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Preventing ACL injuries in Female Athletes: An Analysis of Effective Prevtion Strategies

Bachelor's thesis in Human Movement Science
Supervisor: Karin Roeleveld (NTNU/BEV)
May 2024

Bachelor's thesis

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Abstrakt

Bakgrunn: Fremre korsbåndsskade forekommer hyppig i idretter, spesielt hos kvinnelige idrettsutøvere.

Formål: Se på hvordan forebyggingsprogrammer påvirker ACL-skader hos unge kvinnelige idrettsutøvere.

Metode: Ved å bruke Pubmed ble det gjort et omfattende litteratursøk i januar 2024. Ved å bruke nøkkelord som: ¨anterior¨, ¨cruciate¨, ¨ligament¨, ¨ ACL¨, ¨injury¨, ¨prevention¨, ¨training¨, and ¨exercise¨. De anvendte inklusjonskriteriene var ACL-forebyggende programmer for unge kvinnelige idrettsutøvere, og studier som inkluderte begge kjønn.

Resultater: 8 studier endte opp med å oppfylle inklusjonskriteriene. 6 av dem var oppvarmingsprogram og 2 var separate treningsøkter. 4 av forebyggingsprogrammene var for fotballspillere, 2 for basketball og 1 for håndball. Med varierende resultater viser noen stor nedgang i skader, mens andre små forskjeller mellom kontroll- og intervensjonsgruppene. Funnene tyder på at implementering av forebyggingsprogram har en effekt for å redusere ACL-skader hos kvinnelige idrettsutøvere.

Konklusjon: Tidlig intervensjon med forebyggende trening, som er integrert i oppvarming i den vanlige treningen, kan redusere ACL-skader hos unge kvinnelige idrettsutøvere. Det krever fremtidig forskning for å tilpasse programmene deres for ulike idretter.

Nøkkelord: Fremre korsbånd, ACL-rivning, Sports skade

Abstract

Background: Anterior cruciate ligament injury occurs frequently in sports, especially in female athletes.

Purpose: Look at how prevention programs impact ACL injuries in adolescent female athletes.

Method: Using Pubmed a comprehensive literature search was done in January 2024. Using keywords like: ¨anterior¨, ¨cruciate¨, ¨ligament¨, ¨ ACL¨, ¨injury¨, ¨prevention¨, ¨training¨, and ¨exercise¨. The applied inclusion criteria were ACL prevention programs for young female athletes, and studies that included both genders.

Results: 8 studies ended up meeting the inclusion criteria. 6 of them were warm-up programs and 2 were separate workouts. 4 of the prevention programs were for soccer players, 2 for basketball and 1 for handball. With varying results does some show a large decrease in injuries, while others small differences between the control and intervention groups. The findings suggest that implementation of prevention program have an effect in reducing ACL injuries in female athletes.

Conclusion: Early intervention with preventive training, that is integrated into warm-ups in the regular training, can reduce ACL injuries in young female athletes. Requiring future research to adapt their programs for diverse sports.

Keywords: Anterior Cruciate Ligament, ACL tear, Sports Injury

1.0 Introduction

Over the past few years, sports-related injuries have seen an upward trend, along with an increase in sports participation (Bahr and Krosshaug, 2005). Sports injuries can lead to life-altering limitations for athletes at competitive levels, which may result in a long period without sport (Bahr and Krosshaug, 2005), and potentially decrease the future quality of life for young athletes. Especially in a sport that involves a lot of movement patterns with high speeds and rapid changes of direction has a higher injury rate, where injuries often can occur during acceleration or deceleration of the body (Besier *et al.*, 2001; Stojanovic and Ostojic, 2012).

Anterior cruciate ligament (ACL) injuries represent a growing cause of concern in sports, particularly among female athletes. ACL injuries, which can occur with or without physical contact, range from partial to complete ligament tears and are among the most serious and common knee injuries in several sports like soccer, handball, and basketball (Bahr and Krosshaug, 2005; Gilchrist *et al.*, 2008; Michaelidis and Koumantakis, 2014).
The distinction between noncontact and contact ACL injuries highlights the varied mechanisms through which these injuries can occur, with noncontact injuries happening without external interference, and contact injuries involving external forces (Gilchrist *et al.*, 2008).

