A Systematic Review and Meta-analysis of Anterior Cruciate Ligament Injury Prevention Programs

Training to Stay in the Game

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Background: Approximately 400,000 anterior cruciate ligament (ACL) reconstructions are performed each year in the United States. Effective ACL injury prevention programs may be paramount in reducing this significant injury burden.

Purpose: To determine the effectiveness of ACL injury prevention programs and generate updated guidelines to protect athletes from these injuries.

Study Design: Meta-analysis, Level of evidence, 2.

Methods: The Embase, PubMed, and Ovid (MEDLINE) databases were searched in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Included studies focused on ACL injury prevention as opposed to treatment and provided data on ACL injury rates after intervention implementation. Using random-effects models, the authors generated the pooled risk ratio (RR) for all data and female-only data, <18 years versus ≥18 years of age data, handball data, soccer data, and balance board data.

Results: Eighteen articles were identified (9 randomized controlled trials, 9 prospective cohort studies). The 25,166 studied athletes (mean age, 19.3 ± 3.6 years; >85% female) played handball, soccer, basketball, or volleyball. All interventions were studied for a minimum of 1 season (mean, 1.3 ± 0.59). Athletes who participated in an ACL injury prevention program were significantly less likely to sustain an ACL rupture with a pooled RR of 0.46 (95% CI, 0.36-0.57). When analyzed by age, there was a significant risk reduction in ACL rupture for both athletes <18 years and ≥18 years (RR, 0.35 [95% CI, 0.22-0.55] and RR, 0.50 [95% CI, 0.38-0.64], respectively). The pooled RR was also statistically significant for female players (RR, 0.57 [95% CI, 0.43-0.74]), soccer and handball athletes (RR, 0.30 [95% CI, 0.19-0.46] and RR, 0.66 [95% CI, 0.46-0.96], respectively), and players participating in programs including balance boards (RR, 0.49 [95% CI, 0.35-0.67]).

Conclusion: Athletes who did not partake in an ACL injury prevention program were nearly twice as likely to sustain an ACL rupture compared with those who did. This study provides strong support for using neuromuscular training programs to significantly reduce the risk of ACL rupture among athletes.

Keywords: injury prevention; anterior cruciate ligament (ACL); proprioception and balance; female athletes

Anterior cruciate ligament (ACL) ruptures pose a devastating threat to athletic performance and activities of daily life. The ACL is the most commonly injured ligament in the knee, constituting almost half of all knee injuries.[22] Approximately 400,000 ACL reconstructions are performed each year in the United States alone.[22] In recent years, research has suggested increases in ACL injury rates in adolescent athletes, likely driven by increases in high school sport participation.[5,7,30,45] ACL rupture also remains a challenge in collegiate athletics, especially among female athletes.[11,25] In an epidemiological study using National Collegiate Athletic Association injury data from 2014 to 2019, Dewig et al[11] found that 0.86 ACL injuries occurred per 10,000 hours of collegiate athlete-exposure, with rates as high as 2.60 injuries per 10,000 hours of exposure in women's soccer.

Aside from missed playing time, ACL ruptures incur substantial cost and long-term musculoskeletal deficits. In active patients, ACL reconstruction is typically recommended to prevent secondary knee joint injury, including

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meniscal and cartilage damage.[12] Herzog et al[18] analyzed an administrative claims database in the United States and found that the mean health care utilization for ACL reconstruction was $17,353.97 from 2005 to 2013. While ACL reconstruction can prevent secondary knee joint injuries and allow athletes to return to pivoting movements, surgery does not entirely mitigate the sequelae of ACL rupture; specifically, reconstruction has not been proven to prevent the onset of posttraumatic osteoarthritis.[9,10,37] Therefore, according to the study by Ajuied et al,[2] even when athletes undergo ACL reconstruction, their operative knee is >3 times more likely to develop osteoarthritis within 10 years as compared with their contralateral leg. Notably, patients who did not pursue ACL reconstruction were almost 5 times as likely to experience osteoarthritis.[2]

