[Physical Therapy]

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Prevention of Lower Extremity Injuries in Basketball: A Systematic Review and Meta-Analysis

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Context: Lower extremity injuries are common in basketball, yet it is unclear how prophylactic interventions affect lower extremity injury incidence rates.

Objective: To analyze the effectiveness of current lower extremity injury prevention programs in basketball athletes, focusing on injury rates of (1) general lower extremity injuries, (2) ankle sprains, and (3) anterior cruciate ligament (ACL) tears.

Data Sources: PubMed, MEDLINE, CINAHL, SPORTDiscus, and the Cochrane Register of Controlled Trials were searched in January 2015.

Study Selection: Studies were included if they were randomized controlled or prospective cohort trials, contained a population of competitive basketball athletes, and reported lower extremity injury incidence rates specific to basketball players. In total, 426 individual studies were identified. Of these, 9 met the inclusion criteria. One other study was found during a hand search of the literature, resulting in 10 total studies included in this meta-analysis.

Study Design: Systematic review and meta-analysis.

Level of Evidence: Level 2.

Data Extraction: Details of the intervention (eg, neuromuscular vs external support), size of control and intervention groups, and number of injuries in each group were extracted from each study. Injury data were classified into 3 groups based on the anatomic diagnosis reported (general lower extremity injury, ankle sprain, ACL rupture).

Results: Meta-analyses were performed independently for each injury classification. Results indicate that prophylactic programs significantly reduced the incidence of general lower extremity injuries (odds ratio [OR], 0.69; 95% CI, 0.57-0.85; $P < 0.001$) and ankle sprains (OR, 0.45; 95% CI, 0.29-0.69; $P < 0.001$), yet not ACL ruptures (OR, 1.09; 95% CI, 0.36-3.29; $P = 0.87$) in basketball athletes.

Conclusion: In basketball players, prophylactic programs may be effective in reducing the risk of general lower extremity injuries and ankle sprains, yet not ACL injuries.

Keywords: injury prevention; basketball; lower extremity; anterior cruciate ligament; ankle sprain

High participation rates in basketball have led to a large number of injuries, especially considering that basketball poses one of the highest risks of injury in team sports, with injury rates reported between 7 and 10 injuries per 1000 athletic exposures.[3,17,30,51] Though trunk, head, and upper extremity injuries are prevalent in basketball, evidence suggests that most injuries (58%-66%) are sustained in the lower extremity.[3,17] Specifically, both overuse (eg, tendinopathy, stress

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fracture) and traumatic (eg, ligamentous sprains) injuries are commonly observed in basketball populations.[3,11,16,17]

The 2 basketball-related injuries that traditionally receive the most attention are ankle sprains and anterior cruciate ligament (ACL) ruptures. Ankle sprains, especially lateral ankle sprains, are the most common diagnosed injury in both male and female basketball players, accounting for approximately 25% of all injuries.[11,16,30,58] Though ankle sprains may be relatively less severe than other injuries with regard to time lost from sport,[47] prevention efforts are important, considering the increased risk of recurrent sprain,[46] concomitant injury to the talus[62] and peroneal musculature,[18] and the development of chronic ankle instability with subsequent osteoarthritis[24] that can follow initial ankle sprains. The incidence of noncontact ACL injuries in basketball is of great concern because of the high incidence rate relative to other sports and the debilitating sequelae that accompany injury.[2,30] For instance, up to 16% of female basketball players may incur an ACL injury throughout their playing careers, rates that are typically 2 to 4 times greater than male basketball athletes.[37,61] ACL injuries can also lead to debilitating sequelae, including knee joint osteoarthritis, surgical reconstruction, and significant financial ramifications,[39,56] making prevention of the initial trauma especially important.

Basketball requires specific movements that differentiate its risk factors and mechanisms of injury from other sports. These demands have evolved over the past 2 to 3 decades as rule changes (eg, shorter shot clock, lighter women's ball) have sped up the game, resulting in physiologic adaptations of the participants.[14] Basketball is an inherently vertical sport, requiring 35 to 46 jumping and landing activities per game, which is 2 to 4 times greater than soccer and volleyball.[40,45,52,66] The multidirectional nature of basketball requires constant acceleration and deceleration, forcing athletes to change directions or activities every 2 to 3 seconds.[40,45] While other multidirectional sports emphasize sagittal plane movements (eg, jogging, sprinting), basketball has a greater demand of nonsagittal plane motion, especially frontal plane movements during defensive activity.[6-8]

Current prevention programs vary drastically in their focus and implementation. While some programs focus on neuromuscular training, others use external support (eg, taping, bracing, footwear), with both forms of prevention showing some promise in reducing lower extremity basketball-related injuries.[19,42] However, to progress with the design and implementation of a comprehensive, basketball-specific lower extremity injury prevention program, the current evidence relating to injury prevention programs in basketball needs to be synthesized. Therefore, the purpose of this study was to systematically search, review, and meta-analyze the effectiveness of current lower extremity injury prevention programs in basketball populations, focusing on injury rates of (1) general lower extremity injuries, (2) ankle sprains, and (3) ACL tears. We hypothesized that the literature would present inconsistent results in the prevention of injuries in basketball, ultimately resulting in no significant reduction of general lower extremity, ACL, or ankle sprain injury risk in this population.

