Review

A Comprehensive Summary of Systematic Reviews on Sports Injury Prevention Strategies

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Background: A large volume of systematic reviews and meta-analyses has been published on the effectiveness of sports injury prevention programs.

Purpose: To provide a qualitative summary of published systematic reviews and meta-analyses that have examined the effectiveness of sports injury prevention programs on reducing musculoskeletal injuries.

Study Design: Systematic review; Level of evidence, 4.

Methods: We searched the PubMed, CINAHL, EMBASE, and the Cochrane databases for systematic reviews and meta-analyses that evaluated the effectiveness of sports injury prevention programs. We excluded published abstracts, narrative reviews, articles not published in English, commentaries, studies that described sports injury prevention strategies but did not assess their effectiveness, studies that did not assess musculoskeletal injuries, and studies that did not assess sports-related injuries. The most relevant results were extracted and summarized. Levels of evidence were determined per the Oxford Centre for Evidence-Based Medicine, and methodological quality was assessed using the AMSTAR-2 (A MeaSurement Tool to Assess systematic Reviews, revised version).

Results: A total of 507 articles were retrieved, and 129 were included. Articles pertaining to all injuries were divided into 9 topics: sports and exercise in general (n = 20), soccer (n = 13), ice hockey (n = 1), dance (n = 1), volleyball (n = 1), basketball (n = 1), tackle collision sports (n = 1), climbing (n = 1), and youth athletes (n = 4). Articles on injuries by anatomic site were divided into 11 topics: general knee (n = 8), anterior cruciate ligament (n = 34), ankle (n = 14), hamstring (n = 11), lower extremity (n = 10), foot (n = 6), groin (n = 2), shoulder (n = 1), wrist (n = 2), and elbow (n = 1). Of the 129 studies, 45.7% were ranked as evidence level 1, and 55.0% were evidence level 2. Based on the AMSTAR-2, 58.9% of the reviews reported a priori review methods, 96.1% performed a comprehensive literature search, 47.3% thoroughly described excluded articles, 79.1% assessed risk of bias for individual studies, 48.8% reported a valid method for statistical combination of data (ie, meta-analysis), 45.0% examined the effect of risk of bias on pooled study results, and 19.4% examined the risk for publication bias.

Conclusion: This comprehensive review provides sports medicine providers with a single source of the most up-to-date publications in the literature on sports injury prevention.

Keywords: sports injuries; prevention; musculoskeletal; systematic review; meta-analysis

In the United States, approximately 4.3 million nonfatal sports or recreation-related injuries are seen annually in the emergency department.[81] The highest rates of sports injuries for both boys and girls occur in adolescents aged 10 to 14 years, which is likely due to increased participation in sports among this age group.[81] The lower extremity is most commonly injured during sports participation; however, the incidence of injury to specific body parts varies by sport.[81,185,257] Owing to the influx of participants in sports and the subsequent injuries they sustain, research on sports injury prevention strategies is rapidly growing.[129] Injury prevention is important for reducing long-term health consequences, such as disability, and minimizing the economic burden of treatment.[2]

Injury prevention strategies typically focus on modifiable risk factors, such as rules, equipment, and physical fitness, and prevention strategies may be tailored to a specific sport or injury.[2] Exercise training involves learning proper exercise techniques, such as understanding the limits of range of motion of each joint and avoiding joint positions that

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place the anatomic structures of the joint at risk for injury.[40] Exercise training usually involves some combination of strength, proprioceptive, balance, and neuromuscular training that is important for improving athletic performance and preventing injuries.[30,107,127]

The purpose of this comprehensive review was to quantify the number of systematic reviews and meta-analyses that have examined the effectiveness of sports injury prevention programs on reducing musculoskeletal injuries, evaluate the quality of each systematic review, identify the primary studies included in each review, and provide a succinct summary of this vast body of literature for easy reference. We hypothesized that the largest number of articles would (1) pertain to sports injury prevention in general (as opposed to prevention strategies for specific sports) and (2) focus on preventing knee injuries that are common in sports.

METHODS

We performed a literature search in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[151] using PubMed, CINAHL, EMBASE, and the Cochrane databases to identify articles published in English between inception of these databases and August 31, 2020. Additional articles were found by hand searching the reference lists of included articles. The search terms were ("prevention" or "prevention programs") AND ("sports injury" OR "musculoskeletal injury") AND ("systematic review" or "meta-analysis"). We included systematic reviews and meta-analyses that evaluated the effectiveness of sports injury prevention programs on reducing musculoskeletal injuries. We excluded published abstracts, narrative reviews, articles not published in English, commentaries, studies that described sports injury prevention strategies but did not assess the effectiveness of these strategies, studies that did not assess musculoskeletal injuries, and studies that did not assess sports-related injuries.