The incidence of ACL injuries is particularly higher in female athletes compared to male athletes who participate in the same sports and activities, a difference that is especially pronounced in noncontact ACL injuries (Gilchrist *et al.*, 2008; Barber-Westin *et al.*, 2009). Furthermore, research indicates a gender difference in the incidence of ACL injuries, with female soccer players having a 2-8 times higher risk of such injuries compared to their male counterparts. Other studies reported a sixfold increase in injury frequency among females (Barber-Westin *et al.*, 2009; Michaelidis and Koumantakis, 2014).

Young female athletes involved in sports that require pivoting and cutting movement face a higher risk of ACL injuries. The risk escalates during the adolescent years, coinciding with increased participation in organized sports and the onset of puberty (Renstrom *et al.*, 2008; Hägglund and Waldén, 2016; Werner *et al.*, 2016). It appears to be 3-4 times more likely for females in high school and collegiate ages to suffer from an ACL injury than men competing in the same sports, with the incidence peaking around 15-19 years (Agel, Arendt and

Bershadsky, 2005; Renstrom *et al.*, 2008). The increase in ACL injuries among children and adolescents, combined with the increased risk of developing osteoarthritis following such injuries, underscore the need for effective prevention and management strategies (Myklebust *et al.*, 2003; Lohmander *et al.*, 2007; Caine and Golightly, 2011; Werner *et al.*, 2016). Biomechanical factors, including increased knee valgus and decreased knee flexion, have been identified as risk factors for ACL injuries, highlighting the complexity of these injuries and the multifaceted approach required for prevention (Hewett *et al.*, 2005; Zebis *et al.*, 2008). The purpose of the study is to examine how prevention programs affect ACL injuries in young female athletes. This study aims to look at specific strategies to reduce ACL injuries.
By using a specific training program, it may be possible to reduce the incidence of serious knee injuries and see how the exercise works to reduce injury risk (Bahr and Krosshaug, 2005).

This study focuses on the effect of preventive programs for larger population groups, emphasizing a short warm-up that could be beneficial for ACL injuries. It explores the value of adding some extra time for a session aimed at enhancing motor control and improving concentration before physical activity or competition. The purpose of a warm-up and prevention program is to prepare the body for the high speed and rapid changes. Through exercises such as plyometric training, concentration exercises, Preventive Exercise Program (PEP), Neuromuscular training (NMT), and muscle activation. The goal is to strengthen the body, improve control and timing in muscle work, and increase concentration. That can help reduce the risk of injuries during the jumping and landing phase in relevant sports.

The advantages of ACL injury prevention programs structured in a warm-up format included their cost-effectiveness and the ability to be performed on the field with minimal equipment, requiring time (Bien, 2011). This format also helps to avoid increased fatigue; a factor previously identified as a barrier to success in injury prevention efforts during athletic tasks that elevate the risk of injuries.

2.0 Method

The literature search was carried out using NTNU´s databases in January 2024, where PubMed was used for this study. The study conducted two searches through PubMed with different keywords. It was used keywords as: ¨female¨, ¨athletes¨, ¨prevention¨, ¨ACL injury¨ and anterior cruciate ligament¨ for the first search. That resulted in 375 articles, after going through the articles and the exclusion criteria (table 1) that resulted in 4 articles.

Table 1. Inclusion criteria and exclusion criteria of original articles

Inclusion cirteria	*Exclusion criteria*
Randomized controlled trials (RCT), Clinical trials, Cohort study	Systematic review, Meta-analysis, Laboratory research.
Published in the last 16 years (2008-2024)	Later than 16 years (later than 2008)
Young athletes, adolescent	Children (under 12), Adult, Older
ACL- injury prevention, Injury risk	ACL rehabilitating, and anterior cruciate ligament reconstruction (ACLR)
More than 100 participants	Under 100 participants
Studies who included females and male, and only females	Studies who include just males

For the second search it was used a flowchart (figure 1) to do a more systematic search. Using keywords like: ¨anterior¨, ¨cruciate¨, ¨ligament¨, ¨ ACL¨, ¨injury¨, ¨prevention¨, ¨training¨, and ¨exercise¨. After looking through the articles and exclusion criteria, that resulted in 4 articles included from the second search, in total 8 articles.