METHODS

Study Design

A systematic review and meta-analyses were performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement.[34] The protocol was registered prior to initiation of the project (PROSPERA, #CRD42014007506).

Search Strategy

An electronic search was performed in January of 2015 of the PubMed, MEDLINE, CINAHL, SPORTDiscus, and Cochrane Central Register of Controlled Trials databases. The following terms were used in the search: (anterior cruciate ligament OR ACL OR knee OR ankle OR foot OR non-contact) AND (prevent* OR intervent*) AND basketball. No filters or limitations were imposed during any of the database searches.

Eligibility Criteria

Studies were included if they met the following criteria: (1) the study design was a randomized controlled or prospective cohort trial, (2) the study contained a population of competitive basketball players of any age (eg, professional, collegiate, scholastic, intramural), (3) the intervention was designed specifically to reduce lower extremity injuries, (4) participants remained in either the treatment or control group for the entirety of the study, (5) lower extremity injury incidence was reported in basketball players or this information was accessible by contacting the authors, and (6) the study was written in English.

Study Selection

Studies were independently reviewed by multiple authors, and interrater agreement was calculated using a Fleiss κ with values interpreted as: <0, poor agreement; 0.01 to 0.20, slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 to 1.0, almost perfect agreement.[33] Additionally, an extensive hand search of cited references of relevant articles was performed to identify other possible inclusions to this study.

Quality Assessment

Included studies were analyzed using a modified version of the Reach Efficacy Adoption Implementation Maintenance (RE-AIM) framework tool.[23] Though originally developed to assess the quality of general public health programs, RE-AIM has also been used to assess the quality of reporting of sports injury prevention programs.[55] The original version of the tool, which consists of 31 items, was shortened to include the 12 items most relevant to sports injury prevention, as decided on by the authors of this article (see the Appendix, available at http://sph.sagepub.com/content/by/supplemental-data). Two reviewers independently scored half of the included studies, resulting in substantial intraexaminer agreement (κ = 0.74 [0.57-0.90]). Thus, the scores from 1 reviewer were used for analysis.

Data Collection and Analysis

Data Extraction

Only data specific to basketball athletes were extracted from each study, including descriptive data of the population (sex, age, competitive level), type and details of the intervention, size of control and intervention groups, and number of injuries in each group. Data were classified into 3 groups based on the anatomic diagnosis reported (general lower extremity injury, ankle sprain, ACL rupture). When applicable, data from a single study were included in more than 1 group.

Statistical Analysis

Data were analyzed using Comprehensive Meta Analysis, V2.0 (Biostat) and SPSS V21 (IBM Corp). To standardize data between studies, injury rates were calculated based on player seasons (PS) by multiplying the number of athletes by the number of seasons in which injuries were tracked. This was chosen over athletic exposures because of inconsistent reporting among included studies and previous studies that reported comparable meta-analytic findings between the 2 methods.[70] Odds ratios (ORs) with 95% CIs were calculated based on their statistical properties that best match meta-analytic procedures.[10]

Inverse variance meta-analyses, using a random effects model, were performed to compute the overall effect estimates of injury prevention programs in the reduction of general lower extremity injuries, ankle sprains, and ACL ruptures. The 95% CIs for the mean of each population were calculated, with $\alpha = 0.05$, indicating that the true OR was different than 1. Heterogeneity was assessed via the I^2 statistic to describe the total variation across studies other than by random chance. Values of $I^2 > 75\%$ are considered high, 50% to 75% considered moderate, and 25% to 50% considered low heterogeneity.[27] Publication bias was assessed qualitatively with a standard funnel plot and quantitatively for statistically significant meta-analyses using Rosenthal fail-safe *N*, which determines the number of potential missing studies that could make the overall effect nonsignificant.[63]

