[Athletic Training]

An Evidence-Based Approach to Hamstring Strain Injury: A Systematic Review of the Literature

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Background: Hamstring strain injury is a common problem within sport. Despite research interest, knowledge of risks for and management of hamstring strain is limited, as evidenced by high injury rates.

Objective: To present the current best evidence for hamstring strain injury risk factors and the management of hamstring strain injury.

Methods: MEDLINE, AMED, SportDiscus, and AUSPORT databases were searched (key terms "hamstring" and "strain," "injury," "pull," or "tear") to identify relevant literature published between 1982 and 2007 in the English language. Studies of adult athlete populations (older than 18 years) pertaining to hamstring strain incidence, prevalence, and/or intervening management of hamstring strain injury were included. Articles were limited to full-text randomized, controlled studies or cohort studies. Twenty-four articles were included. Articles were critically appraised using the McMaster Quantitative Review Guidelines instrument. Data pertaining to injury rates and return to sport outcomes were extracted. Each author undertook independent appraisal of a random selection of articles after establishing inter-rater agreement of appraisal.

Results: Previous strain, older age, and ethnicity were consistently reported as significant risks for injury, as was competing in higher levels of competition. Associations with strength and flexibility were conflicting. Functional rehabilitation interventions had preventive effects and resulted in significantly earlier return to sport. Additionally, weak evidence existed for other interventions.

Conclusion: Current evidence is inconclusive regarding most interventions for hamstring strain injury, while the effect of potentially modifiable risks is unclear. Further high-quality prospective studies into potential risks and management are required to provide a better framework within which to target interventions.

Keywords: hamstring; muscle strain; prevention; management; systematic review

Hamstring strain injury is a noted problem within elite and recreational sport, often resulting in lengthy time off sport and frequent recurrence.[9,11,31,37] The reported injury rate varies due to differing injury definitions and sporting populations; however, the reported prevalence in the various codes of football, to which most literature pertains, is generally 8% to 25%, with each injury resulting in a 2- to 6-week sporting absence.[4,9,15,31,37,44,50] However, single-season prevalence in excess of 50% has been reported.[2] Recurrence is also a prominent issue, with rates in excess of 30%, including rates of up to 60% to 70% in subsequent seasons.[31,35,38,44]

Despite much research interest, the risks for and best management of hamstring strains are not clearly understood. Limitations in the available evidence, such as the previously common use of uncontrolled studies and retrospective designs, contribute to this lack of understanding. Indeed, the use of

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retrospective designs for the study of risks fails to address whether theorized risks predisposed to, or were the result of, injury.[4] Few systematic reviews have investigated the risk factors for and/or the management of hamstring strain; and those that have are limited to very few studies and present inconclusive findings.[11,31]

Management of hamstring strain injury has typically revolved around treatment of initial injury and modification of risk factors. However, much of our knowledge of risk and treatment is based on traditional theoretical arguments with little empirical justification. A lack of clear understanding of risks and the effectiveness of intervention may be factors in the high rate of hamstring strain incidence. With approximately 10% of the Australian population regularly participating in organized sport, and up to 66% regularly undertaking some form of exercise,[3] the potential health burden is considerable. Given the health benefits of regular exercise, encouraging and facilitating participation by appropriate prevention and reduction of injury risk must be considered worthwhile.[33]

The purpose of this review is to present the best evidence recommendations regarding risk factors for and best practice management of hamstring strain injury, along with providing recommendations regarding future research direction.

METHODS

A systematic literature review was conducted. MEDLINE, AMED, SportDiscus and AUSPORT databases were searched (key terms: "hamstring" and "strain," "injury," "pull," or "tear") to identify all relevant literature investigating risk factors for and/or interventions for the management of sports-related hamstring strain injury. Titles and abstracts were reviewed by the authors for relevance and satisfaction of inclusion criteria.

Inclusion/Exclusion Criteria

Population

- Professional or amateur athletes older than 18 years

Intervention

- Aim 1: N/A
- Aim 2: Any reported intervention for the prevention or treatment of hamstring strain injury

Comparison

- Aim 1: Adult athletes not suffering hamstring strain injury
- Aim 2: Any reported management comparison (eg, no intervention, usual care, X versus Y)

Outcome

- Aim 1: Incidence/prevalence of hamstring strain injury and/or recurrence
- Aim 2: Return to sport (RTS) time, incidence/prevalence of hamstring strain injury recurrence

Articles were limited to full-text randomized, controlled trials (RCTs) or cohort (prospective or retrospective) studies published in English language between 1982 and 2007.

