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Review Article

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Could Neuromuscular and Proprioceptive Training Programs Prevent Anterior Cruciate Ligament Injuries in Women's Football?

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Abstract

Introduction: Anterior cruciate ligament injury constitutes a serious problem in terms of athletic involvement and overall wellbeing of affected female athletes, both recreationally as well as competitively. Post-operative rehabilitation can take at least 6-9 months, delaying return to sport and in some cases preventing return to prior intensity and skill level. In football, the rate of anterior cruciate ligament injury is between four to eight fold higher in female players than in male players. One theory to account for higher knee and anterior cruciate ligament injury incidence in female athletes is that the absence of neuromuscular control of the knee joint, due to training deficiencies, developmental differences, or perhaps hormonal influences, lead to higher rates of injury.

Methods: We conducted this literature review to analyse and critique randomised controlled trials and controlled clinical trials including neuromuscular and proprioceptive interventions to reduce anterior cruciate ligament injuries in women's football.

Results: Five randomized controlled trials and two controlled clinical trials were included after screening in this literature review.

Conclusion: Of the seven studies, anterior cruciate ligament injury risk was decreased in five studies. Therefore, more than half of the interventions were effective in reducing the incidence of this injury. Although the exercises included differed between studies, there appears to be a measurable effect of neuromuscular and prioprioceptive training interventions on the risk of anterior cruciate ligament injury.

Keywords

Prevention; Female; Sport; Injury; Intervention; Athlete

Abbreviations: ACL: Anterior Cruciate Ligament; CCT: Controlled Clinical Trials; RCT: Randomised Controlled Trial; PEP: Prevent Injury and Enhance Performance

Introduction

Anterior cruciate ligament (ACL) injury represents a severe problem in terms of athletic involvement and overall wellbeing of affected female athletes, both recreationally as well as competitively [1]. Post-operative rehabilitation can take at least 6 months, delaying return to sport and in some cases preventing return to prior intensity and skill level [2]. Long-term follow-up studies indicate that athletes who sustain an ACL injury are at increased risk for developing osteoarthritis, and also prone to secondary injuries including meniscal tears [3-5]. In football, the rate of ACL injury is between four to eight folds higher in female players than in male players [6,7]. The most common type of ACL injury seen in female football players is via a noncontact mechanism, in which the athlete tears the ACL during an awkward movement that does not involve direct contact with another athlete [8,9].

A variety of factors have been extensively studied through the years to determine why females are more at risk than males for sustaining a noncontact ACL injury. Research has focused on differences in level of conditioning, skill level, femoral notch size, ACL dimensions, degree of knee laxity, Q angle, and hormonal differences. The results of these studies have been mixed, and some of these factors, being static and un-modifiable and less conducive to intervention [10]. One of the factors that accounts for increase ACL injury incidence in female football players is that the absence of neuromuscular and proprioceptive control [11]. This resulted in the development of neuromuscular and proprioceptive interventions designed to improve the biomechanical factors toward reducing the risk of noncontact ACL injuries. ACL prevention programs in skiing, basketball and handball have shown promising results in reducing the incidence of ACL injuries with an overall reduction ranging from 60% to 89% [12]. The aim of the literature review was to analyse and critique randomised controlled trials (RCT) and controlled clinical trials (CCT) including neuromuscular and proprioceptive interventions to reduce ACL injuries in women's football.

Methods

A search strategy was conducted using databases of Pubmed, Medline, Google Scholar and the Cochrane library. The following search terms were used in differing combinations: ACL, prevention, anterior cruciate ligament, injury prevention, female, football, soccer, neuromuscular, prioprioception. All titles and abstracts, without time limits, were reviewed and a total of seventy one studies were initially obtained. Five RCTs [13-17] and two CCTs [18,19] were included after screening in this literature review.

Inclusion criteria

- A randomised controlled trial or controlled clinical trial
- Study includes female football players only
- Reported the outcome of ACL injuries.
- Investigated neuromuscular and/or proprioceptive training intervention

Methodological Quality

The methodological quality of each study was determined using the nine item criteria list (Table 1) by Van Tulder et al. [20]. The mean quality score was 4.8 (range 2-7). The method of randomisation was

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adequate in two RCTs (13,17), and not reported in three RCTs (14-16). The allocation of treatment was adequately concealed in only one study (13), unclear in two RCTs (15, 16) and not concealed in four studies (14,17-19). The assessors were blinded for the group allocation in 3 studies (13,16,17), not blinded in 3 studies (14,18,19), and not reported in one study (15). The compliance with exercise interventions was adequate in 4 studies (14,15,18,19), insufficient in 1 trial (17), and not stated in 2 trials (13,16). Table 2 reviews the methodological quality evaluation and shows where specific inadequacies lie.

