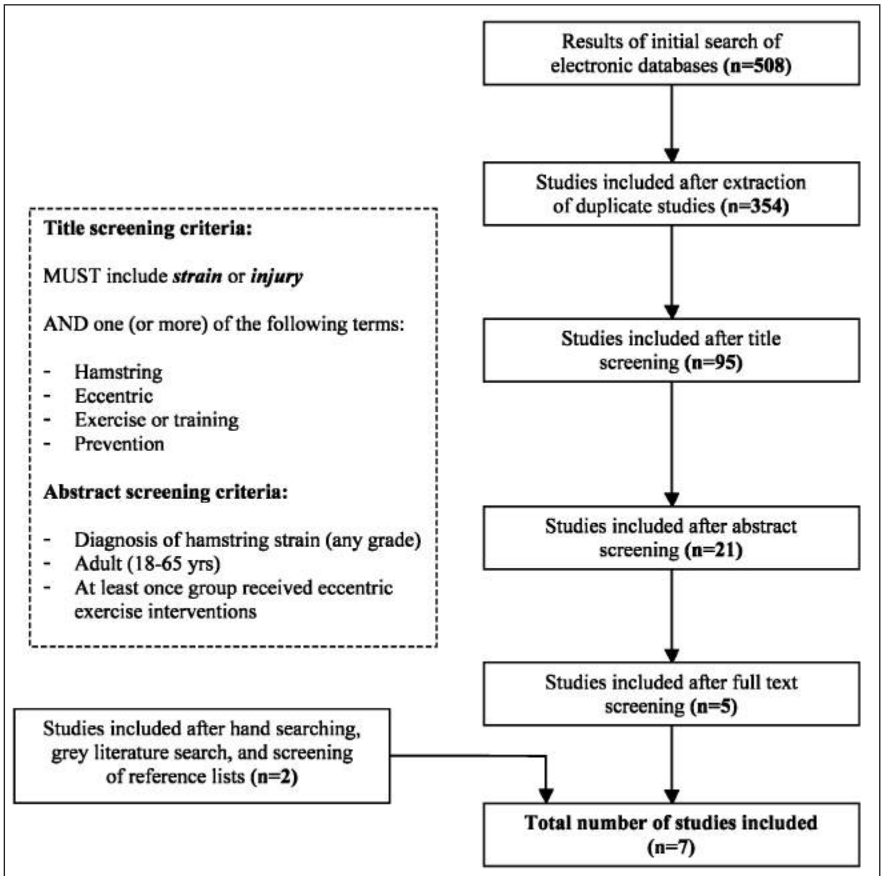

Figure 1. *Search strategy results.*

Figure 2. *"Hamstring lowers."*

In 2004, Sherry Best[14] examined the effectiveness of two rehabilitation protocols. Stretching and strengthening (STST, n = 11) were compared to progressive agility and trunk stability (PATS, n = 13) in 24 male and female subjects with acute hamstring strains. Eccentric strengthening (STST group) for the hamstring muscles was performed using "standing foot catches." "Standing foot catches" were performed by having participants stand on one leg parallel to a wall and simulate the swing phase of walking or running *(Figure 3)*.[14] Participants contracted their quadriceps muscle to perform a rapid knee kick. Eccentric loading of the hamstring occurred when participants "caught" or stopped the lower leg from reaching full extension by eccentrically contracting their hamstrings.[14] Hamstring strain recurrence was significantly lower for athletes in the PATS group when compared to the STST group at 16 days after return to sport. At one year following return to sport, one additional participant in each group sustained a hamstring strain.