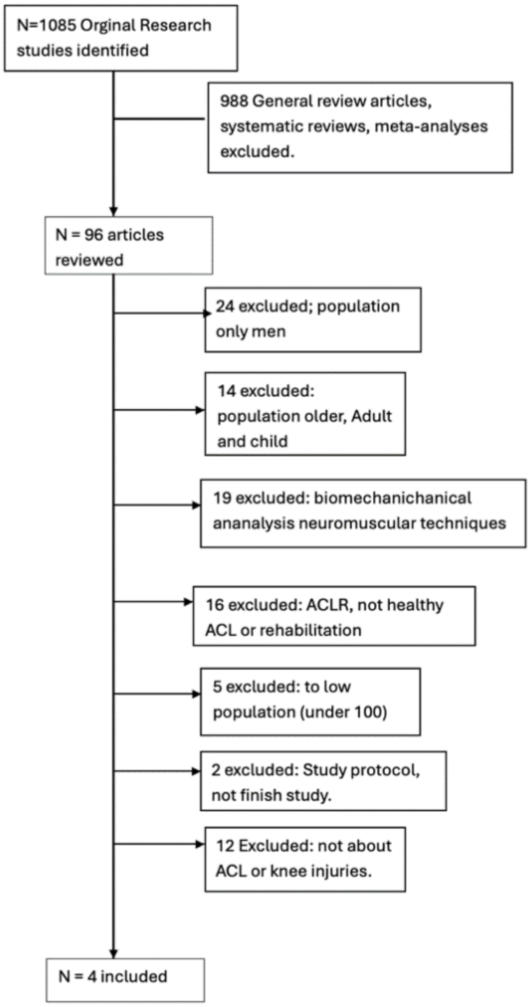

Figure 1: Flowchart of the second search

3.0 Result

The eight research articles upon which this study is based on are systematically presented in Table 2, offering a concise overview of the literature. Seven of the studies (1-7) are randomized control trials (RCT), and study 8 is a prospective non-randomized control trial and cohort study. The eight studies have a population of 10 861 participants, who were allocated in two groups, the participants who did an intervention program (n= 5780) and a control group (n= 5325) who did their regular training program. By choosing to use this study design, from RCTs and a prospective study, and including a wide population of athletes, the studies contribute to a robust and generalizable understanding of how such programs can be implemented effectively.

Study 8 is a 12-year study they had an observation period that was before the intervention program with 309 participants, in the first intervention period where they did the prevention program, they had a population of n=268, and in the second intervention period, they were n=180 in the end. The seven other studies allocated RCT into two groups with clusters where the different teams were either in the control group or an intervention group instead of randomized participants in the same team in different groups.

The intervention groups did the prevention warm-up programs and the sport-specific injury prevention program for the lower extremities. The control group did regular warm-up and training routines (table 2).

The research included healthy athletes, without any existing diseases or injuries that could be affected. The athlete’s level ranges from amateur to semi-professional within each of their sports like handball, soccer, and basketball.