The results of the entire literature search were entered into a single database, and duplicates were removed via electronic search and double-checked manually. Two of the authors (S.D.S. and M.A.K.) independently screened the results of the literature search, and 3 authors (S.D.S., J.W.K., and A.V.V.) reviewed studies that met inclusion in more detail and summarized the germane results. The articles that met inclusion criteria were summarized by 2 major topics: (1) all injuries and (2) injuries by anatomic site. Articles pertaining to all injuries were further subdivided into 9 topics: sports and exercise in general, soccer, ice hockey, dance, volleyball, basketball, tackle collision sports, climbing, and youth athletes. Articles pertaining to injuries by anatomic site were subdivided into 11 topics: general knee, anterior cruciate ligament (ACL), ankle, hamstring, lower extremity, foot, groin, shoulder, wrist, shin, and elbow. We determined the level of evidence for each systematic review according to the definitions set forth by the Oxford Centre for Evidence-Based Medicine.[88] Methodological quality was assessed using the AMSTAR-2 (A MeaSurement Tool to Assess systematic Reviews, revised version).[205] The list of 129 articles was divided in half among 4 authors (S.D.S., M.A.K., J.W.K., and A.V.V.) for AMSTAR-2 assessment, and thus each study was assessed independently by 2 authors (S.D.S. and M.A.K.). Last, we tallied the number of overlapping primary studies between systematic reviews within a particular topic.

RESULTS

Figure 1 presents the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart illustrating the literature search process. The literature search identified 507 unique articles, and of these, 129 met the inclusion criteria. Table 1 illustrates the number of included articles by topic. The majority of "all injury" articles pertained to sports and exercise in general (15.5%) and soccer (10.1%). Most of the "injuries by anatomic site" articles pertained to ACL (26.4%), ankle (10.9%), and hamstring (8.5%) injuries. Three of the 129 included articles covered >1 anatomic site. The level of evidence and the AMSTAR-2 results are shown in Table S1 (available as Supplemental Material). A total of 59 (45.7%) of the included systematic reviews were ranked as evidence level 1, and 71 (55.0%) were level 2. Based on the AMSTAR-2, 76 (58.9%) reviews reported a priori review methods, 124 (96.1%) performed a comprehensive literature search, 61 (47.3%) thoroughly described excluded articles, 102 (79.1%) assessed risk of bias for individual studies, 63 (48.8%) reported a valid method for statistical combination of data (ie, meta-analysis), 58 (45.0%) examined the effect of risk of bias on pooled study results, and 25 (19.4%) examined the risk for publication bias.

All Injuries

A total of 43 studies pertaining to prevention of all injuries were identified and are summarized by topic here. Tables S2 to S4 and Figures S1 to S3 (available as Supplemental Material) illustrate the overlapping primary studies between included systematic reviews.

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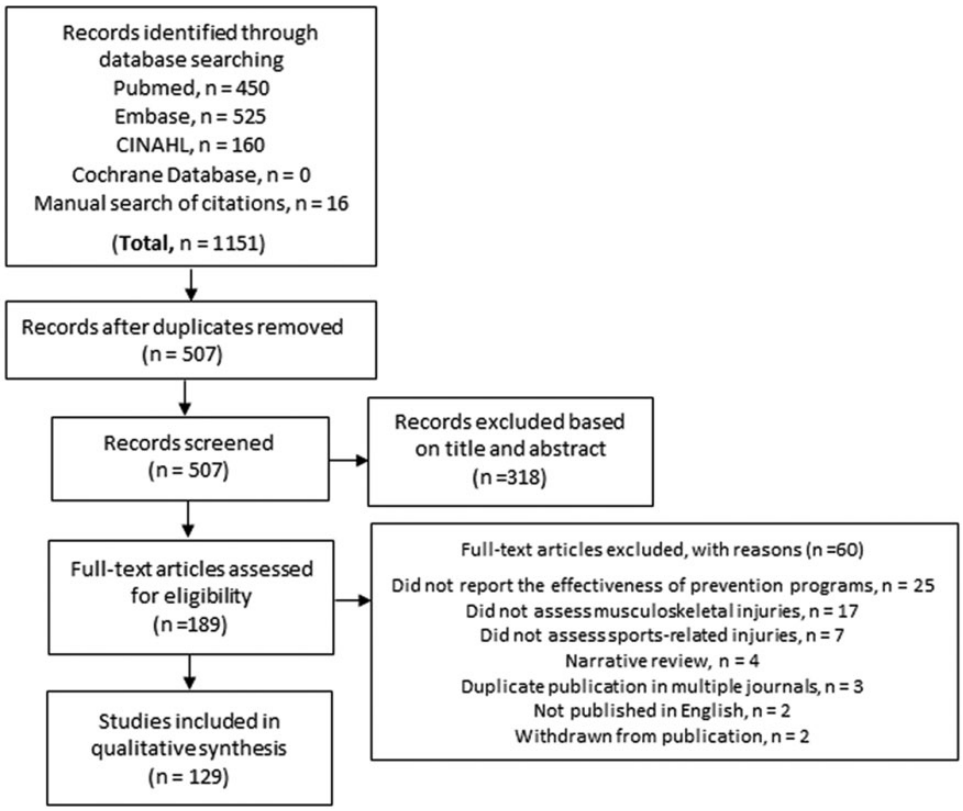