Adverse Effects and Dropouts

Intervention-related muscle soreness was reported during the initial phases of training in three of the seven included studies.[28-30] The majority of subjects in Askling et al[30] (n = 11/15) reported muscle soreness lasting 1-3 days after training sessions. A large dropout rate was observed across all training groups in the Gabbe et al[29] study. With the primary reason for non-compliance, reported by players, being DOMS.[29] Less than half of participants (46.8%) completed at least two of the five training sessions, and less than 10% completed all required sessions over the 12-week period. Adherence in the eccentric strengthening group was lower than in the stretching and range of motion group.[29] Arnason et al[28] reported that DOMS was also the principle factor underlying the dropout of one team. This team opted not to follow the prescribed "hamstring lowers" protocol and adopted a program that was much more intensive.

Other reasons for non-adherence reported in the included studies were unrelated to study design. One participant in the Croisier et al[1] study was excluded following lack of improvement in his isokinetic strength profile following nerve compression related to ectopic calcification. In Sherry Best,[14] four participants did not complete the prescribed training for reasons unrelated to the intervention (e.g., death in a motor vehicle accident).

Diagnosis of Hamstring Strain

The methodology employed to diagnose hamstring strains varied amongst included studies *(Table 5)*. In all seven included studies, sport clinicians (i.e. physiotherapists and other medical personnel) completed the assessment and diagnosis of hamstring strains.[1,2,14,28-30,40] Criteria for clinical diagnoses included tenderness on palpation of the musculotendinous junction, pain with isometric contraction, mechanism of injury that resulted in sudden onset of posterior thigh pain, limitation of activities, and pain with stretching.[2,14, 28-30,40]

DISCUSSION

After a thorough review of the literature, seven studies were included and qualitatively analyzed in the systematic review, including cohort studies and RCTs with Oxford Centre for Evidence-based Medicine Levels of Evidence ranging from 2b to 4. Due to this low level of evidence,[39] limited support exists for the use of "hamstring lowers," isokinetic exercises, and other eccentric strengthening exercises as effective training protocols to reduce the incidence and subsequent recurrence of hamstring strains.