Table 2: Systematic overview of selected studies and their program

Author	*Outcome variables*	*Participants (n)*	*Gender (F or M)*	*Age* (n)	*Amateur or semi professional*	*Intervention*
Achenbach et al. (2018) **(1)**	ACL & Knee injury	279 (I=168, C=111)	M,F	16-18	Amateur Handball	An injury prevention program, in preseason. Jumping and landing, proprioceptive, strength and plyometrics exercise. During pre-season: 15 min, 2-3 times per week, 10-12 weeks program. During competition: 15 min, 1 time per week, no info
Stojanovic et al. (2023) **(2)**	ACL & knee injury	112 (I=57, C=55)	M,F	18-29	Amateur, Semi-professional Basketball	A warm-up combined with running exercises with stretching, plyometrics, balance, strength and agility drills. 20 min, 3-4 times per week, in 8 months.
Gilchrist et al. (2008) **(3)**	ACL-injury	1435(I=583, C=852)	M,F	14-18	Semi-professional Soccer	Warm-up program based on PEP. Contains stretch, strength, agility, and plyometric training. Less than 30 min, 3 times per week, for 3 months
Walden et al. (2012) **(4)**	ACL-injury	4564 (I=2479, C=2085)	F	12-17	Armature Soccer	NMT Warm-up, consist of core stability and knee control, strength exercises and technique for jumping and landing. 15 min for 2 times per week, for 7 months
Steffen et al. (2008) **(5)**	ACL- & knee injury	2092 (I=1091, C=1001)	F	13-17	Armature Soccer	warm-up that contains agility, lower extremity strength, core and neuromuscular control. 15 min, 3 times per week, for 8 months.
Soligard et al. (2008) **(6)**	Knee injury	1892 (I=1055, C=837)	F	13-17	Amateur Soccer	Warm-up program based on PEP and the 11+ program. Exercises for strength, awareness, and neuromuscular control during static and dynamic movement. 20 min, 3 times per week, 8 months
Otsuki et al. (2021) **(7)**	Injury risk/ ACL	178 (I=79, C=75)	F	12.6-16	Amateur Basketball	The training program focused on balance, strength and cutting movement specifically adapted to basketball. 20 min, 3 times per week, for 6 months
Omi et al.(2018) **(8)**	ACL	309 IP I: 268 IP II: 180	F	19,6	Amateur Basketball	HIIP program, with jumping/landing, strength and balance. 20 min, 3 times per week, 12 years OB: 4 years IP I: 4 years IP II: 4 years

x= missing information, I= intervention group, C = control group, NMT = neuromuscular training, PEP= Prevention injury and Enhance Performance, F=Female, M= Male, IP I= intervention period 1, IP II = Intervention period 2, OB= observation period

3.1 Prevention Programs

Injury prevention programs such as “The 11”, PEP, and neuromuscular warm-up routines are effective in reducing the risk of ACL injuries. One of the studies (study 2) looks at prevention programs for knee problems in general, that include ACL, but they aren’t specified in the results.

Study 3 had a high reduction in non-contact ACL injuries, with a rate 3.3 times lower in the intervention group compared to the control group (0.057 vs 0.189, P=0.066). Overall ACL injuries were the rate among the intervention athletes 1.7 times less (0.199 vs 0.340; P=0.198) (Gilchrist *et al.*, 2008). Study 6 observed a reduction in knee and lower-extremity injuries. Between the intervention and control the rate ratio of players with lower-extremity injury was 0.71 (0.49 to 1.03, P=0.072). The number of knee injuries per 1000 player hours was 0.7 in the intervention and 1.3 in the control group and had a rate ratio (95% cl) of 0.55 (0.36 vs 0.84; P=0.005) (Soligard *et al.*, 2008). Study 5 recorded 9 ACL injuries during the trial (0.07 injuries/1000 h, 95% CI 0.02-0.11), with 5 in the control group and 4 in the intervention group (Rate ratio 0.8, 0.2-2.9; P=0.73). No significant result where found (Steffen *et al.*, 2008). Study 4 reported a reduction in ACL injury rate on 64% among the intervention athletes compared to the ones in the control (Ratio 0.36; 0.15 to 0.85), with a P-value on 0.02. There were recorded 21 ACL injuries in total, 7 in the intervention and 14 in the control (Waldén *et al.*, 2012).