Critical Appraisal and Data Extraction

Articles were critically appraised using the McMaster Quantitative Review Guidelines instrument.[25] The instrument, which can be used across quantitative papers of varying design, is a 15-item tool that assesses articles across numerous domains, including research design, sample, intervention, outcomes, and clinical implications. While most items have dichotomous responses (yes/no), provision is made to identify items as either not applicable or not addressed. Scores were attributed to 14 items (yes = 1, no/not addressed = 0), with numerical scores not attributed to Item 3 (research design) as this was a descriptive category. To enable comparison of appraisal, raw scores were expressed as a percentage of the total score possible. Items classified as not applicable (eg, no justification of sample size when all potential subjects were included) were deducted from the total possible score. The wording of the instrument was modified slightly for risk factor studies, whereby the "intervention described in detail" criterion (Item 8) was changed to "exposure described in detail." All other criteria remained the same and were interpreted as outlined by Law et al.[26]

After collectively appraising 5 articles to establish standardization between reviewers, each author undertook independent critical appraisal of a random selection of included articles. A further randomized subset of those articles (n = 7) were independently appraised by all authors to establish inter-rater agreement of appraisal. Each reviewer extracted relevant data into appraisal forms, with the primary reviewer then transcribing data into a purpose-built Microsoft Office Excel file. Meta-analysis was considered, but inadequate sample description and proposed differences between professional and amateur athletes—and those of different sports—precluded this.

RESULTS

Search Results

The search strategy netted 983 hits, of which 24 (4 RCT, 16 prospective cohort, 4 retrospective cohort)

Table 1. Summary of studies.[a]

Author	Subjects, n	Sport	Rate of Injury
Arnason et al, 2004[1]	153	Football	–
Askling, Karlsson and Thorstensson, 2003[2]	30	Football	20% (Intervention), 66.7% (control)
Bennell, Tully and Harvey, 1999[4]	67	ARF	11.9%
Bennell et al, 1998[5]	102	ARF	11.8% initial injury, 16.7% recurrence
Gabbe, Bennell and Finch, 2006[13]	174	ARF	12%
Gabbe et al, 2006[14]	222	ARF	13.96%
Gabbe, Branson and Bennell, 2006[15]	220	ARF	8.2%
Gabbe et al, 2005[16]	126	ARF	15.9%
Hagglund, Walden and Ekstrand, 2006[18]	197	Football	0.4-0.7 injuries/1000 player hours
Heiser et al, 1984[19]	NR	Gridiron	1.1%-7.7% initial injuries
Klingele & Sallay, 2002[22]	11	Var.	0 reruptures postintervention; 0 failed repairs
Lempainen et al, 2006[27]	47	Var.	1 recurrence requiring secondary operation
Levine et al, 2000[28]	58	Gridiron	0% recurrence
Malliaropoulos et al, 2004[30]	80	Var.	–
Orchard et al, 1997[34]	37	ARF	16.2%
Orchard, 2001[35]	1607	ARF	Average 84 per season
Sherry and Best, 2004[38]	24	Var.	0-7.7% (intervention), 54.5%-70% (control)
Upton, Noakes and Juritz, 1996[42]	44	Rugby union	3-57 injuries/1000 playing hours[c]
Verrall, Slavotinek and Barnes, 2005[43]	69-71[b]	ARF	1.3 injuries/1000 playing hours (postRx)
Verrall et al, 2006[44]	162	ARF	18.5% initial injury, 40%-63% recurrence
Verrall et al, 2001[45]	114	ARF	Average 30% (21.1%-44.2%)
Witvrouw et al, 2003[47]	146	Football	21.23%
Woods et al, 2004[49]	2376	Football	12% of all injuries; average 5 per club per season
Yamamoto, 1993[50]	64	Track and field	24.2%

[a] ARF, Australian Rules football; Var., various; football, football/soccer; NR, not fully reported; gridiron, American football; Rx, treatment.
[b] Numbers varied over time.
[c] Prevalence reported from various subgroups.

articles were relevant and satisfied specified inclusion criteria. A summary of studies is provided in Table 1. Additional articles were used as background material, but were not included in this review's results.

Cumulatively, the identified studies investigated more than 6120 predominantly male (99.1%) amateur and professional athletes. Subject gender reflected the sporting populations sampled, which typically revolved around the various codes of football: commonly Australian Rules (45.8%) and soccer ("football") (20.8%). Most studies were conducted in Australia (45.8%); however, studies were also conducted in European (29.2%), American (16.7%), South African, and Japanese settings (4.2% each).

Methodological Quality

The methodological rigor of the included articles varied, however they were typically of moderate quality. Raw scores on the McMaster instrument ranged from 5 to 11, with percentage scores ranging from 41.7% to 91.7% (mean, 68.4% ± 10.5%). Of the 7 articles that underwent duplicate appraisal, differences in item classification for all articles existed in less than 10% of cases, and thus the inter-rater agreement was deemed appropriate.