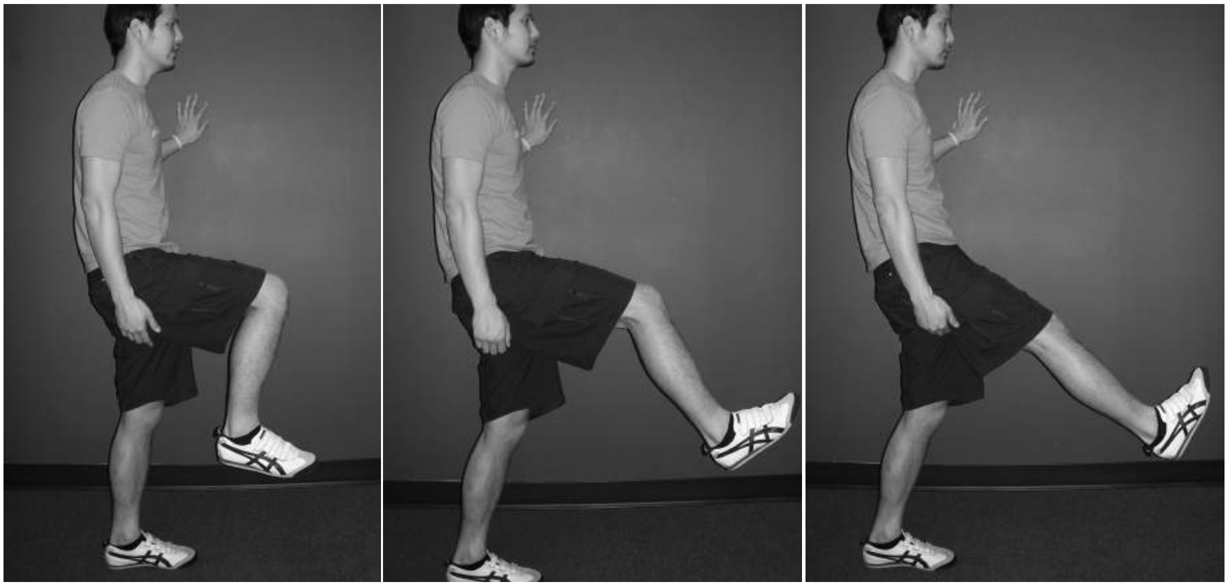

Figure 3. *Simulated swing phase of walking.*

Effect of Eccentric Exercise - "Hamstring Lowers" Protocol

Three included studies [2,28,29] examined effects of eccentric exercise using "hamstring lowers" protocols, in conjunction with other conservative treatments (e.g., stretching, combined eccentric and concentric strengthening exercises, and range of motion of the lumbar spine), on the prevention of hamstring strains and reduction of their severity. The prospective cohort studies showed a lower incidence of hamstring strains with eccentric training, but no significant difference in severity of injury.[2,28] Conversely, the RCT by Gabbe et al[29] found that the "hamstring lowers" group was not at decreased risk for hamstring strains following intention to treat analysis. However, participants in this intervention group who completed at least two training sessions sustained fewer hamstring injuries.

These three studies included competitive to elite level athletes.[2,28,29] In the study of male Premier League soccer players, Askling et al[30] contended that care should be taken when extrapolating findings from elite athletes as they train at a higher intensity and frequency than recreational athletes, and may therefore be at greater risk for hamstring injury.[30,41] Moreover, they argued that significant findings of a protective effect in elite athletes are more remarkable and robust since these athletes are typically closer to a theoretical ceiling effect for eccentric strength gains. Furthermore, Heidt et al[41] suggest the risk of injury may actually increase with progressively higher levels of play.

Poor adherence and high dropout rates plagued two of the three "hamstring lowers" studies.[28,29] Gabbe et al[29] attributed their high dropout rate to participants' subjective responses to DOMS. Arnason et al[28] noted none of the teams that performed the progression of "hamstring lowers" as prescribed, complained of DOMS. However, one team employed a more intensive training protocol than prescribed and consequently incurred considerable DOMS and dropped out of the study.[28] Gabbe et al[29] followed a "hamstring lowers" protocol as described in Brockett et al:[27] 12 sets of 6 repetitions, with 10 seconds of rest between repetitions and 2-3 minutes of rest between sets, in five sessions over a 12-week period. Conversely, Arnason et al[26] followed a protocol proposed by Mjolsnes et al.[26] This protocol involved a 5-week introductory period, increasing from two sets of five repetitions one time in the first week, to three sets of 8-10 repetitions three times per week by the end of the fourth week.[26] Thereafter, participants performed three sets of 8-12 repetitions three times per week for weeks 5-10.[26] It stands to reason that the progressive nature of the program suggested by Mjolsnes et al,[26] which incorporated a lower intensity introductory period, may explain why fewer participants reported DOMS in the Arnason et al[26] study compared to Gabbe et al.[29]

Based on the low level of evidence and paucity of published "hamstring lowers" studies, these results should be interpreted cautiously. While the included studies suggest that "hamstring lowers" appear to provide a clinically useful and inexpensive means of loading the hamstring muscles eccentrically to help protect against strain, none of the three studies adequately controlled for concurrent training methods (e.g., combined stretching and strength training). Consequently, it is impossible to isolate the effects of the "hamstring lowers" protocols. Thus, additional research isolating "hamstring lowers" from other interventions needs to be conducted in order to draw any definitive conclusions with respect to their effectiveness in the primary and secondary prevention of hamstring strains.