Both the medical community and the general public have acknowledged the cost, prevalence, and gravity of ACL ruptures. In an effort to combat these devastating outcomes, neuromuscular training programs focused on agility, speed, and strength have been developed with the aim to prevent ACL injuries. Examples include the Prevent Injury and Enhance Performance Program, Frappier Acceleration Training Program, and FIFA 11+ injury prevention program, all of which emphasize correct form and avoidance of high-risk biomechanics (see Appendix 1, available in the online version of this article).[14,17,27,40] However, there are few studies that have implemented these ACL injury prevention protocols, and even fewer that have aggregated the data from these individual trials to draw meaningful conclusions. Many works are narrow in scope and impact, limited to narrative reviews, single-sport studies, or single-sex studies.[3,4,15,31,39,46] One of the most recent studies to conduct a comprehensive meta-analysis of ACL injury prevention programs including both male and female athletes was performed by Sadoghi et al[38] in 2012. In the following 11 years, the data set for our analysis has more than doubled and includes a more diverse sample of athletes. This study systematically reviewed ACL injury prevention literature and synthesized data from 18 implemented ACL injury prevention programs. The purpose of this meta-analysis was to determine the effectiveness of ACL injury prevention programs and generate updated guidelines to protect athletes from these injuries.

METHODS

Search Strategy

We performed a systematic search of the Embase, PubMed, and Ovid (MEDLINE) databases from inception through November 19, 2023. Search terms included "anterior cruciate ligament," "injury," "tear," "rupture," "prevention," "control," "training," and "program." Results were filtered for English-language and human studies. This study was not registered with PROSPERO.

Study Screening

Two reviewers (S.L.W. and M.M.O.) independently completed title, abstract, and full-text screens in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[34] All duplicates were removed. Discrepancies at each stage of review were carried forward to the next stage of screening. Disagreements at the full-text stage would have been reviewed by a third reviewer, but S.L.W. and M.M.O. agreed on each included text. To assess interrater reliability, the kappa statistic (κ) was calculated for the title, abstract, and full-text screens. After screening the references of included articles, 2 additional articles were identified and incorporated into analyses.[19,32]

Included studies were interventional in nature, focusing on ACL injury prevention as opposed to treatment. To be included, studies must have provided data on ACL injury rates after intervention implementation; studies that only showed changes in biomechanical risk factors were not considered. We excluded case reports (n = 1), reviews, commentaries, and studies focused on individuals with ACL-deficient knees. We also excluded studies that focused on rehabilitation or reinjury after ACL reconstruction.

Data Collection

Data were extracted and recorded in Microsoft Excel (Version 16.82). Extracted data included the sample size, sport, level of play, type of intervention, salient components of intervention, mean age, and number of ACL injuries.

Data were prepared for subgroup analyses, including female-only data, <18 years versus $\geq$18 years of age data, handball data, soccer data, and balance board data. Lastly, for soccer and handball subanalyses, studies including multiple sports were reviewed and data were included if a breakdown was provided for the sport of interest. Subanalyses were only performed if at least 4 papers reported the metric of interest; for this reason, there are no male-only analyses.

Statistical Analysis

Given the number of players in the intervention/control groups and number of ACL ruptures in the intervention/

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control groups, the individual risk ratios (RRs) and 95% confidence intervals were calculated for each study. Using Meta-Mar (Version 3.5.1), we utilized an inverse variance method to compare the log risk ratio across the included studies and generate a pooled risk ratio.[6] A restricted maximum-likelihood estimator was used to calculate the heterogeneity variance (T^2). A continuing correction of 0.5 was used in studies with zero cell frequencies. Statistical significance was defined as a P value <.05.

Once the pooled risk ratio and forest plot were generated for all data, pooled risk ratios were also calculated for female-only data, <18 years versus ≥18 years of age data, handball data, soccer data, and balance board data. When preparing for subgroup analyses, data from Pfeiffer et al[36] and Hewett et al[19] were extracted for soccer subanalyses. The study by Stojanović et al[44] included professional players >16 years of age and was therefore excluded from age analyses. Lastly, the paper by Myklebust et al[29] included 3 years of study, 1 control season and 2 intervention seasons; therefore, 2 data points were produced, each including the control season and one of the intervention seasons. Before deciding to handle the data in this way, we considered a dose-response phenomenon between the first and second intervention seasons. We tested the analysis using 3 approaches: including only the first season, including only the second season, and including both seasons together to evaluate their individual and combined impacts. We found that using both seasons produced the most conservative estimate of the pooled risk ratio for all data (ie, suggested a lower impact of ACL injury prevention programs), and therefore we chose to use both seasons.