Common methodological problems identified via critical appraisal included inadequate description of the sample and no justification of the sample size. Issues of sample size took on particular significance when studies did not record enough injuries to determine clear relationships with putative risks. Reliability and validity of the outcome measures used was typically not addressed. Definition and measurement of hamstring strain injury often varied, with no evidence presented for the technique used. A summary of the critical appraisal scores is presented in Table 2.

Table 2. Article critical appraisal.[a]

	Item Number[b]															Score	
Author	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Raw	%
Arnason et al, 2004[1]	√	√	PC	×	na	√	?	√	na	na	√	√	√	×	√	8	72.7
Askling, Karlsson, and Thorstensson, 2003[2]	√	√	RCT	√	×	?	?	×	√	?	√	√	√	√	√	9	64.3
Bennell, Tully, and Harvey, 1999[4]	√	√	PC	√	×	?	?	√	na	na	√	√	√	√	√	9	75.0
Bennell et al, 1998[5]	√	√	PC	√	×	?	?	√	na	na	√	√	√	×	√	8	66.7
Gabbe, Bennell, and Finch, 2006[13]	√	√	PC	√	×	√	?	√	na	na	√	√	√	×	√	9	75.0
Gabbe et al, 2006[14]	√	√	PC	√	×	?	?	√	na	na	√	√	√	×	√	8	66.7
Gabbe, Branson, and Bennell, 2006[15]	√	√	RCT	√	×	?	?	√	√	?	√	√	√	√	√	10	71.4
Gabbe et al, 2005[16]	√	√	PC	√	×	√	√	√	na	na	√	√	√	√	√	11	91.7
Hagglund, Walden, and Ekstrand, 2006[18]	√	√	PC	√	na	?	?	√	na	na	√	√	√	√	√	9	81.8
Heiser et al, 1984[19]	√	×	RC	×	na	?	?	√	×	×	√	√	√	na	×	5	41.7
Klingele and Sallay, 2002[22]	√	√	RC	√	na	?	?	√	na	×	×	?	√	√	√	7	58.3
Lempainen et al, 2006[27]	√	√	RC	√	na	?	?	√	√	na	×	√	√	na	√	8	72.7
Levine et al, 2000[28]	√	√	RC	×	na	?	?	√	na	×	na	√	√	na	√	6	60.0
Malliaropoulos et al, 2004[30]	√	√	RCT	×	×	?	?	√	?	√	√	√	√	×	√	8	57.1
Orchard et al, 1997[34]	√	√	PC	√	×	?	?	√	na	na	√	√	√	√	√	9	75.0
Orchard, 2001[35]	√	√	PC	×	na	?	?	√	na	na	√	√	√	na	√	7	70.0
Sherry and Best, 2004[38]	√	√	RCT	√	×	?	?	√	?	√	√	√	√	√	√	10	71.4
Upton, Noakes, and Juritz, 1996[42]	√	√	PC	×	×	?	?	√	na	?	√	√	√	√	√	8	61.5
Verrall, Slavotinek, and Barnes, 2005[43]	√	√	PC	×	na	?	?	√	na	×	√	√	√	×	√	7	53.9
Verrall et al, 2006[44]	√	√	PC	×	×	?	?	√	na	na	√	√	√	×	√	7	58.3
Verrall et al, 2001[45]	√	√	PC	√	×	?	?	√	na	na	√	√	√	√	√	9	75.0
Witvrouw et al, 2003[47]	√	√	PC	√	na	?	?	√	na	na	√	√	√	√	√	9	81.8
Woods et al, 2004[49]	√	√	PC	×	na	?	?	√	na	na	√	√	√	√	√	8	72.7
Yamamoto, 1993[50]	√	√	PC	√	×	?	?	√	na	na	√	?	√	√	√	8	66.7

[a] √, yes; ×, no; ?, not addressed; na, not applicable; PC, prospective cohort, RC, retrospective cohort; RCT, randomized controlled trial.
[b] McMaster items: 1, study purpose stated clearly; 2, relevant background literature reviewed; 3, research design; 4, sample described in detail; 5, sample size justified; 6, outcome measures reliable; 7, outcome measures valid; 8, intervention/exposure described in detail; 9, contamination avoided; 10, cointervention avoided; 11, results reported in terms of statistical significance; 12, appropriate analysis methods; 13, clinical importance reported; 14, drop-outs reported; 15, appropriate conclusions.

Risk Factors for Hamstring Strain Injury

Numerous potential risk factors for hamstring strain injury were investigated in the identified literature. Commonly studied factors included flexibility and muscle length, hamstring strength and strength ratios, demographic characteristics, and history of previous injury.