Study 2 showed a tendency towards fewer knee injuries in the intervention groups (95% CI=0.03-1.78; P=0.07) than in the control groups, 4 of the knee injuries were ACL injuries, 3 (0.28 IR per 1000 h) of them in the control, and 1 (0.09 IR per 1000 h) in the intervention (P=0.27). Study 1 demonstrated a reduction in severe knee injuries. There were sustained 3 severe knee injuries in females and 4 males and occurred more in the control group (0.33/1000 h) than in the intervention group (0.04/1000 h). And had an odds ratio of 0.11 (95% CI 0.01-0.90, P=0.019) (Stojanović *et al.*, 2023).

The research by Study 7 points out how puberty stages impact serious knee injuries and the importance of specifically tailored interventions. The study looks at injuries from a different angle by researching the relationship between puberty stages and the risk of ACL injuries by categorizing the participants into six groups, based on their puberty stage (early, late, or post-puberty) and involvement in either an intervention or control group. The study discovered that among the post-puberty control group, which consisted of 38 individuals, there were 3 cases of ACL injuries, indicating a significant difference in injury rates between intervention participants and control (P=0.005). In early and late pubertal groups, there was no significant difference in injuries (Otsuki *et al.*, 2021).

The last study is research that was based on a 12-year prospective intervention hip-focused study, conducted by study 8. It featured a 4-year observational phase where participants followed a regular program. This was succeeded by two consecutive 4-year intervention periods. The study documented a decrease in ACL injuries, documenting 16 incidents in the initial observational stage to 6 and then 3 in the subsequent intervention phase.
A reduction in the relative risk (RR) of ACL injuries was observed during the intervention periods compared to the observation phase. The RR for overall ACL injured dropped to 0.38 (P=0.017), while for noncontact ACL injuries, it further decreased to 0.37 (P=0.026), indicating the efficacy of the intervention strategies implemented in reducing ACL injury risk (Omi *et al.*, 2018).

T*able 3: Numbers and percentages of ACL injuries rate in control and intervention groups.*

Authors	*Injury*	*Injury control (n)*	*Injury intervention (n)*	*Injurie in total (n)*	*Statistical significance for IG between CG and IG (P-value)*
Achenbach et al. (2018) **(1)**	ACL Knee	ACL: 2 Knee: 7	ACL: 1 Knee: 8	ACL: 3 Knee: 15	0.019
Stojanovic et al. (2023) **(2)**	ACL Knee	ACL: 3 Knee:4	ACL: 1 Knee: 2	ACL: 4 Knee: 6	0.27 0.7
Gilchrist et al. (2008) **(3)**	ACL	ACL: 18	ACL:7	25	0.198
Walden et al. (2012) **(4)**	ACL	ACL:14	ACL: 7	21	0.002
Steffen et al. (2008) **(5)**	ACL	ACL: 5	ACL: 4	9	0.73
Soligard et al. (2008) **(6)**	Knee	Knee: 58	Knee: 35	93	0.005
Otsuki et al. (2021) **(7)**	ACL	ACL: 3	ACL: 0	3	0.005
Omi et al. (2018) **(8)**	ACL	ACL: 16 (OP)	ACL IP I: 6 ACL IP II: 3	25	0.017

**n = Number, IG= intervention group, CG= Control group, IR= injury rate, OB= observation period, IP = intervention period,*

Table 4: overview of articles that looked at noncontact ACL injuries.

Authors	*Injurie control (n)*	*Injurie intervention (n)*	*Injuries in total (n)*	*Statistical significance for IG between CG and IG (P-value)*
Omi et al. (2018) **(8)**	13	8	21	0.026
Gilchrist et al. (2008) **(3)**	10	2	12	Training: 0.066 Game: 0.218

4.0 Discussion

Based on the present findings, multiple studies indicate a significant reduction in the risk of ACL injuries and general knee injuries among athletes participating in specific preventative programs. This underscores the importance of implementing targeted interventions to mitigate the risk of injury. The results concerning injury risk provide a deeper understanding of the injury risk among young female athletes.

4.1 The different strategies

The prevention programs include a variety of exercises designed to strengthen muscles and improve flexibility, balance, and control during jumping, landing, and sport-specific movements. All include several of the different focuses and designs, even though they have different main focuses on the strategies.