The Methodological Index for Non-Randomized Studies (MINORS) criteria were used to assess the methodological quality of included studies that were nonrandomized, whereas the Cochrane Collaboration tool for assessing risk of bias was used for randomized studies.[21,41] A funnel plot was generated to assess publication bias, and the heterogeneity of pooled data was assessed using the I^2 statistic.

RESULTS

Search Strategy

The initial search of the Embase, PubMed, and Ovid (MEDLINE) databases generated 11,447 results, and 7003 results remained after duplicate removal. Final review yielded 16 articles; after searching the references of included articles, 2 additional articles were incorporated into analyses for a total of 18 included articles (Figure 1).[19,32,34] Interrater reliability was calculated as follows: 0.94 for the title screen (almost perfect agreement), 0.84 for the abstract screen (strong agreement), and 1 for the full-text screen (almost perfect agreement).[28]

Study Quality

Of the 18 included studies, there were 8 cluster randomized controlled trials (RCTs),[1,14,24,32,40,42,44,47] 1 RCT using individual players as the unit of randomization,[17] and 9 nonrandomized prospective cohort (PC) trials.[‖] As all 18 studies were either RCTs or PC studies, they were designated as evidence level 1 or 2, respectively (Table 1).[48]

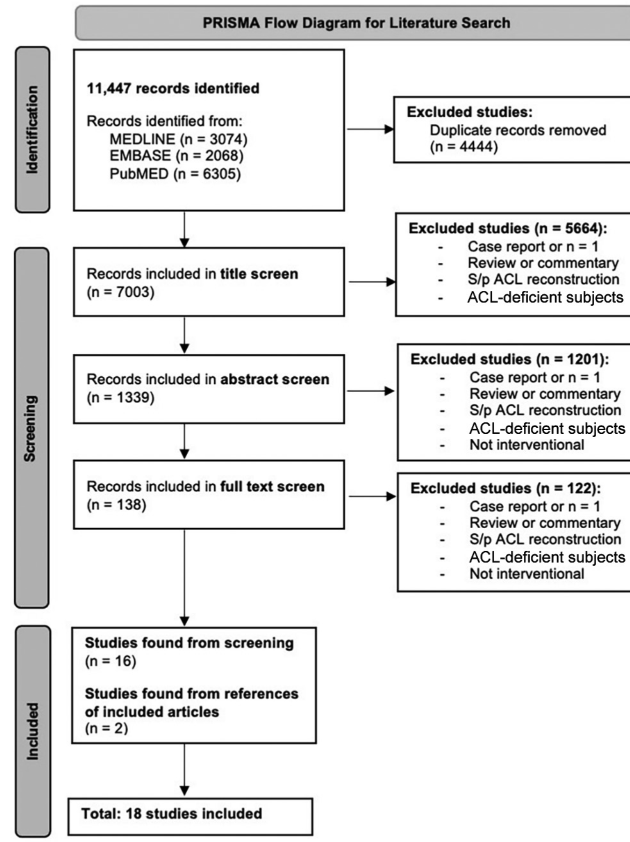

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram for literature search. ACL, anterior cruciate ligament; S/p, status post.

For the 9 RCTs, the Cochrane Collaboration tool for assessing bias was implemented; the 8 cluster RCTs were evaluated using an additional domain considering the recruitment of individual participants within clusters.[20,21] The articles by Gilchrist et al[14] and Silvers-Granelli et al[40] had some risk of bias due to the lack of allocation concealment for individual players and per-protocol statistical analysis, respectively. The other RCTs were found to have low risk of bias. MINORS criteria for comparative studies were applied to the 9 PC trials; each study was evaluated for validated methodological criteria with a maximum score of 24.[41] The mean MINORS score for these 9 studies was 19 (range, 18-21). All studies prospectively collected data with clear aims and appropriate outcome measures.

A funnel plot was generated to assess publication bias, with data appearing approximately symmetrical about the pooled risk ratio (Figure 2). To quantify this analysis, the Egger regression test was performed (P = .1887), and no significant evidence of publication bias was found.

[‖]References 8, 19, 23, 27, 29, 33, 35, 36, 49.