Table 5. *Criteria for hamstring strain diagnosis*

Criteria	Arnason et al.[28]	Askling et al.[30]	Brooks et al.[2]	Croisier et al.[1]	Gabbe et al.[29]	Queiros Da Silva et al.[40]	Sherry Best[14]	Total
Tenderness on palpation		x			x	x	x	4
Pain with isometric contraction		x			x	x	x	4
Pain with stretching		x			x	x		3
Known mechanism of injury	x				x		x	3
Limitation of activities	x	x	x				x	4

Effect of Eccentric Exercise - Isokinetic Strengthening

Two studies investigated the use of isokinetic eccentric strengthening for preventing recurrent hamstring strains – both showed protective effects. No participants in the Croisier et al[1] study examining male athletes sustained a hamstring strain during the first 12 months after returning to sport, and rehabilitation seemed to be successful in reducing self-reports of muscle pain and discomfort. Likewise, during a six-to-nine month follow-up period in the Queiros Da Silva et al[40] study of athletes, no recurrent hamstring strains were reported.

Both of the foregoing studies were prospective cohort studies with no control groups. In addition, they incorporated isokinetic eccentric strengthening in conjunction with other interventions. As a result, data need to be interpreted with caution. Due to weak study design, it is unclear exactly how much protection against recurrent hamstring strains was due to isokinetic eccentric strengthening and how much was due to other factors. Possibly, other physiotherapy interventions used in these studies (i.e., concentric strengthening and stretching of the quadriceps and hamstring muscles, trans-cutaneous electrical nerve stimulation, "kinesiotherapy," and sport specific activities) contributed to the observed protection against recurrent hamstring strains. Another limitation of both studies was small sample size, leading to a lack of precision to provide reliable answers to the questions investigated by reducing the likelihood of observing any significant effect. As well, neither study conducted follow-up beyond one year, so longer term outcomes are not known.

Despite the inherent limitations and lack of supporting evidence in these studies, both Croisier et al[1] and Queiros Da Silva et al[40] recommended that eccentric exercise should be included in the rehabilitation of hamstring strains to help prevent recurrent strains. More specifically, Croisier et al[1] concluded that persistence of muscle strength abnormalities may give rise to recurrent hamstring strains and pain, and that "classic rehabilitation" may be improved by including individualized isokinetic eccentric strengthening exercises.

Results of these two studies suggest that adequate warm-up followed by isokinetic eccentric strengthening at low velocities (5-30°/second) is necessary to avoid DOMS.[1,40] However, without an established means of differentiating muscle strain from DOMS, it is not possible to distinguish hamstring strain and DOMS from these results. Treatment should be progressed by increasing eccentric velocity, and should ideally be performed three times per week, which is in agreement with Cotte,[42] in order to minimize time to return to sport.[1,40] Isokinetic eccentric strength values can also be used to determine when return to sport is appropriate. Both studies agreed that bilateral strength differences should be no less than 5% before returning to competition. This 5% value has been repeatedly cited in the literature[1,21,43,44] since it is believed that hamstring strength deficits are a risk factor for strain.[1,11,16,44,45]

Due to study limitations (i.e., no control groups, isokinetic strengthening not examined in isolation, and small sample sizes), these protocols and recommendations must be interpreted carefully. Additional high-level research examining primary prevention and involving larger sample sizes is needed. Also, incorporating better controls, such as isokinetic eccentric strengthening in isolation compared with no exercise, concentric exercise or stretching, is necessary to accurately assess the degree to which hamstring strain incidence may be decreased using isokinetic eccentric training.

Effect of Eccentric Exercise - Other Strengthening Protocols

Two RCTs included in the systematic review utilized other eccentric strengthening protocols.[14,30] Using a YoYo™ flywheel ergometer, Askling et al[30] examined the effects of pre-season hamstring strengthening, incorporating concentric and eccentric overload, on the occurrence and severity of hamstring strains in elite Swedish male soccer players. The eccentric training group had a significantly lower number of injuries compared to the control group. The results of this study suggest a pre-season eccentric strengthening program may reduce the incidence of hamstring strains. One major limitation of the Askling et al[30] study was the inability to differentiate between the concentric and eccentric phases of the YoYo™ flywheel ergometer exercise. Therefore, the effects of eccentric training in isolation are unknown. Also, the small sample size may have decreased the reliability of the reported results by reducing its power to detect small size effects. It should also be noted that participants involved in the study were all elite male athletes. As previously discussed, research has suggested that elite level athletes may be at greater risk for hamstring injury,[41] thus limiting the extrapolation of these results to other populations.