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart.

Sports and Exercise in General. A number of overlapping systematic reviews[‡] have examined the effectiveness of various injury prevention strategies for sports and exercise in general. Salam et al[194] pooled data from 24 studies and found that sports injury prevention interventions were effective in that interventions decreased the incidence of (1) injuries in general (relative risk [RR], 0.66; 95% confidence interval [CI], 0.53-0.82), (2) injuries per hour of exposure (RR, 0.63; 95% CI, 0.47-0.86), and (3) injuries per number of exposures (RR, 0.79; 95% CI, 0.70-0.88); however, the results of their study were not stratified by type of intervention. Two meta-analyses by Lauersen et al[127,128] found that strength training was effective for reducing the risk of sports injuries, and 1 of these studies[128] also found that proprioception training (RR, 0.55; 95% CI, 0.35-0.87) and a combination of exercises (RR, 0.66; 95% CI, 0.52-0.83) were effective at reducing sports injuries. Smyth et al[214] found moderate evidence demonstrating the effectiveness of exercise and psychological interventions for reducing injuries in pre-elite athletes competing in the Olympics or professional sports, but evidence was lacking with respect to the effectiveness of equipment and nutrition-related interventions. Two systematic reviews[1,129] found that the use of insoles, external joint supports, and multi-intervention or sport-specific training programs were effective for injury prevention. Of note, several overlapping systematic reviews have found no or minimal evidence regarding the effectiveness of stretching,[§] warm-up exercises,[1,69] or prevention videos[1,129] for injury prevention. Two systematic reviews[30,107] demonstrated that balance training was favorable for reducing overall injuries (RR, 0.49; 95% CI, 0.13-1.80) and defined the optimal balance training program for injury prevention as lasting for 8 weeks and including two 45-minute training sessions per week. Three overlapping systematic reviews[77,131,239] found that psychological interventions, including cognitive behavioral therapy and stress management—based interventions, were effective at reducing sports injuries. Ernst and Posadzki[60] found conflicting results regarding the effectiveness of chiropractic interventions for preventing sports injuries in their review of 6 studies. To summarize, there are multiple systematic reviews and meta-analyses demonstrating that injury prevention programs are effective, with strength, proprioception, balance, and psychological programs being specifically beneficial.

Soccer. Four overlapping systematic reviews[43,64,182,243] found mixed results for exercise-based prevention programs in soccer players, and all of these reviews were poor quality and at high risk for bias. Based on their review of 18 studies, Kirkendall et al[123] concluded that a structured warm-up program can be effective at reducing

[‡]References 1, 24, 30, 69, 77, 107, 127–130, 194, 207, 212, 214, 235, 258.

[§]References 1, 24, 94, 128–130, 207, 212, 235, 258.