History of Previous Injury

History of previous hamstring strain injury was one of the most commonly reported significant risk factors for recurrence. Seven studies of footballers from Australia (Australian Rules) and Scandinavia examined this, with only 1 study not identifying a significant association between injury history and future strain incidence.[34] Most studies deemed that athletes with a history of hamstring strain were between 2 to 6 times more likely to suffer subsequent strains.[1,5,14,18,35,45] Most recurrences happened soon after RTS (history of hamstring strain within previous 8 weeks: relative risk [RR], 6.33; [95% confidence interval (CI): 5.21-7.70][35]), however, the risk remained significant over time.[1,5,14,18] Footballers remained approximately 3 times as likely to suffer a recurrence even beyond a year from the initial injury.[14,18] While most strains involved the biceps femoris, the muscle injured did not predict recurrence.[44,49] Similarly, the size and severity of the initial injury was not significantly associated with recurrence within the same season.[24] However, athletes with larger strains had a significantly higher risk of recurrence within 2 seasons.[49]

Other lower limb injuries were also associated with an increased risk of hamstring strain, supporting arguments of the role of the hamstrings as part of a larger kinematic chain.[35,45] Australian Rules footballers with a previous calf injury were 1.37 times more likely to suffer hamstring strain (95% CI: 1.08-1.76),[35] while athletes who had sustained a previous substantial knee injury (P = .009) or who had a history of osteitis pubis (P = .023) were also at greater risk.[45] Hamstring strain risk with respect to back injury history was also investigated but no significant association was identified.[45]

Flexibility and Muscle Length

Hamstring flexibility demonstrated no significant association with the rate of injury in 4 prospective cohort studies.[1,13,16,34] Only one study, of footballers in the Belgian professional leagues, reported a significant association, with players who suffered hamstring strains during the 1999-2000 season having significantly less flexibility at preseason baseline testing (P = .02).[47] However, methods of assessing hamstring flexibility have been criticized for being unable to differentiate from lumbo-pelvic flexibility.[4] Recognizing the relationship between these 2 motion segments, combined hamstring and lumbo-pelvic flexibility has been investigated yet demonstrated no significant risk.[4,14] Similarly, neural flexibility displayed no significant association with injury.[14,16]

The flexibility of other thigh muscles, however, appears to be of more importance than that of the hamstring group. Increased quadriceps flexibility was inversely associated with hamstring strain incidence in a group of amateur Australian Rules footballers; with athletes achieving greater than 51° knee flexion in a modified Thomas test being 70% less likely to suffer hamstring strain (RR, 0.3; 95% CI: 0.1-0.8).[13] Tight hip flexors was reportedly a significant risk for hamstring strain (RR, 1.15; 95% CI: 1.01-1.31), however this was in a subgroup of older athletes, with age as a possible confounder.[13] Iliopsoas tightness was not a significant risk in a group of elite Australian Rules footballers of younger mean age.[14]

Hamstring Strength

The available evidence for hamstring weakness as a risk is conflicting. Hamstring peak torque was assessed during preseason in 6 professional and amateur Australian Rules football teams, however there was no difference between injured and noninjured players during the season.[5] Similarly, hamstring power (watts) demonstrated no significant association with injury rate in the Icelandic professional football leagues.[1] However, Yamamoto[50] identified significantly less hamstring strength, as a proportion of body weight, in injured compared to noninjured Japanese collegiate athletes.

Thigh muscle strength imbalances may play a larger role than strength in isolation. Preseason testing revealed that Australian Rules footballers who went on to suffer a hamstring strain during the following season had a significantly decreased hamstring/opposite hamstring peak torque ratio (60°/s).[34] However, no significant differences existed between injured and noninjured players at 180°/s and 300°/s.[34] Similarly, while a 10% between-leg discrepancy in hamstring peak torque (hamstring/opposite hamstring ratio < 0.9) is often cited as a risk for injury, Bennell et al[5] determined that it was not a significant predictor of future hamstring strain (P > .05). Indeed, players with strength ratios greater than 0.9 displayed a significantly higher injury incidence (P = .02).[5] With respect to hamstring/quadriceps muscle strength imbalances, significantly reduced peak torque ratios (60°/s)—representing increased quadriceps relative to hamstring strength—were identified in footballers who suffered subsequent hamstring strain.[34] The work of Yamamoto supports this; however, such strength imbalances were not predictive of future strain in the work of Bennell et al.[5,10]

Demographic Characteristics

Increased age appears to be a significant risk for hamstring strain injury, with 8 of 10 prospective cohort studies displaying significant associations between age and hamstring strain prevalence.[§] The age at which the risk becomes significant potentially occurs between 23 and 25 years.[13,14,16,35,49] Athletes older than 23 years were reportedly between 1.3 and 3.9 times more likely to suffer a hamstring strain,[16,35] with athletes aged 25 years or older between 2.8 and 4.4 times more likely to suffer injury.[13,14] As these figures suggest, the magnitude of risk appears to increases with age, with Verrall et al[45] claiming that the risk increases by 30% annually. Why age is a risk remains contentious; however, age-related muscle changes and prolonged exposure to additional risks have been proposed.[16,35]