Sherry Best[14] investigated the effectiveness of two different rehabilitation programs for the secondary prevention of hamstring strains. This study demonstrated that a rehabilitation program consisting of progressive agility and trunk stabilization (PATS) exercises was significantly more effective than a program of hamstring stretching and concentric-eccentric strengthening (STST). Of note, the interventions in both the PATS and STST groups incorporated multiple training modes. The use of agility training, which involved considerable eccentric loading through stopping and starting, was not identified as a specific eccentric intervention, which may be a confounding factor explaining why the PATS group sustained fewer hamstring strains. Furthermore, no attempt was made to measure trunk stability, making it difficult to determine the extent that trunk stabilization had on preventing hamstring strains. A small sample size and lack of therapist blinding also reduced the methodological rigor of this study. Because of the limitations in these two studies, it is not possible to affirmatively support the use of other eccentric strengthening protocols in hamstring strain prevention.

Additionally, Sherry Best[14] were the only investigators to include both male and female participants. Numerous studies have shown sex differences in muscle response to eccentric exercise.[17,18,46,47] For example, MacIntyre et al[47] found sex differences in severity of DOMS, muscle torque, and inflammatory markers following eccentric exercise. Therefore, eccentric training protocols designed to prevent hamstring strains may have to be modified to address these sex differences. It is imperative that the results of studies utilizing only male participants not be generalized to females. Furthermore, the effect of sex differences on the incidence of hamstring strains following eccentric training should be investigated in more rigorous controlled trials.

Adverse Effects and Dropouts

As previously discussed, YoYo™ flywheel ergometry and "hamstring lowers" both resulted in increased participant dropout due to occurrence of muscles soreness and DOMS.[28-30] The lack of adherence to eccentric training protocols and subsequent adverse effects reported in Arnason et al,[28] Gabbe et al,[29] and Askling et al,[30] may restrict the implementation of these protocols in clinical settings. However, it is interesting to note the eccentric isokinetic intervention used in the Croisier et al[1] study seemed to decrease the severity of initial injury.

Diagnosis of Hamstring Strains

Hamstring strains are typically diagnosed through clinical examination by a team physician or physical therapist.[5,48] Verrall et al[7] confirmed that the common clinical features of hamstring strains are sudden onset associated with running or acceleration, pain, posterior thigh tenderness, and pain on resisted muscle contraction. Other clinical features include loss of function and pain provocation with range of motion.[5,48] Therefore, it can be assumed that clinical assessment was an appropriate method to diagnose hamstring strains in the seven included studies.

CONCLUSION

Previous investigations show improvements in the structural integrity and performance of the hamstring muscles with eccentric training.[3,6,27] Although authors of these studies advocated the use of eccentric exercise to prevent hamstring strains, limited evidence exists to support its use. A lack of high-level trials impedes the ability to effectively generalize these findings to the clinical settings.

The studies included in this review varied in methodological rigor, population, sample size, and most notably, type of eccentric intervention. While the interventions varied in their prescription, no studies examined the effect of eccentric training in isolation. The coupling of eccentric training with other interventions may have limited, or conversely enhanced, the observed effects of eccentric training on the incidence and severity of hamstring strains. Thus, results of the included studies must be interpreted with caution.

In summary, seven studies were included in this review following a comprehensive appraisal of the available literature. This limited number of relevant articles highlights the need for future well-designed randomized controlled trials to conclusively evaluate the effectiveness of eccentric training in the prevention of hamstring muscle strains. Until more evidence becomes available, concrete recommendations to support or counter the use of eccentric training protocols for the primary and secondary prevention of hamstring strains cannot be made.

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