TABLE 1
Number of Included Articles by Topic

Topic	No. of Articles
All injuries	
Sports and exercise in general	20
Soccer	13
Ice hockey	1
Dance	1
Volleyball	1
Basketball	1
Tackle collision sports	1
Climbing	1
Youth athletes	4
Injuries by anatomic site	
General knee[a]	8
Anterior cruciate ligament[a]	34
Ankle[a]	14
Hamstring	11
Lower extremity	10
Foot	6
Groin	2
Shoulder	1
Wrist	2
Elbow	1
Total unique articles	129

[a]Categories are not mutually exclusive.

soccer injuries by one-third. Based on their review of 13 studies, Slimani et al[211] found that psychological-based interventions were effective at reducing injury rates in soccer players. Seven overlapping systematic reviews and meta-analyses[4,6,21,79,119,192,238] examined the effectiveness of 2 soccer injury prevention programs developed by the Federation Internationale de Football Association (FIFA). The FIFA 11 and FIFA 11+ programs combine training in both technique and balance along with neuromuscular training exercises including strengthening and plyometrics with the goal of eliminating injuries. Al Attar et al[4] examined the combined effects of FIFA 11 and FIFA 11+ and found that overall injuries were reduced by 34% (RR, 0.66; 95% CI, 0.60 to 0.73) and lower limb injuries were reduced by 29% (RR, 0.71; 95% CI, 0.63 to 0.81). Gomes Neto et al[79] observed that FIFA 11 was associated with reduced injury risk (RR, 0.69; 95% CI, 0.49 to 0.98) and improvement in both dynamic balance (weighted mean difference, 2.68; 95% CI, 0.44 to 4.92) and agility (standardized mean difference, –0.36; 95% CI, –0.70 to 0.02) compared with controls. Two systematic reviews[21,192] demonstrated that FIFA 11+ resulted in (1) 30% to 70% fewer injuries and (2) significant improvement in many features of motor and neuromuscular performance. Two systematic reviews[6,238] directly compared FIFA 11 and FIFA 11+ and found that FIFA 11+ was associated with a greater reduction in injuries. In their review of 33 articles, Kilic et al[119] concluded that the FIFA 11+ program and the Nordic Hamstring Exercise (NHE) program were most effective for reducing musculoskeletal injuries in adult soccer players, while FIFA 11, balance board, the Prevent Injury and Enhance Performance program, a groin program, and balance board training were not effective injury prevention programs. To summarize, the FIFA 11+ program has been shown to reduce injuries and improve neuromuscular performance in soccer.

Ice Hockey. Cusimano et al[45] identified 13 studies that examined rule changes intended to minimize aggression (eg, restriction of body-checking) during ice hockey, of which 9 studies demonstrated a decrease in penalties ranging from 1.2 to 5.9 per game and in injury rates by 3- to 12-fold.

Dance. Hincapie et al[103] reviewed 2 cohort studies and concluded that there was weak evidence for the effectiveness of injury prevention programs in dancers.

Volleyball. Kilic et al[120] found evidence from 3 studies that (1) a resistance training program, (2) a program aimed at reducing anterior knee pain, and (3) balance board training were effective at reducing musculoskeletal injuries in volleyball players.

Basketball. Based on their systematic review of 4 studies, Kilic et al[121] concluded that each of the following programs was successful at reducing musculoskeletal injuries in basketball players: (1) a jump-landing technique intervention during warm-up, (2) a multistation proprioceptive exercise program, (3) a wobble board and sport-specific balance training program during warm-up, and (4) the FIFA 11+ program.

Tackle Collision Sports. Sewry et al[202] identified 7 studies that demonstrated that exercise-based intervention programs were successful at reducing injuries in tackle collision sports (ie, rugby union or league and American, Australian, and Gaelic football).

Climbing. Based on their systematic review of 19 studies, Woollings et al[260] found that both taping and weight training reduced injury rates in sport climbing and bouldering. However, the authors did not find any support for stretching, yoga, using instructors, regulating equipment usage, taking supplements, heating hands before climbing, and corticosteroid injections as injury prevention measures for sport climbing.

Youth Athletes. Several overlapping systematic reviews[2,37,189,217] have examined the effectiveness of various sports injury prevention strategies in youth (ie, adolescents or teenagers aged <20 years). Soomro et al[217] pooled data from 10 studies and found a 40% reduction (injury rate ratio, 0.60; 95% CI, 0.48-0.75) in injuries for multifaceted injury prevention programs (ie, a combination of warm-up, neuromuscular strength, and proprioception training) in adolescent team sports. Abernethy and Bleakley[2] reviewed 12 studies and found preseason conditioning, functional training, education, balance, and sport-specific skills to be moderately effective at preventing adolescent sports injuries. However, the effectiveness of protective equipment (eg, knee pads and knee braces) was inconclusive and requires further research. Rossler et al[189] conducted a meta-analysis of 21 randomized controlled trials (RCTs) and found that prevention programs geared toward both specific injuries and all injuries in children and adolescents were effective. Furthermore, the authors concluded that prevention programs including jumping or plyometric exercises were more effective than programs that did not include these types of exercises. Carder et al[37]

systematically reviewed 6 studies and found that 43% of youth athletes specialized in a single sport and these athletes were at greater risk for injury compared with youth athletes that sampled a variety of sports (RR, 1.37; 95% CI, 1.19-1.57).