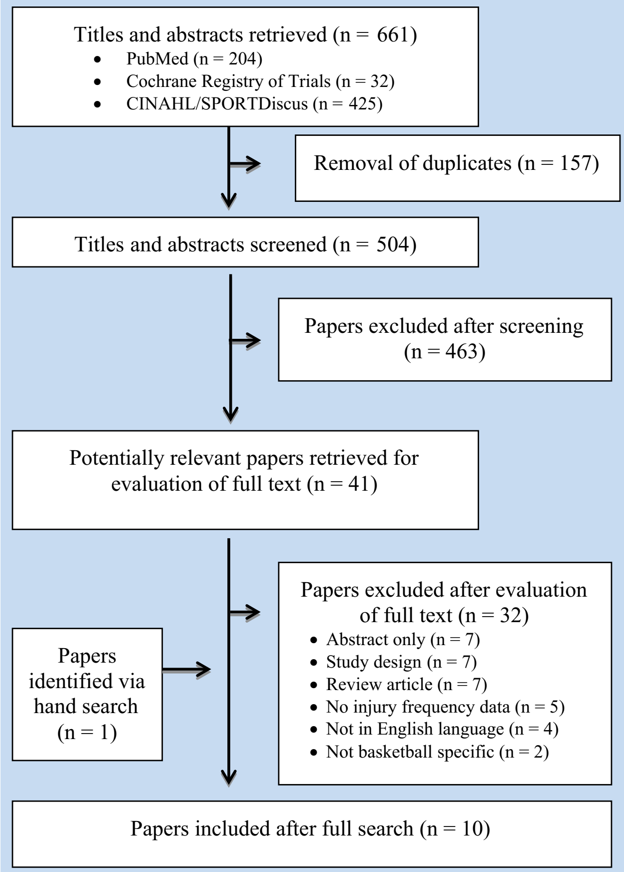

Figure 1. Flow diagram of retrieved, screened, and included studies.

RESULTS

Search Results

The electronic database search of PubMed, MEDLINE, CINAHL, SPORTDiscus, and the Cochrane Register of Controlled Trials yielded 661 results (Figure 1). The 2 raters exhibited substantial agreement in title and abstract ($\kappa = 0.74$; 95% CI, 0.61-0.86) and full-text review ($\kappa = 0.72$; 95% CI, 0.48-0.95). One additional study was included after an exhaustive hand search, leaving 10 studies included in the final analysis (Tables 1-3 in Appendix, available at http://sph.sagepub.com/content/by/supplemental-data).

Quality Assessment

The quality assessment analysis using the modified RE-AIM framework showed a wide range of scores (2-10 out of 12), with an average score of 5.0 (Tables 1-3 in Appendix). In general, included studies consistently reported about reach (target population), efficacy, and adoption, yet were less consistent in reporting aspects of implementation (compliance) and long-term maintenance of the program.

General Lower Extremity Injury

Four studies reported total lower extremity injury rates rather than exclusively reporting 1 injury diagnosis (Table 1 in Appendix).[1,21,36,42] Though only 1 prevention program individually exhibited a statistically significant reduction of lower extremity injuries,[42] pooled meta-analysis revealed an overall statistically significant reduction in general lower extremity injury rates (OR, 0.69; 95% CI, 0.57-0.85; $P < 0.001$) in basketball athletes (Figure 2). I^2 was calculated as 0%, indicating that meta-analysis results were considered to have minimal effect from heterogeneity, and no further examination was warranted. Visual inspection of a funnel plot revealed some publication bias in the analysis due to lack of inclusion of small studies with insignificant findings that may have been unpublished or not found by our search strategies. A classic fail-safe *N* test showed that 10 additional studies would need to be included in the meta-analysis to change the results to nonsignificant.

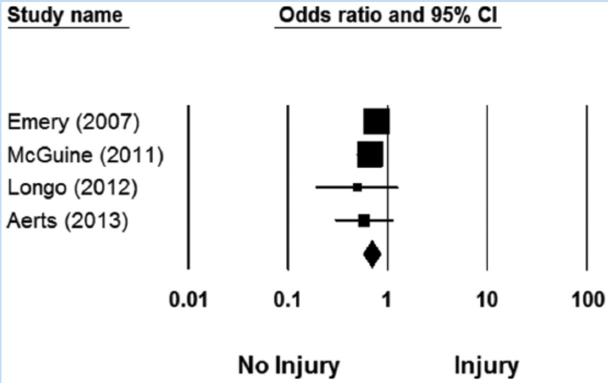

Figure 2. Meta-analysis forest plot of the effect of injury prevention programs on general lower extremity injuries in basketball players.

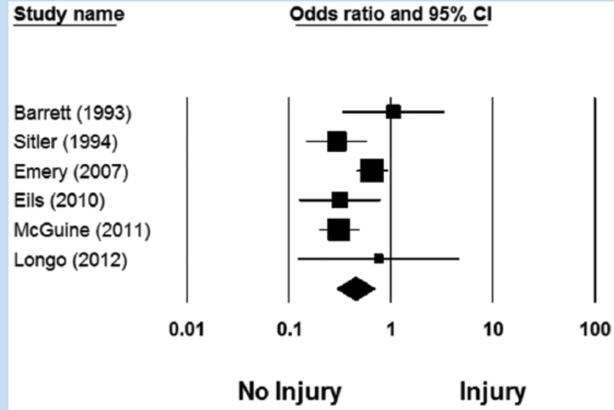

Figure 3. Meta-analysis forest plot of the effect of injury prevention programs on ankle sprain injuries in basketball players.