TABLE 1
Summary Characteristics of the Included Studies[a]

Lead Author (Year)	Study Type	Level of Evidence	Cochrane Risk of Bias	MINORS Score	Study Duration	Sports Included	Level of Play	Player Sex	Salient Components of Intervention
Achenbach (2018)[1]	Cluster RCT	1	Low	—	1 season	Handball	High school/<18 y	M and F	NMT
Caraffa (1996)[8]	Prospective cohort	2	—	18	1 season	Soccer	Collegiate/professional/>18 y	NR	NMT + balance board
Gilchrist (2008)[14]	Cluster RCT	1	Some concerns	—	1 season	Soccer	Collegiate/professional/>18 y	F	NMT
Heidt (2000)[17]	RCT	1	Low	—	1 y (school and select seasons)	Soccer	High school/<18 y	F	NMT
Krutsch (2020)[23]	Prospective cohort	2	—	20	1 season	Soccer	Collegiate/professional/>18 y	M	NMT
LaBella (2011)[24]	Cluster RCT	1	Low	—	1 season	Soccer, basketball	High school/<18 y	F	NMT
Mandelbaum (2005)[27]	Prospective cohort	2	—	19	2 seasons	Soccer	High school/<18 y	F	NMT
Myklebust (2003)[29]	Prospective cohort	2	—	18	3 seasons	Handball	Collegiate/professional/>18 y	F	NMT + balance board
Omi (2018)[33]	Prospective cohort	2	—	21	12 y	Basketball	Collegiate/professional/>18 y	F	NMT
Petersen (2005)[35]	Prospective cohort	2	—	20	1 season	Handball	Collegiate/professional/>18 y	F	NMT + balance board
Pfeiffer (2006)[36]	Prospective cohort	2	—	19	2 seasons	Soccer, basketball, volleyball	High school/<18 y	F	NMT
Silvers-Granelli (2017)[40]	Cluster RCT	1	Some concerns	—	1 season	Soccer	Collegiate/professional/>18 y	M	NMT
Söderman (2000)[42]	Cluster RCT	1	Low	—	1 season	Soccer	Collegiate/professional/>18 y	F	NMT + balance board
Waldén (2012)[47]	Cluster RCT	1	Low	—	1 season	Soccer	High school/<18 y	F	NMT
Zebis (2008)[49]	Prospective cohort	2	—	18	2 seasons	Soccer, handball	Collegiate/professional/>18 y	F	NMT + balance board
Stojanović (2023)[44]	Cluster RCT	1	Low	—	1 season	Basketball	Professional but included players as young as 16 y	M and F	NMT
Hewett (1999)[19]	Prospective cohort	2	—	19	1 season	Soccer, basketball, volleyball	High school/<18 y	F (M included in controls)	NMT + balance board
Olsen (2005)[32]	Cluster RCT	1	Low	-	1 season	Handball	High school/<18 y	M and F	NMT

[a]F, female; M, male; MINORS, Methodological Index for Non-Randomized Studies; NMT, neuromuscular training program; NR, not reported; RCT, randomized controlled trial.

Study Characteristics

Across all 18 included studies, 25,166 players were included. The studied athletes were overwhelmingly female (21,470 female, 3096 male); the sex of the 600 players studied by Caraffa et al[8] was not specified. Athletes played handball, soccer, basketball, or volleyball. For the 11 studies that provided explicit age data, the mean age of players was 19.3 ± 3.6 years. For the 8 studies that provided age data for each sex, the mean male age was 21.4 ± 1.3 years and the mean female age was 19.4 ± 4.1 years.

On average, implemented interventions were 18 ± 4.6 minutes long (often implemented multiple times per week), excluding the intervention studied by Hewett et al,[19] which ran for 60 to 90 minutes. All interventions included a strong neuromuscular training emphasis, and 6 studies specifically included the use of a balance board (Table 1). The studies included a variety of established neuromuscular training programs focused on agility, speed, and strength, including the Prevent Injury and Enhance Performance Program, Frappier Acceleration Training Program, and FIFA 11+ injury prevention program (Appendix 1, available online).[14,17,27,40] All interventions were studied for a minimum of 1 season (mean, 1.3 ± 0.59 seasons, excluding the intervention by Omi et al,[33] which was studied for 12 years).

Injury Data

Across all 18 studies, the pooled risk ratio was 0.46 (95% CI, 0.36-0.57; I^2 = 49%; T^2 = 0.2500) (Figure 3).[¶] Therefore, athletes who participated in an ACL injury prevention program were significantly less likely to sustain an ACL injury. The absolute rate of ACL injury was 1.0% in the experimental group and 2.3% in the control group.