Study 6 is based on the PEP and the "11" program with added running activities. This gives the program similarities to study 3 which used PEP and study 5 which used the "11" program. All three have strength in focus during the warm-up, but Study 5 and Study 6 have neuromuscular control and have more focus on neuromuscular control than Study 3. Both study 3 and 5 have agility exercises in their programs, and Gilchrist also has incorporated plyometric training. All three are used on soccer players, and that might explain why the prevention programs had some similarities and why study 6 based their program on The "11" and PEP programs. (Gilchrist *et al.*, 2008; Soligard *et al.*, 2008; Steffen *et al.*, 2008).

Study 4 also aimed at soccer players with a neuromuscular warm-up program, and proper knee control and alignment, balance, and core stability were aimed at. Neuromuscular control where more in focus during this program than in the other three. Since all the studies show a reduction, even with a variation in reduction, does it suggest that a combination of strength, agility, plyometric training, and neuromuscular control can be a key component in preventing ACL injuries. That improves body awareness and technical execution in injury prevention efforts. (Waldén *et al.*, 2012).

Study 7 and 2 are both warm-up prevention programs for basketball players. Study 8 is also for basketball players but is not a warm-up program. When Study 1 is not a warm-up program and is specific for handball. Study 2 had a multicomponent neuromuscular warm-up program which consisted of a combination of balance, plyometrics, strength, agility drills, stretching, and running exercises. Throughout the implementation was there a focus on the quality of the execution of the movements. Study 7 included cutting and pivoting exercises that are skills

specific to basketball. The focus of the program was to secure proper movement patterns, in particular, knee flexion during cutting and landing and avoiding knee valgus motion. Study 8 aimed with the hip-focused prevention program to enhance hip joint function progressively through balance exercises, jump-landing manoeuvres, and hip strength training.
Study 1 had a handball-specific prevention program, that included jumping and landing exercises, plyometric and proprioceptive exercises, and strength training for hamstring, quadriceps, and core muscles. This supports that the component mentioned earlier works well combined. Also, with a focus on movement patterns and technique training, can provide particularly effective injury prevention measures. Comparing these studies reveals that a multi-component approach to injury prevention, incorporating physical exercises and technique improvement, is effective in reducing the risk of ACL injuries. (Omi *et al.*, 2018; Otsuki *et al.*, 2021; Stojanović *et al.*, 2023).

Five studies (2, 4-7) of the prevention programs lasted around 6-8 months, study 3 lasted for three months, and study 8 lasted for eight years. Study 1 doesn't say exactly how long it lasted, but that it was during the preseason and competition period. The duration of the prevention program can have an impact on the long-term effect and results the research obtains. Longer periods can allow better evaluation of long-term results, and more time and collecting more data might give more credibility. Study 8 who had the intervention for 8 years can more certainly pinpoint the effect their prevention program provides the athletes than the others that all lasted under a year. Study 3 lasted for 3 months and had more limited ability to conclude their prevention program effect over time than study 8. Six to eight months gives more time to evaluate the programs and might also have fewer participant that drops out than long-term studies. Both short- and long-term studies give us important insights, but more long-term studies should be done.

4.2 Effectives of the Injury Prevention Programs

The studies show generally positive effects on the reduction of the incidence of ACL injuries, even though the data they collected show varying results. Study 6 had a significant reduction in the number of knee injuries from 58 to 35 between the control and intervention groups (P=0.005). Emphasizing the importance of implementing prevention measures in soccer where knee and ACL injuries are prominent (Soligard *et al.*, 2008).
Study 1 reported a major reduction in serious knee injuries, the odds ratio was 0.11 for

sustaining a serious knee injury in the intervention groups compared to the control group (95% Cl 0.01-0.90). With a significant P-value of 0.019. This shows that a targeted warm-up program has an effect on improving muscle control and then reducing ACL injuries (Achenbach *et al.*, 2018).
Study 4 had a significant reduction in the rate of ACL injuries by 64% in the intervention group, with a P-value of 0.02 (Ratio 0.36; 0.15 to 0.85). This shows that the prevention program has a significant effect in reducing ACL injuries (Waldén *et al.*, 2012).