Injuries by Anatomic Site

A total of 86 studies pertaining to prevention of injuries by anatomic site were identified and are summarized by topic here. Tables S5 to S10 and Figures S4 to S9 (available as Supplemental Material) illustrate the overlapping primary studies between included systematic reviews.

General Knee Injuries. Grimm et al[85] found insufficient evidence regarding the effectiveness of knee injury prevention programs in athletes based on their review of 10 RCTs; however, the authors did not distinguish among different types of injury prevention programs. Thacker et al[236] found limited evidence supporting the effectiveness of neuromuscular training and conditioning programs for reducing knee injuries. On the other hand, 3 overlapping systematic reviews[51,84,99] have demonstrated that neuromuscular training programs reduced knee injuries by 27%. Ter Stege et al[233] systematically reviewed 35 studies and found that neuromuscular injury prevention programs were effective at reducing several risk factors (ie, knee valgus moments, knee flexion angles, hamstring activation profiles, and vertical ground-reaction forces) that are associated with knee injuries in team ball sports. Three overlapping systematic reviews[179,195,236] have found that wearing a knee brace is not effective at reducing knee injuries in athletes.

ACL Injuries. All Athletes. Two systematic reviews[7,163] concluded that the available evidence was too weak to make any conclusions about the effectiveness of ACL injury prevention programs in general; however, several more recent systematic reviews[85,152,232] have found ACL injury prevention programs to be effective. Grindstaff et al[86] conducted a meta-analysis of 5 studies and estimated that 89 individuals (95% CI, 66-136) would need to participate in an injury prevention program to prevent 1 ACL injury per season. Furthermore, these authors concluded that the most important components of an ACL injury prevention program were plyometrics, strengthening, flexibility, agility, and feedback. Padua and Marshall[168] found moderate evidence to support the use of ACL injury prevention programs, which incorporate proprioception/balance or plyometric/agility training in athletes; however, no studies directly compared the effectiveness of multifaceted versus single exercise programs. Arundale et al[15] found substantial evidence supporting the use of exercise-based prevention programs for reducing knee and ACL injuries in athletes. Several overlapping systematic reviews[‖] have found that neuromuscular training programs were effective at reducing ACL injuries by 51% to 62%, and 1 meta-analysis[193] found that neuromuscular training was more effective at reducing ACL injuries in male versus female patients. Sugimoto et al[224] found that participant age (ie, training was more effective for younger athletes compared with adults), dosage of training, exercise variations, and verbal feedback were the most effective components of a neuromuscular training program. Inclusion of at least 1 of these 4 components in a training program reduced the risk of ACL injury by 18%, and if all 4 components were incorporated into the program, the risk was reduced by as much as 73%.

Benjaminse et al[26] concluded that when teaching motor learning, giving athletes an external focus of attention (eg, soft landing) was more effective for increasing performance and decreasing the risk of ACL injuries compared with an internal locus of attention (eg, knee flexion). Furthermore, Armitano et al[12] found that motor learning programs using augmented information improved risk factors that were associated with ACL injuries. Neilson et al[157] concluded that using augmented feedback with jump landing training was an effective way to reduce 2 of the major risk factors for ACL injury: maximum knee flexion angle and vertical ground-reaction force.