Subgroup analyses were only performed if data from ≥4 studies were available. Therefore, sex-specific analyses were limited to female players (subgroup forest plots are included in Appendix 2, available online). Of the 12 studies that included data for female players, the pooled risk ratio

[¶]References 1, 8, 14, 17, 19, 23, 24, 27, 29, 32, 33, 35, 36, 40, 42, 44, 47, 49.

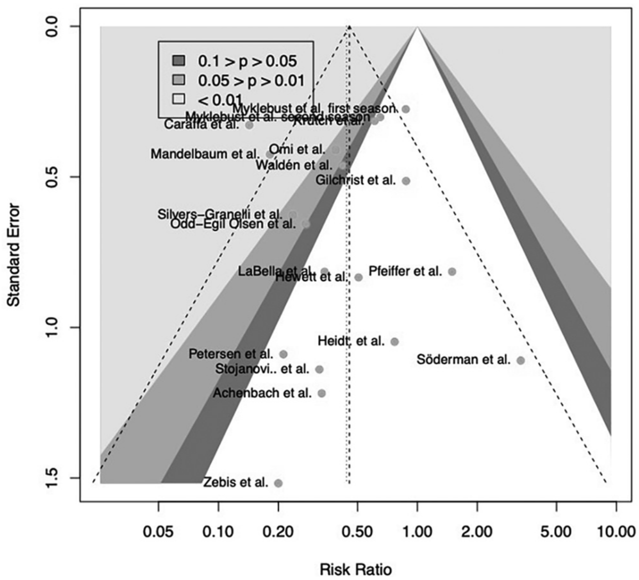

Figure 2. Funnel plot with 1 data point for each of the 18 included studies. Each data point represents the risk ratio for each study plotted against its standard error. The vertical dashed line represents the pooled risk ratio (0.46) incorporating all data, and the diagonal dashed lines depict the 95% confidence interval. The data appear approximately symmetrical about the pooled risk ratio, indicating a lower risk of publication bias. The Egger regression test was performed (P = .1887) to provide numeric assessment of bias, and no significant evidence of publication bias was found.

was 0.57 (95% CI, 0.43-0.74; I^2 = 32%; T^2 = 0.1487; 5 RCTs, 7 PC studies) and statistically significant.[#]

When analyzed by age, there was a significant risk reduction in ACL rupture for both athletes <18 years and ≥18 years of age. The pooled risk ratio for the 9 studies including players ≥18 years was 0.50 (95% CI, 0.38-0.64; I^2= 66%; T^2 = 0.3489; 3 RCTs, 5 PC studies).[**] For the 8 studies including players <18 years, the pooled risk ratio was 0.35 and also statistically significant (95% CI, 0.22-0.55; I^2= 0%; T^2 = 0.0738; 5 RCTs, 3 PC studies).[17,19,23,24,27,32,36,47]

Regarding the efficacy of ACL injury prevention programs by sport, the 9 studies including soccer players showed that those who participated in interventions were less than one-third as likely to experience ACL rupture compared with their control group counterparts (pooled RR, 0.30 [95% CI, 0.19-0.46]; I^2= 47%; T^2 = 0.4734; 6 RCTs, 3 PC studies).[††] For the 4 studies including handball players, there was also significant risk reduction (pooled RR, 0.66 [95% CI, 0.46-0.96]; I^2= 5%; T^2 = 0.0207; 2 RCTs, 2 PC studies).[1,29,32,35] Given that these confidence intervals overlapped, a Z test was subsequently performed ($Z = -2.69$, P = .0072), and it was confirmed that there is a statistically significant difference between the 2 pooled risk ratios.

[#]References 14, 17, 19, 24, 27, 29, 33, 35, 36, 42, 47, 49.
[**]References 8, 14, 23, 29, 33, 35, 40, 42, 49.
[††]References 1, 8, 14, 17, 19, 24, 36, 40, 42.

While all the studied interventions emphasized neuromuscular training, 6 interventions specifically incorporated the use of balance boards. Players who participated in these programs exhibited a significantly lower risk of sustaining an ACL rupture, with injury about 50% less likely compared with players in control groups (pooled RR, 0.49 [95% CI, 0.35-0.67]; I^2= 74%; T^2 = 0.5800; 1 RCT, 5 PC studies).[8,19,29,35,42,49] Programs not utilizing balance boards had other salient components, including cardiovascular conditioning, plyometric balance, and agility exercises, but there were not sufficient, specific data for further subanalyses.