Over the 12 years, study 8 reported a significant reduction in ACL injuries. It went from 16 injuries in the observation period that lasted 4 years, to a total of 9 during the first and second intervention periods each lasting 4 years. That gives an overall reduction in ACL injuries a relative risk of 0.38 (P=0.017) and for only non-contact ACL injuries a relative risk of 0.37 (P=0.026). Study 8 demonstrates the long-term value of a prevention program, with the number of ACL injuries almost being cut in half in the intervention program, even though it lasted 4 years longer. Since study 8 is over a longer period, validity is strengthened by following changes before and after the implementation of the intervention program. This provides strong evidence that change in injury incidence can be attributed to the intervention (Omi *et al.*, 2018).

In Study 7 the intervention group for post-pubertal athletes had no ACL injuries, in contrast, was there three ACL injuries in the control group. With a P-value of 0.005 making the reduction in this group significant. In the early- and late pubertal groups was there little to no difference in the intervention and control groups. The reduction in the post-pubertal group suggests that biomechanical changes during puberty, such as knee selection, decreased knee flexion, and increased medial knee displacement, may elevate ACL injury risk. Study 7 took a different approach by adapting the intervention based on the participant´s puberty stage, increasing external validity by showing that intervention effects can vary based on the participant´s developmental stages (Otsuki *et al.*, 2021).

Despite the positive findings in five of the studies (1, 4, 6-8), the effectiveness isn’t equally evident in all the studies. Study 2 had fewer knee injuries in the intervention group than in the control group (95% CI=0.03-1.78; P=0.07). That had an injury rate per 1000 hours of 0.96 in ACL injuries in the control group and an injury rate per 1000 hours of 0.09 in ACL injuries in the intervention groups. The P-value for the reduction in ACL injuries between the intervention and control is 0.27. The reason for that might be that few ACL injuries occurred during the study which makes it difficult to assess the effect the program has on ACL injury reduction (Stojanović *et al.*, 2023).

Study 3 had a high reduction in noncontact ACL injury that had a P-value of 0.066 and for overall ACL injuries P=0.198. Even though there was a high reduction was the data not significant. Study 5 had few ACL injuries occurring during the study and small differences between the control and intervention (P=0.73). This indicates that not all programs will provide a huge reduction in ACL injury (Gilchrist *et al.*, 2008).

4.2.1 Noncontact ACL

The prevalence of noncontact ACL injuries presents a challenge and opportunity for prevention and intervention strategies. It is well-documented that noncontact mechanisms, such as improper muscle activation, lapses in attention, and flawed technique, play an important role in the occurrence of these injuries. This contrasts with contact ACL injuries, which are often a direct result of physical interactions between layers during a game, involving actions that can be aggressive or unpredictable.

While this study is looking at eight research studies, just two have separated ACL injuries. Those studies were conducted by studies 3 and 8, where they separated noncontacted injuries from the total results of ACL injuries.

The athletes who were participating in study 3, which was a specific intervention program, experienced a rate of noncontact ACL injuries that was 3.3 times lower than those in the control group, translating to a 70% reduction. Furthermore, the rate of game-related noncontact ACL injuries was more than halved in the intervention group. This stark contrast not only underscores the potential of preventive measures but also highlights the important role that noncontact mechanisms play in the overall incidence of ACL injuries. (Gilchrist *et al.*, 2008).

Similarly, study 8 longitudinal research, spanning eight years of interventions, illustrates a progressive decrease in noncontact ACL injuries over time. From a total of 13 noncontact injuries observed before the intervention to a reduction to 8 during the intervention period, the phased approach of the study provides valuable insights into the long-term benefits of sustained preventive strategies. (Omi *et al.*, 2018).