Ankle Sprain

Six studies analyzed the effect of prophylactic interventions on ankle sprain in basketball players (Table 2 in Appendix).[5,20,21,36,42,67] Meta-analysis revealed a statistically significant reduction of ankle sprains in basketball athletes with prophylactic intervention (OR, 0.45; 95% CI, 0.29-0.69; $P < 0.001$) (Figure 3). Analysis of a funnel plot suggested that publication bias may be present due to the lack of inclusion of small studies with significant findings that have not been found or identified by our search strategy, though results of a classic fail-safe *N* test revealed that 42 additional tests would need to be included in the meta-analysis to change the results to nonsignificant. Moderate heterogeneity concerns were identified ($I^2 = 55.3\%$). Therefore, an exploratory subgroup analysis attempted to explain the heterogeneity by differentiating the effectiveness of neuromuscular training relative to the use of external ankle support in reducing ankle sprain incidence. Both neuromuscular training (OR, 0.58; 95% CI, 0.38-0.88; $P = 0.010$) and external ankle supports (OR, 0.38; 95% CI, 0.22-0.68; $P < 0.001$) were effective in reducing ankle sprain injury risk in basketball athletes. The subgroup analysis resulted in minimal heterogeneity in the neuromuscular training group ($I^2 = 10.4\%$), yet moderate heterogeneity remained in the external ankle support group ($I^2 = 49.8\%$). Removing 1 study from the external ankle support group that utilized footwear as opposed to an ankle brace would have substantially reduced the heterogeneity of effect sizes. However, because of the exploratory nature of this article and in favor of a more comprehensive analysis, we decided to include all studies in our final analysis. It is also worth noting that 2 of the 3 studies that examined the role of external ankle supports have been performed in an intramural population, which may not have as strict an organization or as high athletic demands as other more competitive populations and could potentially bias the results.

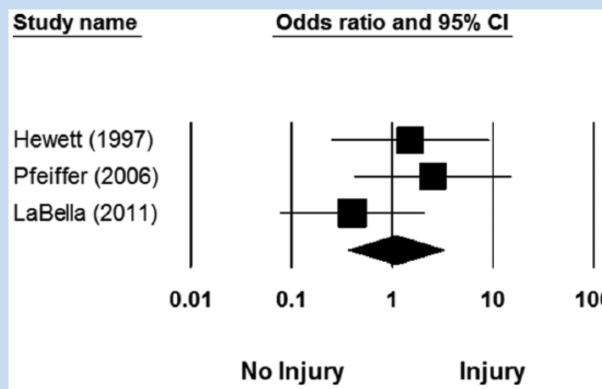

Figure 4. Meta-analysis forest plot of the effect of injury prevention programs on general anterior cruciate ligament injuries in basketball players.

Anterior Cruciate Ligament Injury

Three studies that examined the effect of neuromuscular training on the incidence of ACL rupture in basketball players were included (Table 3 in Appendix).[25,32,60] Results of the meta-analysis revealed no statistically significant reduction in ACL injury rates (OR, 1.09; 95% CI, 0.36-3.29; $P = 0.87$) in basketball athletes (Figure 4). I^2 was calculated to be 16.0% for this analysis, suggesting that meta-analysis results had a low effect from heterogeneity, warranting no further examination. Visual inspection of a funnel plot revealed some publication bias, though the small number of included studies makes interpretation difficult.

DISCUSSION

Basketball requires significant vertical and frontal plane demands that distinguishes it from other multidirectional sports.[6,7,12] Consequently, injury prevention programs may need to account for these sport-specific demands, as they could lead to different risk factors and mechanisms of lower extremity injury in basketball than other sports. Injury prevention programs in basketball are lacking, with interventions often being uniformly administered to basketball players and other athletes, such as soccer and volleyball players. Only 10 basketball-specific studies were included in this review and analysis, which is consistent with other studies highlighting the dearth of quality evidence in basketball injury prevention.[48,55] Despite the low number of studies, results positively indicate that injury prevention programs may be successful in reducing general lower extremity injuries and ankle sprains in basketball athletes. In line with previous systematic reviews and meta-analyses,[48,61] injury prevention programs appear to be less successful in reducing basketball-related ACL injuries.