DISCUSSION

This systematic review and meta-analysis aimed to determine the effectiveness of ACL prevention programs in reducing ACL injuries in athletes to produce guidelines that support injury prevention. The main finding of this study is that athletes who did not partake in an ACL injury prevention program were nearly twice as likely to sustain an ACL rupture compared with their intervention group counterparts. There was a significant risk reduction in ACL ruptures for all subgroup analyses: athletes <18 years, athletes ≥18 years, athletes playing soccer and handball, and players who used balance boards. For athletes playing soccer and handball, a Z test ($Z = -2.69$, P = .0072) confirmed that there is a statistically significant difference between the 2 pooled risk ratios (RR, 0.30 [95% CI, 0.19-0.46] for soccer and RR, 0.66 [95% CI, 0.46-0.96] for handball). This suggests that soccer players are notably less likely to sustain an ACL injury when utilizing an ACL injury prevention program as compared with handball players.

As mentioned, the 2012 meta-analysis by Sadoghi et al[38] was one of the most recent studies to aggregate data from ACL injury prevention programs including both male and female athletes. Given the time elapsed since the publication of their study, we were able to build on their foundational work. Sadoghi et al included 8 papers in their final analysis, whereas the present study includes 18 papers. Sadoghi et al elected to exclude the data from Söderman et al[42] due to loss to follow-up; in our analyses, we included the work of Söderman et al after satisfactory evaluation using the Cochrane Collaboration tool for assessing risk of bias. At the time, Sadoghi et al found a significant pooled risk ratio of 0.38 (95% CI, 0.20-0.72). Eleven years later, we found a significant pooled risk ratio of 0.46 (95% CI, 0.36-0.57). Given the 95% confidence intervals, our results roughly reproduce the findings of Sadoghi et al with substantially more data. Notably, the I^2 statistic for our summary forest plot was 49% and the I^2 statistic for the original study by Sadoghi et al was 64%, indicating reduced heterogeneity in the present study and increased confidence in the pooled result. Sadoghi et al found no effect of balance board use (P = 0.712), whereas our study suggests that programs emphasizing balance board use significantly reduce the risk of ACL rupture (RR, 0.49

Study	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Risk Ratio IV, Fixed, 95% CI
Achenbach. et al.	1	168	2	111	0.9%	0.33 [0.03; 3.60]
Caraffa. et al.	10	300	70	300	12.0%	0.14 [0.08; 0.27]
Gilchrist. et al.	6	583	10	852	4.9%	0.88 [0.32; 2.40]
Heidt. et al.	1	42	8	258	1.2%	0.77 [0.10; 5.98]
Krutsch. et al.	15	529	28	601	13.1%	0.61 [0.33; 1.13]
LaBella. et al.	2	737	6	755	1.9%	0.34 [0.07; 1.69]
Mandelbaum. et al.	6	1885	67	3818	7.2%	0.18 [0.08; 0.42]
Myklebust. et al. first season	23	855	29	942	17.1%	0.87 [0.51; 1.50]
Myklebust. et al. second season	17	850	29	942	14.2%	0.65 [0.36; 1.17]
Omi. et al.	9	448	16	309	7.7%	0.39 [0.17; 0.87]
Petersen. et al.	1	134	5	142	1.1%	0.21 [0.03; 1.79]
Pfeiffer. et al.	3	577	3	862	1.9%	1.49 [0.30; 7.38]
Silvers–Granelli. et al.	3	675	16	850	3.3%	0.24 [0.07; 0.81]
Söderman. et al.	4	121	1	100	1.1%	3.31 [0.38; 29.11]
Waldén. et al.	7	2479	14	2085	6.1%	0.42 [0.17; 1.04]
Zebis. et al.	0	20	2	20	0.6%	0.20 [0.01; 3.91]
Stojanovi... et al.	1	57	3	55	1.0%	0.32 [0.03; 3.00]
Hewett. et al.	2	366	5	463	1.9%	0.51 [0.10; 2.59]
Odd–Egil Olsen. et al.	3	958	10	879	3.0%	0.28 [0.08; 1.00]
Total (95% CI)		**11784**		**14344**	**100.0%**	**0.46 [0.36; 0.57]**