Female Athletes. Several overlapping systematic reviews[¶] have focused on ACL injury prevention in female athletes. Two systematic reviews[161,223] have demonstrated the effectiveness of ACL injury prevention programs in female athletes; however, there were insufficient data to determine which specific program was most effective for reducing ACL injuries. On the other hand, 3 overlapping systematic reviews concluded that plyometrics,[38,254] strengthening,[227,254] and neuromuscular exercises[254] were the most effective components for injury prevention in female athletes. Moreover, Noyes and Barber Westin[160] found that both the Sportsmetrics and the Prevent Injury and Enhance Performance programs successfully reduced ACL injuries in female athletes; however, the Sportsmetrics program is very time-intensive (ie, 1-2 hours of training for 3 d/wk) and may compromise compliance. Based on their meta-analysis of 14 studies, Sugimoto et al[226] found that the most effective ACL injury prevention programs in female athletes were those (1) of longer duration (>20 minutes vs <20 minutes), (2) done more frequently (multiple times versus once per week), and (3) with a higher training volume. Myer et al[155] found that neuromuscular training was most effective at reducing ACL injuries in female athletes aged ≤18 years compared with >18 years (odds ratio [OR], 0.28; 95% CI, 0.18-0.42). Based on their meta-analysis of 18 studies, Petushek et al[176] found that interventions that targeted female athletes in middle school and high school (OR, 0.38; 95% CI, 0.24-0.60) reduced the odds of ACL injury more so than interventions targeting college or professional female athletes (OR, 0.65; 95% CI, 0.48-0.89). Only 1 meta-analysis[225] examined compliance with neuromuscular training in female athletes and found that high compliance was associated with a greater reduction in ACL injuries compared with low compliance (risk reduction ratio, 0.27; 95% CI, 0.07-0.80). Pfile and Curioz[178] concluded that both mixed leadership (RR reduction, 48.2%; 95% CI, 22%-65%) and

[‖]References 72, 96, 99, 106, 144, 171, 184, 193, 222, 228, 262.

[¶]References 38, 160, 161, 176, 178, 223, 225–227, 254.

coach-led (RR reduction, 58.4%; 95% CI, 40%-71%) injury prevention programs were successful at reducing ACL injuries in female athletes; however, the available evidence was low to moderate quality.

Ankle Injuries. Eight overlapping systematic reviews[#] have found the use of external supports, such as ankle bracing and taping, to be effective at reducing ankle injuries. Barelds et al[20] conducted a meta-analysis of 6 studies and found that ankle bracing was effective for both primary (RR, 0.53; 95% CI, 0.32-0.88) and secondary (RR, 0.37; 95% CI, 0.24-0.58) prevention of acute ankle injuries; however, the available evidence was low quality. Two systematic reviews[25,50] found that external supports reduced ankle injuries by 62% to 64%; however, another review[49] found that external supports were only effective in athletes with a history of ankle injuries.

Several overlapping systematic reviews have found evidence supporting the effectiveness of neuromuscular training,[34,35,250] proprioception and balance training,[25,34,48,143,197] and exercise interventions[50,83] for preventing ankle injuries. Four overlapping systematic reviews[25,48,116,197] found that proprioception or balance training reduced ankle injuries by 31% to 46%, and these training programs primarily consisted of single-leg stance challenges, wobble/balance board exercises, and sport-specific agility drills. Furthermore, Schiftan et al[197] found that proprioceptive training (ie, balance exercise with or without balance/wobble board or ankle disc for at least 8 weeks) was effective at reducing ankle sprains in athletes with (RR, 0.64; 95% CI, 0.51-0.81) and without (RR, 0.57; 95% CI, 0.34-0.97) a history of ankle sprain. Doherty et al[50] conducted a meta-analysis of 23 studies and found that exercise interventions reduced recurrent ankle sprains by 41% (pooled OR, 0.59; 95% CI, 0.51-0.68), and the most effective intervention was ankle disc or balance/wobble-board training for a minimum of 4 to 6 weeks. Grimm et al[83] conducted a meta-analysis of 10 RCTs and found that an exercise protocol focused on stretching, strength training, balance, and coordination reduced the risk of ankle injuries by 40% (RR, 0.60; 95% CI, 0.40-0.92). In summary, several systematic reviews and meta-analyses have found external supports and balance and proprioceptive training to be effective in preventing ankle injuries.