Height displayed no significant association with the rate of initial or recurrent hamstring strain injury in any study.[1,14,16,34,35,44,45] In contrast, race and ethnicity were strongly associated with injury, with black athletes significantly more likely to suffer hamstring strains.[45,49] Notably, Aboriginal Australian Rules

§References 1, 13, 14, 16, 18, 35, 45, 49.

footballers were 11.2 times more likely to suffer hamstring strain than non-Aboriginals (95% CI: 2.1-62.5).[45] A study of the English professional football leagues (English Premier League [EPL]-League 2) suggests that this is not specific to any one nationality or ethnic group but to all players of black racial background.[49]

The evidence for weight and body mass index (BMI) as risks for hamstring strain injury is conflicting. Two studies identified no significant association between BMI with the rate of initial or recurrent hamstring strains[1,44]; however, 2 studies identified significant relationships with hamstring strain incidence.[14,35] Compared to professional Australian Rules footballers with a BMI of 25 kg/m^2 or less, players with increased BMIs were nearly 2.5 times more likely to suffer a hamstring strain in a given season (RR, 2.41; 95% CI: 1.25-4.66).[14] Whether increased BMI is a risk factor in itself is unclear, as BMI was strongly correlated with age and injury history.[35] With respect to weight, 5 of 7 prospective cohort studies found no significant association with hamstring strain incidence.[1,14,34,44,45] Two studies identified significant relationships[13,35]; however, it should be noted that one studied a group of older athletes who had higher rates of injury, while the magnitude of risk was small (RR, 1.07; 95% CI: 1.01-1.15).[13]

Sport-Specific Risks

In 2 studies of professional footballers (soccer and Australian Rules), the prevalence of hamstring strain was significantly ($P < .01$) greater in higher levels of competition (EPL vs Championship–League 2; Australian Football League [AFL] vs South Australian National Football League [SANFL]).[45,49] In the study of professional Australian Rules footballers, prevalence differed by more than 20%.[45] While infrequently reported, the prevalence of hamstring strain injury in amateur sport was at the lower end of the reported range of all studies (8.2%-15.9%).[15,16] Within kicking sports, the risk appears to be similar between dominant and nondominant limbs, but playing position may be a significant risk, with outfield players experiencing a 22% to 37% higher incidence of hamstring strain than goalkeepers in English football.[34,44,47,49]

While level of competition may be a risk for hamstring strain, evidence suggests that exposure time (time spent in training or games) is not. Three studies, involving amateur Australian Rules footballers and footballers from 2 professional European leagues, investigated this, with none identifying a significant association with hamstring strain.[1,16,47] Nonetheless, in-game fatigue may be a risk, as significantly more injuries ($P < .01$) were recorded toward the end of each match half.[49] However, further studies found no association between decreased VO_2 max and hamstring strain (VO_2 max is the maximum amount of oxygen that can be consumed and used in 1 minute at sea level).[1,34]

While sport-specific risks may exist, functional testing demonstrated a poor association with hamstring injury. Standing jump and counter-movement jump test performance in a group of professional footballers demonstrated no significant association with the rate of injury,[1] while the rate of recurrence was significantly different between 2 groups of Australian Rules footballers, despite both groups displaying no significant difference with respect to any functional measure (hop height, hop distance, sprint time).[38] There was no evidence to suggest that playing conditions, including ground condition and air temperature, were significant risks.[35]

Management of Hamstring Strain Injury

Comparatively less literature (10 of 24 studies) was identified dealing with hamstring strain management. Conservative interventions were most frequently investigated, but surgical interventions were reported. For the purpose of this review, "management" was considered to refer to any intervention aimed at influencing the hamstrings, whether it be preventive or pertaining to acute management and rehabilitation.