General Lower Extremity Injury

Our meta-analysis results indicate that injury prevention programs are effective in reducing the incidence of general lower extremity injuries in basketball players. This finding is both interesting and significant since injury of any single joint of the lower extremity is complex. For example, increased risk of ACL injury can be attributed to biomechanical factors at the knee and hip,[26] deficits in neuromuscular control of the trunk,[75] and anatomic factors at the hip and knee.[53,69] “General lower extremity injuries” as a category encapsulates a heterogeneous group of injuries involving multiple joints and multiple mechanisms. Therefore, improving risk factors for 1 pathology may increase the risk for another. For example, decreasing hip adduction and internal rotation by strengthening hip extensors and external rotators is a primary goal of most ACL prevention programs, and yet, increased external rotation strength may increase the risk of patellofemoral pain syndrome,[9] all of which may be triggered by different risk factors or mechanisms of injury. Results of 1 of the studies in our review may have exhibited a similar relationship.[42] While prophylactic ankle braces reduced the risk of ankle injury, there was a trend toward injuries elsewhere in the lower extremity.[42] It may be that artificially adding stability at 1 joint redirects force to another joint, making that joint more likely to be injured.

Though the programs in this review differed in their exercise prescription and intensity, pooled meta-analysis results indicate that lower extremity injury risk may be reduced through dedicated neuromuscular prevention efforts, likely indicating that this approach is foundational to any lower extremity injury prevention program. Whether by neuromuscular training, the use of external support, or a combination of both, the optimal methodology for reducing lower extremity injury risk in basketball players needs further study.

Ankle Injury

Basketball-specific injury prevention programs significantly reduce the incidence of ankle sprains in basketball athletes. One study reported a numbers needed to treat analysis, stating that only 7 basketball players need to participate in a 9-week balance training program to prevent 1 ankle injury.[20] While neuromuscular programs utilized multiple training components, the most emphasis was placed on static and/or dynamic balance training. Prevention programs that emphasize proprioception and balance training have also been successful in reducing ankle injuries in other high-risk multidirectional sports, including soccer and volleyball.[4,44,72] There is strong evidence that supports the effect of a neuromuscular balance training program on improving balance (postural sway) and multiplanar joint position sense.[20,73,74] Considering that poor balance control and ankle joint position sense have been reported to be the intrinsic risk factors most predictive of ankle sprain,[43,59] balance training warrants incorporation into ankle sprain prevention efforts.

External ankle supports, including high-top shoes and ankle braces, were also found to reduce the risk of ankle injury in basketball players. Individual study results suggest that ankle bracing may be more effective than high-top shoes in preventing ankle injury.[42,54] Ankle braces reduce nonweightbearing and weightbearing inversion range motion,[19,35,71] increase muscle activation and excitability,[35,54] and decrease joint velocity,[41,71] which may explain the mechanism for reduced risk of ankle injury in basketball players.

Long-term use of ankle braces is a highly debated topic because the surrounding muscles may become weak and/or lose the ability to respond to perturbation, potentially increasing the risk of injury. However, there is evidence that the onset latency of the peroneal musculature is not affected, which is the main dynamic restraint to sudden ankle inversion, in response to a sudden inversion perturbation.[13] This suggests that extended use of an ankle brace does not result in neuromuscular changes in the dynamic stabilizer of the ankle and may not increase the risk of lateral ankle sprains.

Our search did not identify any studies that specifically analyzed the effect of ankle taping on injury risk in the basketball population. This was surprising considering that taping is equally as common as bracing.[46] Current evidence is mixed whether bracing or taping is more effective in reducing ankle injury risk.[49,64,72]

Of note, ankle sprains are rarely a 1-time occurrence for a basketball athlete, as those with a history of ankle sprain are almost 5 times more likely to incur a recurrent injury.[46] To date, secondary prevention (reducing the risk of subsequent injury) of ankle sprains has been more successful than primary prevention (reducing the risk of initial injury).[65] After an ankle sprain, athletes characteristically exhibit reduced balance, strength, and joint stability and increased peroneal reaction time.[28,29] Evidence is currently mixed as to whether neuromuscular training[65,68] or the use of external ankle support (specifically bracing)[31,57] is more effective at reducing recurrent ankle sprains. However, it could be argued that both neuromuscular training and external ankle supports may help alleviate the risk of subsequent injury by improving 1 or more of the aforementioned risk factors and may be most effective in combination.