Hamstring Injuries. Hibbert et al[101] systematically reviewed 7 studies in 2008 and concluded that hamstring lowers, isokinetic strengthening, and other strengthening were effective at reducing hamstring strains; however, the included studies were deemed low quality and none of the studies examined eccentric strengthening in isolation. Two systematic reviews, 1 by Prior et al[183] in 2009 and the other by Monajati et al[152] in 2016, found low-level evidence suggesting that hamstring injury prevention programs in general may be effective at reducing hamstring injuries. Goldman and Jones[78] systematically reviewed 7 RCTs in 2010 and concluded that there was insufficient evidence regarding the effectiveness of strengthening, manual therapy, proprioception, and warm-ups/cool-downs for preventing hamstring injuries. Based on 2 systematic reviews[145,186] published in 2016 and 2013, respectively, there is inconclusive evidence regarding the effectiveness of stretching on reducing hamstring injuries. The NHE was designed to increase eccentric hamstring strength in soccer players, and 4 overlapping systematic reviews[5,80,203,245] conducted between 2015 and 2019 found that the NHE (used in isolation or combined with other interventions) reduced hamstring injuries by 49% to 65%. Two overlapping systematic reviews[80,203] published in 2015 and 2017, respectively, found that using a YoYo flywheel ergometer for eccentric hamstring strengthening was effective at reducing hamstring injuries in soccer players. In 2019, Vatovec et al[247] conducted a meta-analysis of 17 studies and found that hamstring injuries were reduced by 51% after exercise interventions and by 50% after neuromuscular interventions.

Lower Extremity Injuries. Several overlapping systematic reviews have demonstrated that exercise programs[33,261] and neuromuscular training programs[58,95,221,231] were effective at reducing lower extremity injuries. Emery et al[58] found that neuromuscular training reduced lower extremity injuries by 36% in youth athletes (injury risk reduction, 0.64; 95% CI, 0.49-0.84). Based on their meta-analysis of 10 RCTs, Taylor et al[231] found that neuromuscular training with or without lace-up ankle braces reduced the odds of lower extremity injuries in basketball players by 31% (OR, 0.69; 95% CI, 0.57-0.85). Steib et al[221] concluded that neuromuscular training was effective at reducing lower extremity injury risk in youth athletes, and the optimal regimen was 10- to 15-minute sessions 2 to 3 times a week. Herman et al[95] reviewed 9 studies and concluded that to be effective at reducing lower limb injuries, neuromuscular warm-up strategies should be completed for at least 3 months and should incorporate stretching, strengthening and balance exercises, sports-specific agility drills, and landing techniques. Yeung and Yeung[261] concluded that there was strong evidence suggesting that the incidence of lower extremity soft tissue running injuries can be reduced by decreasing running frequency, duration, and distance; however, the optimum training load could not be determined. There is weak or insufficient evidence regarding the effectiveness of (1) eccentric exercise, proprioception, and balance exercise for reducing lower extremity injuries in soccer players[137]; (2) exercise programs for prevention of lower limb injuries in Australian football players[10]; and (3) lower limb injury prevention programs in high school athletes.[138] Thacker et al[234] systematically reviewed 9 studies and found that using shock-absorbent orthotic inserts and a preseason conditioning regimen focused on lower extremity strength, agility, and flexibility may reduce the occurrence of shin splints in young male athletes.

Foot Injuries. Several overlapping systematic reviews found low to moderate evidence that shock-absorbing insoles may be effective at preventing stress fractures in an active military population; however, no other types of interventions (eg, reducing training volume and intensity) have been effective at reducing stress fractures, and no studies have been done in the general population.[29,76,114,187,204] A meta-analysis of 11 studies found that foot orthoses reduced

[#]References 20, 25, 34, 49, 50, 237, 249, 250.

the risk of stress fractures by 41% (RR, 0.59; 95% CI, 0.45-0.76).[29] Peters et al[173] found limited evidence supporting the use of balance training, shoe adaptations, and hormone replacement therapy in active postmenopausal women for reducing Achilles tendinopathy, and there was no evidence to support stretching for reducing Achilles tendinopathy.

Groin Injuries. Two nonoverlapping systematic reviews[39,62] found limited evidence to support the use of hip adductor and abdominal strengthening exercises for groin injury prevention.

Shoulder Injuries. Asker et al[16] identified only 1 study[9] that examined prevention of shoulder injuries in overhead sports and found no statistically significant effects of a strength and conditioning regimen on shoulder injuries in Norwegian handball players.

Wrist Injuries. Two overlapping systematic reviews[122,191] found that the risk for wrist injury, wrist fracture, and wrist sprain was reduced by 54% to 83% in snowboarders with the use of wrist guards.

Elbow Injuries. Deal et al[47] found that injury prevention programs were effective at reducing elbow injuries in baseball players.