Heterogeneity: $Tau^2 = 0.2500$; $Chi^2 = 35.17$, df = 18 ($P < 0.01$); $I^2 = 49\%$

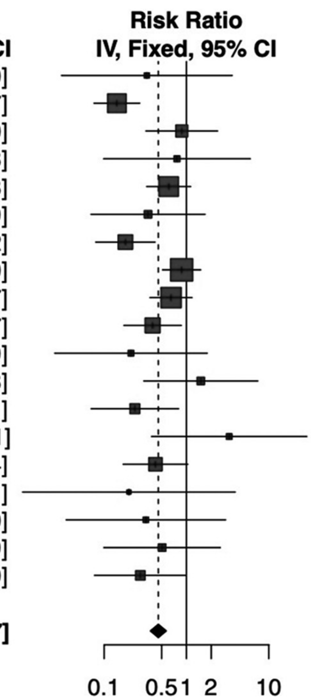

Figure 3. Forest plot including all data. The risk ratios for each of the 18 included studies are plotted along the x-axis. The size of the corresponding squares represents the sample size of each study, and the length of the horizontal lines extending from each square represents the 95% confidence interval. If the 95% confidence interval does not cross the vertical line at a risk ratio of 1, the results of the study are statistically significant. The dashed vertical line with a diamond represents the pooled risk ratio for the meta-analysis (0.46), and the width of the diamond represents the 95% confidence interval (0.36-0.57).

[95% CI, 0.35-0.67]; $P < .01$). Our study included 6 balance board studies,[8,19,29,35,42,49] whereas the work by Sadoghi et al only included 3.[8,35,42]

There is low risk and little cost associated with implementing neuromuscular training programs in established athletic programs; these interventions even have the potential to enhance athletic performance.[43] Still, there are many perceived barriers to implementation. According to a survey of collegiate women's soccer coaches by Dix et al,[13] many coaches were reluctant to adopt knee injury prevention programs due to time constraints. Therefore, training programs must be efficient to maximize compliance. As evidenced in the present study, the effects of injury prevention can be seen with interventions <20 minutes long implemented multiple times per week. Furthermore, many athletic programs may designate injury prevention protocols as the responsibility of athletic trainers or strength coaches; this model would potentially require more staff and therefore increase the hypothetical cost of implementation.[13] Therefore, athletic programs should be encouraged to utilize a team-based approach in which all staff members participate in order to implement these protocols with minimal extra cost. While most collegiate coaches surveyed by Dix et al[13] agreed that soccer injuries could be prevented, the youth coaches included in the review by Hawkinson et al[16] had disparate knowledge of preventing youth sport injury. Furthermore, few youth coaches knew the potential long-term impact of youth ACL injury.[16] For high school teams, a 2024 study found that New York coaches were more likely to implement ACL injury prevention programs at a higher level of play (varsity as opposed to junior varsity); while many utilized neuromuscular training, only 12% of coaches administered injury prevention programs with the frequency and duration suggested by evidence-based guidelines.[26] Given the significant potential of ACL injury prevention programs to reduce these injuries, athletic programs must prioritize training time, coaching resources, and player education.

Aside from barriers to implementation, there are some limitations to the methodology of the present study. Studies were restricted to team-based interventions, and therefore conclusions cannot be made for individual athletes. Furthermore, data were heavily focused on female athletes, and it was difficult to ensure that participating athletes had no prior musculoskeletal injuries. The data were also heavily focused on team sports and did not include several sports that also pose risk for ACL injury. Lastly, the absolute rates of ACL rupture were low, indicating a need for further research. Despite these limitations, our study's conclusions strongly suggest the protective power of ACL injury prevention programs. Future research should investigate the effects of ACL injury prevention programs for those who do not play team sports, including recreational gym goers and students in physical education classes. Additional studies should also focus on implementing programs in more sports, analyzing program effects on more male athletes, and incorporating other injury prevention strategies like coach feedback on exercise form.

CONCLUSION

Neuromuscular training programs as short as 20 minutes per practice can significantly reduce the risk of athletes sustaining ACL rupture. When possible, programs should utilize balance boards to enhance injury prevention potential. Implementation of these prevention programs should be encouraged, and future research can focus on individual athlete programs rather than team-based approaches.

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