Anterior Cruciate Ligament Injury

Only 3 studies were identified that investigated ACL injury prevention in basketball, all of which involved female athletes. Injury prevention programs were not successful in reducing ACL injuries in basketball athletes. This finding is consistent with previous meta-analyses that have reported that ACL injury prevention programs are significantly less successful in basketball than other multidirectional sports, such as soccer.[48,61] However, interventions that involved other female sports such as soccer, team handball, and volleyball have been successful at reducing ACL injuries.[22,25,32,38] The distinct sport-specific demands in basketball, including more frequent jumping and both single- and double-leg landings and frontal plane movements such as lateral shuffling, may influence the relative success of basketball injury prevention programs.[6-8,52] Interestingly, the 3 ACL injury prevention programs included in this study were also uniformly administered to soccer and/or volleyball players. Basketball athletes have distinct movement strategies, evidenced by greater vertical ground reaction forces that occur over a shorter time during landing[15] and greater levels of lower extremity valgus during single-leg activities[50] than soccer players. Movement differences specific to each sport indicate that focused injury prevention may be necessary in basketball players. The ACL injury prevention programs contained relatively few frontal plane and single-leg activities, despite the inherent demands of basketball. Instead, programs were mainly focused on double-leg sagittal plane activities in efforts to improve lower extremity strength and neuromuscular control of dynamic lower extremity valgus, the primary biomechanical risk factor for ACL injury.[26] However, modifying biomechanics during sagittal plane tasks may not translate to the same neuromuscular movement strategies during frontal plane tasks, suggesting that current prevention programs may not provide the appropriate stimulus to improve the high-risk biomechanics specifically associated with ACL injury in basketball.

Limitations

The systematic review and meta-analyses are subject to limitations based on the quantity and quality of previously published programs in a basketball population. Considering the few number of included studies, diverse definition of injury and injury tracking systems, the lack of high-quality studies, and the heterogeneity of the prevention programs and populations studied, it is difficult to make specific recommendations regarding the optimal lower extremity injury prevention programs. No studies have specifically addressed the extent to which a prevention program reduces the risk of general lower extremity injury, ankle sprains, and ACL tears, leaving open the possibility that what has a protective effect on 1 injury may be detrimental in reducing the risk of another.

CONCLUSION

Current injury prevention programs may be effective in reducing the risk of general lower extremity injury and ankle sprains, but not anterior cruciate ligament injuries in basketball athletes.

REFERENCES

1. Aerts I, Cumps E, Verhagen E, et al. A 3-month jump-landing training program: a feasibility study using the RE-AIM framework. *J Athl Train*. 2013;48:296-305.
2. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in National Collegiate Athletic Association basketball and soccer: a 13-year review. *Am J Sports Med*. 2005;33:524-530.
3. Agel J, Olson DE, Dick R, Arendt EA, Marshall SW, Sikka RS. Descriptive epidemiology of collegiate women's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42:202-210.
4. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scand J Med Sci Sports*. 1997;7:166-171.
5. Barrett JR, Tanji JL, Drake C, Fuller D, Kawasaki RI, Fenton RM. High-versus low-top shoes for the prevention of ankle sprains in basketball players. *Am J Sports Med*. 1993;21:582-585.
6. Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, El Ati J. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. *J Strength Cond Res*. 2010;24:2330-2342.
7. Ben Abdelkrim N, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*. 2007;41:69-75.
8. Bloomfield J, Polman R, O'Donoghue P. Physical demands of different positions in FA Premier League soccer. *J Sports Sci Med*. 2007;6:63-70.
9. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. *Am J Sports Med*. 2009;37:2108-2116.
10. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. *Introduction to Meta-Analysis*. Chichester, UK: Wiley; 2009.
11. Borowski LA, Yard EE, Fields SK, Comstock RD. The epidemiology of US high school basketball injuries, 2005-2007. *Am J Sports Med*. 2008;36:2328-2335.
12. Conte D, Favero TG, Lupo C, Francioni FM, Capranica L, Tessitore A. Time-motion analysis of Italian elite women's basketball games: individual and team analyses. *J Strength Cond Res*. 2015;29:144-150.
13. Cordova ML, Cardona CV, Ingersoll CD, Sandrey MA. Long-term ankle brace use does not affect peroneus longus muscle latency during sudden inversion in normal subjects. *J Athl Train*. 2000;35:407-411.
14. Cormery B, Marcil M, Bouvard M. Rule change incidence on physiological characteristics of elite basketball players: a 10-year-period investigation. *Br J Sports Med*. 2008;42:25-30.
15. Cowley HR, Ford KR, Myer GD, Kernozek TW, Hewett TE. Differences in neuromuscular strategies between landing and cutting tasks in female basketball and soccer athletes. *J Athl Train*. 2006;41:67-73.
16. Cumps E, Verhagen E, Meeusen R. Prospective epidemiological study of basketball injuries during one competitive season: ankle sprains and overuse knee injuries. *J Sports Sci Med*. 2007;6:204-211.
17. Dick R, Hertel J, Agel J, Grossman J, Marshall SW. Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42:194-201.
18. Dombek MF, Lamm BM, Saltrick K, Mendicino RW, Catanzariti AR. Peroneal tendon tears: a retrospective review. *J Foot Ankle Surg*. 2003;42:250-258.
19. Eils E, Demming C, Kollmeier G, Thorwesten L, Völker K, Rosenbaum D. Comprehensive testing of 10 different ankle braces. Evaluation of passive and rapidly induced stability in subjects with chronic ankle instability. *Clin Biomech (Bristol, Avon)*. 2002;17:526-535.
20. Eils E, Schröter R, Schröder M, Gerss J, Rosenbaum D. Multistation proprioceptive exercise program prevents ankle injuries in basketball. *Med Sci Sports Exerc*. 2010;11:2098-2105.
21. Emery CA, Rose MS, McAllister JR, Meeuwisse WH. A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clin J Sport Med*. 2007;17:17-24.
22. Gilchrist J, Mandelbaum BR, Melancon H, et al. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med*. 2008;36:1476-1483.
23. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health*. 1999;89:1322-1327.
24. Golditz T, Steib S, Pfeifer K, et al. Functional ankle instability as a risk factor for osteoarthritis: using T2-mapping to analyze early cartilage degeneration in the ankle joint of young athletes. *Osteoarthritis Cartilage*. 2014;22:1377-1385.
25. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med*. 1999;27:699-706.

26. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33:492-501.
27. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327:557-560.
28. Hiller CE, Nightingale EJ, Lin CW, Coughlan GF, Caulfield B, Delahunt E. Characteristics of people with recurrent ankle sprains: a systematic review with meta-analysis. *Br J Sports Med*. 2011;45:660-672.
29. Hoch MC, Mckeon PO. Peroneal reaction time after ankle sprain: a systematic review and meta-analysis. *Med Sci Sports Exerc*. 2014;46:546-556.
30. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311-319.
31. Janssen KW, Van Mechelen W, Verhagen EA. Bracing superior to neuromuscular training for the prevention of self-reported recurrent ankle sprains: a three-arm randomised controlled trial. *Br J Sports Med*. 2014;48:1235-1239.
32. Labella CR, Huxford MR, Grissom J, Kim KY, Peng J, Christoffel KK. Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. *Arch Pediatr Adolesc Med*. 2011;165:1033-1040.
33. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159-174.
34. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol*. 2009;62:e1-e34.
35. Lohrer H, Alt W, Gollhofer A. Neuromuscular properties and functional aspects of taped ankles. *Am J Sports Med*. 1999;27:69-75.
36. Longo UG, Loppini M, Berton A, Marinozzi A, Maffulli N, Denaro V. The FIFA 11+ program is effective in preventing injuries in elite male basketball players: a cluster randomized controlled trial. *Am J Sports Med*. 2012;40:996-1005.
37. Malone TR, Hardaker WT, Garrett WE, et al. Relationship of gender to anterior cruciate ligament injuries in intercollegiate basketball players. *J South Orthop Assoc*. 1993;2:36-39.
38. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*. 2005;33:1003-1010.
39. Mather RC 3rd, Koenig L, Kocher MS, et al; MOON Knee Group. Societal and economic impact of anterior cruciate ligament tears. *J Bone Joint Surg Am*. 2013;95:1751-1759.
40. Matthew D, Delextrat A. Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *J Sports Sci*. 2009;27:813-821.
41. McCaw ST, Cerullo JF. Prophylactic ankle stabilizers affect ankle joint kinematics during drop landings. *Med Sci Sports Exerc*. 1999;31:702-707.
42. McGuine TA, Brooks A, Hetzel S. The effect of lace-up ankle braces on injury rates in high school basketball players. *Am J Sports Med*. 2011;39:1840-1848.
43. McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*. 2000;10:239-244.
44. McGuine TA, Keene JS. The effect of a balance training program on the risk of ankle sprains in high school athletes. *Am J Sports Med*. 2006;34:1103-1111.
45. McInnes SE, Carlson JS, Jones CJ, Mckenna MJ. The physiological load imposed on basketball players during competition. *J Sports Sci*. 1995;13:387-397.
46. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med*. 2001;35:103-108.
47. Medina McKeon JM, Bush HM, Reed A, Whittington A, Uhl TL, McKeon PO. Return-to-play probabilities following new versus recurrent ankle sprains in high school athletes. *J Sci Med Sport*. 2014;17:23-28.
48. Michaelidis M, Koumantakis GA. Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: a systematic review. *Phys Ther Sport*. 2013;15:200-210.
49. Mickel TJ, Bottoni CR, Tsuji G, Chang K, Baum L, Tokushige KA. Prophylactic bracing versus taping for the prevention of ankle sprains in high school athletes: a prospective, randomized trial. *J Foot Ankle Surg*. 2006;45:360-365.
50. Munro A, Herrington L, Comfort P. Comparison of landing knee valgus angle between female basketball and football athletes: possible implications for anterior cruciate ligament and patellofemoral joint injury rates. *Phys Ther Sport*. 2012;13:259-264.
51. National Federation of State High School Associations. 2011-12 high school athletics participation survey. http://www.nfhs.org/ParticipationStatics/PDF/2011-12 Participation Survey.pdf. Accessed January 19, 2015.
52. Nedelec M, Mccall A, Carling C, Legall F, Berthoin S, Dupont G. The influence of soccer playing actions on the recovery kinetics after a soccer match. *J Strength Cond Res*. 2014;28:1517-1523.