DISCUSSION

This comprehensive review provides a thorough and concise summary of all systematic reviews and meta-analyses on the topic of sports injury prevention in general and for specific sports and injury types. The majority of "all injury" articles pertained to sports and exercise in general (15.5%) and soccer (10.2%). Most of the "injuries by anatomic site" articles pertained to ACL (26.4%), ankle (10.9%), and hamstring (8.5%) injuries. In line with our hypothesis, we found that most injury prevention systematic reviews pertained to sports injuries in general (as opposed to specific sports) and focused on prevention of knee injuries (both in general and specifically on the ACL). To our knowledge, this is the first comprehensive review of the systematic reviews and meta-analyses published on sports injury prevention.

Injury prevention programs are effective and can reduce injuries by at least 40% in both youth and adults.[194,217] Strength training, proprioception, balance, and psychological programs have all been shown to be beneficial, while stretching has not. Much of the research on preventing sport-related injuries in general has focused on specific sports,[45,103,120,121,202,260] primarily soccer.[**††] There is substantial evidence supporting the FIFA 11+ program for preventing soccer-related injuries; however, the systematic reviews on this topic include many overlapping studies.[4,6,21,79,119,192,238] There is limited low-quality research demonstrating that other exercise and psychological-based interventions are effective at reducing soccer-related injuries.[43,64,123,182,211,243] Several systematic reviews have found injury prevention programs tailored toward hockey,[45] volleyball,[120] basketball,[121] tackle collision sports,[202] and sport climbing and bouldering[260] to be effective at reducing musculoskeletal injuries in general.

Evidence regarding the effectiveness of neuromuscular training for preventing knee injuries in general has been contradictory,[51,84,99,236] and there is currently no systematic review evidence to support wearing a knee brace for injury prevention.[7,179,236] However, there is moderate evidence to support exercise and neuromuscular training programs for ACL injury prevention,[7,85,152,163,232] and the most effective components of these programs included plyometrics, strengthening, flexibility, agility, and feedback.[86] A number of systematic reviews have focused on ACL injury prevention in female athletes[††] and found that plyometrics,[38,254] strengthening,[227,254] and neuromuscular training[254] were most effective in this cohort. ACL injury prevention programs were most effective in female athletes aged <18 years[155] and among those who were highly compliant with the programs.[225] The most effective ACL injury prevention programs in female athletes were those lasting at least 20 minutes per session, with multiple sessions per week and at a high training volume.[226] It should be noted that the ACL injury prevention literature may be skewed toward female athletes since most of the studies evaluated female athletes only or included more female athletes than male athletes. There is substantial evidence supporting the use of ankle bracing and taping, which can reduce ankle injuries by at least 60%.[‡‡] Neuromuscular,[34,35,250] balance,[25,34,48,143,197] and exercise training[50,83] have also been shown to be effective for reducing ankle injuries. Exercise and neuromuscular training have been demonstrated to be effective at reducing hamstring injuries by 50%[247]; however, the effectiveness of strengthening remains uncertain,[78,80,101,203] and there is no evidence to support stretching[145,186] for hamstring injury prevention. Lower extremity injuries can be reduced by exercise[33,261] and neuromuscular training[58,95,221,231] programs, and the risk for stress fractures may be reduced by foot orthoses.[29,76,114,187,204] Wrist guards have been shown to reduce wrist injuries by 54% to 83% in snow boarders.[122,191] There is limited evidence available to be able to make any conclusions regarding groin,[39,62] shoulder,[16] and elbow[47] injuries and shin splints.[234]

There are several limitations of this study. There were a number of overlapping studies between systematic reviews and meta-analyses, which may have resulted in more weight being placed on the strength of evidence for certain topics than was truly warranted. Only 19.4% of the included reviews assessed publication bias, and 47.3% thoroughly described exclusion criteria. Thus, selection and/or publication biases may have affected the results of individual reviews. Also, only 48.8% of systematic reviews pooled their data for analysis. The remaining 50.2% did not pool data mainly because of considerable heterogeneity among included studies. Finally, this review was limited to a qualitative summary of the literature since there was too much heterogeneity between studies to warrant any pooled data

**References 4, 6, 21, 43, 64, 79, 119, 123, 182, 192, 211, 238, 243.

††References 38, 160, 161, 176, 178, 223, 225–227, 254.

‡‡References 20, 25, 34, 49, 50, 237, 249, 250.

analyses. However, strengths of this study include performing a thorough literature search in accordance with PRISMA and performing a thorough review of study quality and risk for bias using the AMSTAR-2.

CONCLUSION

This comprehensive review provides sports medicine providers and other interested parties with a single source of the most up-to-date published literature focused on the effectiveness of sports injury prevention and organizes the literature by anatomic site and general injury patterns.

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