The results underscore that many ACL injuries, especially noncontact injuries, occur in situations without physical contact with other players. This is supported by study 8, where 21 out of 25 total ACL injuries were noncontact, and in study 3, 12 out of 21 were such injuries. The collection of these findings leads to the that a significant portion of ACL injuries occur in noncontact situations, emphasizing the urgent need for targeted intervention programs. The success of these programs in reducing the incidence of noncontact and in general ACL injuries confirms the potential for preventive strategies to fundamentally change the landscape of sports-related injuries. By delving into the mechanisms behind noncontact injuries and the demonstrable effect of intervention programs, this gives a deeper understanding of ACL injury prevention and highlights the critical role that customized preventive measures in protecting athletes from the risk of serious injuries.

4.3 Reliability and validity of the intervention program

The studies show a reduction in ACL injuries across different sports, such as soccer (3, 4 and 6), handball (1), and basketball (2,7 and 8). The cross-sports effect strengthens the reliability of the findings by indicating that injury prevention programs can be effective across varying sports and overload.

It is a variation in the program-specific exercises and implementation methods, most of the studies report a positive effect on reducing ACL injuries. Where study 4 shows a 64% reduction in ACL injuries, and study 8 reported a significant decrease over time. Which contributes to consistently positive effects and contributes to the reliability of the conclusion that injury prevention programs are important.

All eight studies show a general tendency towards a reduction in ACL injuries among participants in injury prevention programs, despite variation in significance and population size. The reliability across studies confirms the credibility of injury prevention programs as an effective method to reduce the risk of ACL injuries in cutting and pivoting sports.

Through defined intervention programs, ensure that the concept of injury prevention is accurately and concisely measured. This is supported by the reduction in ACL injuries reported in the studies, which shows that the programs affect the measurement of the prevention of serious knee injuries and ACL injuries.

Challenges can be adapting programs to different sports and development stages, which underlines the need for further research to optimize the intervention´s design and implementation.

4.4 Challenges in implementing

Challenges in implementing prevention programs can be compliance for athletes or coaches, integration of the program into the routine and training program for the athletes and teams, and lastly drop-outs among the participants.
Sugimoto (2017) looked at athletes' and coaches' compliance rates with a neuromuscular training program. They found out that athletes had higher compliance with programs in all the different groups they studied than the coaches (Sugimoto *et al.*, 2017). Some of the reasons behind the lack of compliance among coaches were concluded to be attributed to a lack of available time and busy schedules during competition season. When the research of a prevention program lasts over a longer period the risk of participant dropping becomes higher, study 8 who had the intervention for a total of 8 years had participants that left their teams during the observation and intervention periods. Athletes will not always play for the same teams or quit sports during a long period.

4.5 Future Research

Future research on ACL injury prevention is necessary for several reasons, one of them being that ACL injuries continue to occur and are common among athletes. Especially in cutting and pivoting sports such as soccer, handball, and basketball, so the existing prevention programs need to improve and adapt to be more effective in lowering the occurrence of ACL injuries. The long-term effects of various ACL injury prevention programs should also be more focused on, and so studies should have their intervention over several years. Exploring new strategies and approaches should also be taken into consideration.

Another reason why future research is needed is to examine more of the many factors that are speculated to have an impact on ACL injuries. Training techniques, genetics, and biomechanics can all affect the occurrence and ACL injuries. And better understanding of the different factors and their connections to ACL injuries might help in identifying potential risk factors in athletes and be used to develop prevention strategies and programs. As well it needs to look more at why ACL injuries occur more frequently in female athletes than in men. The existing theories and knowledge should be more researched to get a deeper understanding of the differences between the genders. That would make it possible to customize prevention programs better for female athletes and hopefully reduce ACL injuries in female athletes.

5.0 Conclusion

Young female athletes are at high risk of ACL injuries, especially for noncontact injuries. Studies show that early intervention in preventive training can reduce the risk of such injuries. Effective training should include multicomponent such as plyometric exercises, NMT, coordination, hip and knee strengthening, and balance, as well as techniques for jumping and landing, integrated into the warm-up before the activity. They require little time and resources but are important in preventing injuries and promoting sports careers for young females at in early age. Future research should focus on noncontact ACL injuries and adapt preventive programs to different sports and athlete groups to maximize the effectiveness and motivation for such interventions.

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