53. Nguyen AD, Shultz SJ, Schmitz RJ. Landing biomechanics in participants with different static lower extremity alignment profiles. *J Athl Train*. 2015;50:498-507.
54. Nishikawa T, Grabiner MD. Peroneal motoneuron excitability increases immediately following application of a semirigid ankle brace. *J Orthop Sports Phys Ther*. 1999;29:168-173.
55. O'Brien J, Finch CF. The implementation of musculoskeletal injury-prevention exercise programmes in team ball sports: a systematic review employing the RE-AIM framework. *Sports Med*. 2014;44:1305-1318.
56. Oiestad BE, Engebretsen L, Storheim K, Risberg MA. Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am J Sports Med*. 2009;37:1434-1443.
57. Olmsted LC, Vela LI, Denegar CR, Hertel J. Prophylactic ankle taping and bracing: a numbers-needed-to-treat and cost-benefit analysis. *J Athl Train*. 2004;39:95-100.
58. Pappas E, Zazulak BT, Yard EE, Hewett TE. The epidemiology of pediatric basketball injuries presenting to US emergency departments: 2000-2006. *Sports Health*. 2011;3:331-335.
59. Payne KA, Berg K, Latin RW. Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *J Athl Train*. 1997;32:221-225.
60. Pfeiffer RP, Shea KG, Roberts D, Grandstrand S, Bond L. Lack of effect of a knee ligament injury prevention program on the incidence of noncontact anterior cruciate ligament injury. *J Bone Joint Surg Am*. 2006;88:1769-1774.
61. Prodromos CC, Han Y, Rogowski J, Joyce B, Shi K. A meta-analysis of the incidence of anterior cruciate ligament tears as a function of gender, sport, and a knee injury-reduction regimen. *Arthroscopy*. 2007;23:1320-1325.e6.
62. Roemer FW, Jomaah N, Niu J, et al. Ligamentous injuries and the risk of associated tissue damage in acute ankle sprains in athletes: a cross-sectional MRI study. *Am J Sports Med*. 2014;42:1549-1557.
63. Rosenthal R. The file drawer problem and tolerance for null results. *Psychol Bull*. 1979;86:638-641.
64. Rovere GD, Clarke TJ, Yates CS, Burley K. Retrospective comparison of taping and ankle stabilizers in preventing ankle injuries. *Am J Sports Med*. 1988;16:228-233.
65. Schiftan GS, Ross LA, Hahne AJ. The effectiveness of proprioceptive training in preventing ankle sprains in sporting populations: a systematic review and meta-analysis. *J Sci Med Sport*. 20145;18:238-244.
66. Sheppard JM, Gabbett TJ, Stanganelli LC. An analysis of playing positions in elite men's volleyball: considerations for competition demands and physiologic characteristics. *J Strength Cond Res*. 2009;23:1858-1866.
67. Sitler M, Ryan J, Wheeler B, et al. The efficacy of a semirigid ankle stabilizer to reduce acute ankle injuries in basketball. A randomized clinical study at west point. *Am J Sports Med*. 1994;22:454-461.
68. Stasinopoulos D. Comparison of three preventive methods in order to reduce the incidence of ankle inversion sprains among female volleyball players. *Br J Sports Med*. 2004;38:182-185.
69. Sturnick DR, Vacek PM, Desarno MJ, et al. Combined anatomic factors predicting risk of anterior cruciate ligament injury for males and females. *Am J Sports Med*. 2015;43:839-847.
70. Taylor JB, Waxman JP, Richter SJ, Shultz SJ. Evaluation of the effectiveness of anterior cruciate ligament injury prevention programme training components: a systematic review and meta-analysis. *Br J Sports Med*. 2015;49:79-87.
71. Vaes PH, Duquet W, Casteleyn PP, Handelberg F, Opdecam P. Static and dynamic roentgenographic analysis of ankle stability in braced and nonbraced stable and functionally unstable ankles. *Am J Sports Med*. 1998;26:692-702.
72. Verhagen EA, Van Mechelen W, De Vente W. The effect of preventive measures on the incidence of ankle sprains. *Clin J Sport Med*. 2000;10:291-296.
73. Waddington G, Adams R, Jones A. Wobble board (ankle disc) training effects on the discrimination of inversion movements. *Aust J Physiother*. 1999;45:95-101.
74. Waddington G, Seward H, Wrigley T, Lacey N, Adams R. Comparing wobble board and jump-landing training effects on knee and ankle movement discrimination. *J Sci Med Sport*. 2000;3:449-459.
75. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35:1123-1130.