Prevention

Athletes and sporting teams invest much time in preventive strategies. Hamstring strengthening programs are commonly used, however their effects are variable. Eccentric strengthening programs demonstrated effectiveness, in terms of reduced strain prevalence, in professional footballers (soccer), but not in a group of amateur Australian Rules footballers.[2,15] Compliance with the intervention was poor in the latter study, and findings trended in an unintended direction (increased prevalence) during the first follow-up year.[15] Isokinetic strengthening led to significantly fewer strains postintervention in a group of gridiron players (7.7% vs 1.1%; $P < .005$), however this program was used with existing stretching, running, and weight training protocols, thus its effects in isolation are unclear.[19]

Open-chain lower limb strengthening was avoided by Verrall, Slavotinek, and Barnes,[43] who tested a functional intervention in a group of Australian Rules footballers. The program, which was conducted at all training sessions (2-3 times/week) for 2 winter seasons, consisted of interval sprints, functional running drills (running while tapping ball along ground), and isometric stretching, and significantly reduced matchplay strains by 3.4 injuries/1000 playing hours.[43] While the reduction in training injuries was not significant, it should be noted that the rate of training injury was low throughout (1.7 [preintervention] vs 0.7 [postintervention] injuries/1000 player weeks).[43]

Theorizing that reduced muscle temperature was a putative risk, the use of thermal shorts was studied in a group of South African rugby union players.[42] Wearing thermal shorts, comprising neoprene material with nylon lining, was at the players' discretion. Players not wearing the shorts at any stage during the 1992 season had a higher rate of injury compared to those who wore the shorts for all of the season (32 vs 24 injuries/1000 playing hours), yet this difference was not significant.[42] However, very few players wore the shorts for all of the season (n = 5).[42] Interestingly, a significant difference existed in the rate of injury for players who occasionally wore the shorts, with more injuries occurring when players in this group were not wearing the shorts (57 vs 3 injuries/1000 playing hours).[42]

Treatment

Randomized, controlled trials and well-designed cohort studies on the treatment of hamstring strain injury are lacking. An RCT on the effects of hamstring stretching was conducted on a group of 80 Greek athletes who had suffered grade II hamstring strains, but this study looked only at the frequency of stretching.[30] The athletes were randomized into 2 groups that performed standing static hamstring stretching either once or 4 times daily.[30] Athletes within the increased stretching frequency group had a significantly reduced RTS time ($P < .001$), but no information was provided on recurrence.[30] The clinical importance is also questionable, with the mean between-group difference in RTS being 1.7 days.[30]

Similar to evidence for its use as a preventive intervention, successful results have been reported with a functional rehabilitation program.[38] This program, which incorporated progressive agility and trunk stabilization exercises, demonstrated greater benefit over "traditional rehabilitation" of stretching and strengthening, with reduced RTS time and significantly fewer recurrences.[38] No athlete in the functional rehabilitation group sustained a recurrence within 2 weeks of RTS, and only 7.7% (n = 1/13) within 1 year; whereas recurrence rates for the "traditional" group were 54.5% (n = 6/11) and 70% (n = 7/10), respectively.[38]

Surgical repair of severe hamstring strain injuries, including ruptures and avulsions, were infrequently reported. While surgical techniques vary, the mean RTS time was similar, ranging between 5 and 6 months.[22,27] Recurrences and failed repairs were minimal, with Klingele and Sallay[22] reporting no reruptures and only 1 recurrence requiring a secondary operation in Lempainen et al.[27] However, recurrences not requiring surgical intervention, if present, were not reported.[27] Similarly, a retrospective cohort of American football players (gridiron) identified no recurrences when injured players were treated with intramuscular corticosteroid injection in addition to conventional treatment, but players were only followed during the course of their employment at one NFL club.[28] Given the high squad turnover and player trading within the NFL,[32] it is highly probable that unrecorded recurrences may have occurred in players while playing for another team. However, players returned to sport quickly postintervention (mean RTS, 7.6 days), with 84.5% of players missing no game time.[28]

DISCUSSION

Hamstring strain is a well-documented problem within both the amateur and professional sporting populations. With sports injuries costing Australia an estimated $1.65 billion annually,[33,36] the contribution of hamstring injury to this is likely considerable. With the increasing commercialization of professional sport, costs to clubs and individuals are no longer limited to those incurred by rehabilitation.[40,48,49] Despite much research interest, knowledge of how to prevent and treat hamstring strains is incomplete, as evidenced by the high rate of injury and recurrence reported in the literature.

The methodological rigor of the identified literature varied. Most of the literature was of moderate quality, but inadequate sample description was common, as was a lack of sample size justification. Where low injury rates were described, which limited determining associations with potential risks, inadequate sampling may have contributed. In addition, where retrospective designs were used, whether variables were risks or outcomes is debatable.[4] Studies of professional athletes have intrinsic limitations. Minor strains may go unreported to medical staff for fear of professional future or loss of income, while the effect of unreported preventive interventions is a potentially important confounder.

Definitions and measurement of hamstring strain varied, which assumes particular relevance because hamstring strain diagnosis potentially confounds much of the literature. Clinical assessment was often used to diagnose injury; however, this may not correctly identify all injuries.[8,16,21,45] This is evident in minor injuries, whereby hamstring strain symptoms can be mimicked by injury to the lumbar spine, neural structures, and surrounding musculature.[23,27,35,45] Magnetic resonance imaging (MRI) is reportedly the preferred standard to diagnose hamstring strain, although the use of ultrasonography has merit.[8,21,24,41,45] However, MRI has notable limitations in the acute phase when distinguishing muscle tissue change from hemorrhage is difficult; thus, MRI may be more beneficial with severe cases.[17,24,41]

The strongest risk factor for hamstring strain was a history of previous hamstring strain. Debate exists as to whether this is because of inadequate rehabilitation and premature RTS, or whether an intrinsic risk is created by the initial injury.[1,37,42,45,46] Premature RTS arguably places the athlete at higher risk, but even in the presence of thorough rehabilitation, with corresponding functional improvement, recurrence remains high.[5,42] The argument exists, therefore, that the hamstrings are at risk because of scar tissue formation and reorganization secondary to initial strain.[7,9,29,45] However, other studies suggest that this may not be the predominant factor, citing the lower levels of recurrence for other muscle strains.[46]

Functional performance measures had no significant association with either initial or recurrent hamstring strain injury. This is an important finding, questioning the validity of such commonly used tests by sporting clubs in determining a player's injury risk and suitability to RTS.[1,13,38] Whether other functional measures in a simple, field-based environment can predict the relative risk for hamstring strain is unknown. At this time, it would appear that consideration of other risk factors, in conjunction with functional capacity, is needed before RTS, recognizing that the initial injury has already placed the athlete at a heightened risk.[5,14,18,35]

Lower limb strength imbalances may be of greater importance than muscle weakness as a risk for hamstring strain. Particularly, decreased hamstring strength relative to quadriceps strength appears to increase the risk for injury.[34,50] The hamstrings eccentrically decelerate the lower limb during the swing phase of running before extending the hip to achieve propulsion, while their braking function is also obvious in kicking sports; these are biomechanical demands that are frequently noted as the mechanism of injury.[4,5,16,37,49] Should quadriceps strength be increased relative to hamstring strength, the capacity to exert increased lower limb swing force is conceivably greater, thereby placing increased demands on the hamstrings to decelerate the limb. Players, especially professional athletes in kicking sports, may be undertaking much quadriceps strengthening, which may influence their hamstring strain risk.

Evidence to support hamstring inflexibility as a significant risk is lacking. Much of the existing literature linking hamstring tightness with strain incidence has been retrospective, posing questions as to whether muscle tightness is a predisposing factor to or a consequence of injury.[4] However, hamstring inflexibility cannot be ruled out as a risk factor; flexibility was often assessed via sit-and-reach and straight leg raise (SLR) tests, with such tests criticized for being unable to differentiate hamstring from lumbo-pelvic flexibility or identify contralateral muscle differences.[13,16,20,34,47] The concept of a critical degree of inflexibility also poses questions, as authors have noted that the athletes studied were relatively flexible, likely due to regular stretching as part of their training, and were thus studying a group in whom inflexibility was not an issue.[4]

The role of muscle tightness in hamstring strain appears most likely related to biomechanical factors. With hamstring muscle tightness, theoretical and animal models contend that there is decreased stretch and force absorption before failure, which compromises the muscle when required to lengthen.[4,42] Increased muscular temperature also influenced the viscoelastic properties of muscle in animal models, increasing the required force and stretch before failure.[42] Consequently, the lack of prospective research on warm-up and stretching interventions is surprising. Quadriceps flexibility is not widely reported as a significant risk, but the biomechanical explanation is similar to that of relative hamstring weakness. With increased quadriceps tightness, potential energy created by hip extension and knee flexion in the preswing phase may cause increased forward propulsion of the leg during swing due to passive recoil, thereby increasing the load on the hamstrings to decelerate the limb.[16]

Evidence suggests that the risk for hamstring strain increases with age, yet the reasons for this are unclear.[14,18,45] Age-related muscle changes, particularly reductions in muscle cross-sectional area, are proposed, yet this theory has limitations.[16,35] The implication of reduced cross-sectional area is that the hamstrings can no longer produce sufficient tension to resist load before failure; however, evidence for hamstring weakness as a risk is conflicting.[1,5,50] Also, most athletes were relatively young (30 years) and likely undergoing extensive training resulting in muscle hypertrophy, which negates theories of reduced muscle cross-sectional area. Other theories include age-related lumbar degeneration, which may affect nerve roots innervating the hamstrings, causing decreased muscle activation and coordination.[35]

The commonly reported mechanisms of hamstring strain injury suggest that there are nonmodifiable risks intrinsic to participation in certain sports. Moreover, the risk may differ among athletes of different playing position within the same sport. It is reasonable to suggest that athletes who are sprinting or kicking with increased frequency or intensity are more likely to suffer injury, thereby explaining the lower injury rate in football goalkeepers.[49] Brooks et al[6] support this, finding that rugby union backs, whose role involves comparatively more sprinting and kicking, had significantly more strains than forwards.

The risk of hamstring strain increased with higher levels of competition. Higher levels are likely to be faster and more physically demanding, potentially explaining this finding. Increased exposure time is also proposed as a possible reason; however, no studies were identified that displayed significant links. Nonetheless, it would seem odd that no significant association with exposure time was identified if, conceivably, this resulted in increased exposure to the influence of other risks. For example, in a study of English football[49] many players in the top league (EPL) were involved in a greater volume of games (domestic/European cup, international fixtures), possibly leading to increased fatigue. Fatigue is a commonly proposed risk yet is difficult to quantify; moreover, it is not necessarily synonymous with exposure time.[42,45] Fatigue may be higher after short periods of time in which repeated high-intensity effort is required than at the end of a competition where player involvement has been low. Poor aerobic capacity is involved with general fatigue yet had no significant association with hamstring strain.[1,34] If "fatigue" is a factor, it must be intrinsic to the muscle itself.

The notion of sport-specific risks is supported by the effectiveness of functional interventions to prevent injury. Mimicking competition requirements (interval sprints, running while tapping ball) during the intervention led to the effect. Repetitive high-intensity sprint efforts and bending to gather the ball when running are characteristic of Australian Rules football.[43] Emphasis on anaerobic interval training represents a change from traditional preseason training but may prevent injury via muscle conditioning and improved fatigue threshold.[43]

Functional interventions also appear to be effective in rehabilitation following hamstring strain injury.[38] An important aspect of Sherry and Best's work is that it investigated athletes from various sports, and thus its results are potentially more applicable to a wider population than much of the existing literature.[38] Of interest was the use of trunk stabilization exercises; because of the origin of the hamstrings at the pelvis. Theoretically, adequate neuromuscular control of the trunk and pelvis is required to both optimize function and prevent inappropriate length-tension relationship changes.[38] This is consistent with previous research. Similar biomechanical arguments may explain the higher rate of hamstring strain in black athletes, who reportedly frequently had anteriorly tilted pelvises.[49]

The use of surgical and specialist medical interventions is infrequently reported but reflects the prevalence of severe strains (eg, grade 3) rather than effectiveness of intervention. However, intramuscular corticosteroid injection use is controversial, with deleterious effects on tendon and other soft tissue observed in animal models, resulting in decreased load before failure.[10,12,28] Speculative links with subsequent tendon rupture in humans are noted.[10,12,28,39] However, collective knowledge on the effects of intramuscular corticosteroid use is limited.[28] While no injury recurrences were reported, given the high player turnover rate in American football, it is possible that many were not identified.[28,32] The risk of corticosteroids with existing comorbidities also warrents consideration.[12] Further research is needed to determine if such interventions are safe and beneficial, and, if so, to determine indications for their use.

Limitations of This Review

While efforts have been made to minimize their effect, several limitations are present in this review. Given the date and language limits on the search strategy, and as non-database–indexed "grey literature" was not searched, it is possible that relevant articles may have been overlooked. Given the interest in hamstring injury, additional studies may have been published after this review. Most of the appraised literature pertained to studies of male footballers, thus the extent to which results can be extrapolated to other sporting populations, particularly female athletes, is uncertain.

While there was high agreement between reviewers for article critical appraisal using the McMaster Quantitative Review Guidelines instrument, it should be noted that there have been no published studies on the tool's reliability and validity. Moreover, whether minor wording changes to the instrument in this review make the tool any less applicable has not been studied.

CONCLUSION

Current research evidence is inconclusive regarding many interventions used to prevent or treat hamstring strain injury. Many significant risks are nonmodifiable, yet the extent to which potentially modifiable factors are risks is unclear. Current thinking regarding risk and management may not be incorrect, but the underlying evidence has notable limitations and is inappropriately designed to produce conclusive answers.

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy

A: consistent, good-quality patient-oriented evidence

B: inconsistent or limited-quality patient-oriented evidence

C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Previous history of hamstring strain injury, increased age, race, and participation in higher levels of competition be considered significant risks for hamstring strain injury.[1,5,13–16,18,34,35,44,45,47,49]	A
Functional rehabilitation programs incorporating sport-specific drills along with traditional interventions be used for both the prevention and management of hamstring strain injury.[38,43]	B
Further high-quality prospective studies with large samples taken from broader sporting populations looking into potential risk factors and management are needed to provide a better framework within which to target interventions for hamstring strain injury.[15,16,18,36,38,42,44,49]	A

For information about the SORT evidence rating system, see www.aafp.org/afpsort.xml and Ebell MH, Siwek J, Weiss BD, et al. Strength of Recommendation Taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician.* 2004;69:549-557.

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