Description of Included Studies

Three studies were done in the United States (14, 16, 18), three studies in Sweden (13, 15. 19) and one study in Norway (17). The mean sample size comprised 1597 subjects (range = 221-5703) with a mean age of 16.6 SD ± 2.4. In all seven studies the intervention was performed by the intervention group and the control group took part in their normal training and game program. Three studies primarily focused on ACL injuries (13, 14, 18). Heidt et al, monitored knee injuries including ACL, collateral ligament, patella dislocation / subluxations, meniscus lesions and chondral injuries (16). Kiani et al, monitored all knee injuries (19). Two other studies reported on lower limb injuries overall, including sprains, contusions, fractures, and strains of the feet, ankle, calf, knee, thigh and groin [15,17].

Soderman et al. [15] did a RCT using balance boards in 221 Swedish second and third division female soccer players in which 121 were randomized to a balance board regimen and 100 to their regular training. The athletes were given a balance board and performed balance board exercises on a single leg for 10 to 15 minutes. The exercise protocol was done at home every day for 30 days and then continued three times per week during the season. Unexpectedly the intervention group sustained 4 out of the 5 ACL injuries with no statistical differences in the ACL injury rates between the 2 groups. These results contrast with the findings of balance board training programs in Caraffa et al. [21] and Wederkopp et al. [22]. Caraffa [21] reported a decrease in the incidence of ACL injuries in male soccer players and Wederkopp [22] reported a reduction in traumatic injuries in handball players.

In 2005, Mandelbaum et al. [18] studied the effects of implementing the Prevent Injury and Enhance Performance (PEP) program in a nonrandomised prospective cohort study. The PEP was specifically designed by Santa Monica Orthopaedic and Sports Medicine Research Foundation in 1999 to prevent non contact ACL injuries and this could be readily used with any specialised equipment. Female soccer players between the ages of 14 and 18 were examined over a two year period. The intervention group was comprised of 1041 players in year 1 of the study and 844 players in year 2. The controls included 1905 players in year 1 and 1913 in year 2. The neuromuscular training intervention consisted a warm up, stretching, strengthening, plyometrics, and agility exercises. This 20 minute intervention was done 2-3 times a week during 12 weeks of the season. Over the 2 years of the study, only 6 ACL injuries occurred in the intervention group compared to 67 in the control group. The 88% and 74% reductions in ACL ruptures in the first year and second year respectively reached statistical significance (p=0.005), however contact and non contact ACL injuries were not separated out.

In 2008 the same group studied the effect of the PEP program on NCAA division 1 women's soccer teams in a randomized controlled trial. 852 control athletes were compared with 583 intervention athletes who underwent the same PEP protocol for 20 minutes 3x/ week for 12 weeks of the season [14]. Consistent with the previous study [18] there were lower rates of total and noncontact ACL injuries (overall 41% reduction) in the intervention group but the difference was not statistically significant. However when the results were evaluated for the second half of the season, weeks 6-11, there were significantly lower rates of total ACL injury in the intervention group (5 vs 0, P = 0.025).

The "11" intervention program was investigated by Steffen et al. [17] in a cluseter-randomised controlled trial. The study was over an 8 month season where the 15 minute warm up program was

Table 1: Criteria List for methodological quality assessment.

A	Was the method of randomization adequate?	Yes/ No / Don't Know
B	Was the treatment allocation concealed?	Yes/ No / Don't Know
C	Were the groups similar at baseline regarding the most important prognostic indicators?	Yes/ No / Don't Know
D	Was the outcome assessor blinded to the intervention?	Yes/ No / Don't Know
E	Were cointerventions avoided or similar?	Yes/ No / Don't Know
F	Was the compliance acceptable in all groups?	Yes/ No / Don't Know
G	Was the drop-out rate described and acceptable?	Yes/ No / Don't Know
H	Was the timing of the outcome assessment in all groups similar?	Yes/ No / Don't Know
I	Did the analysis include an intention-to-treat analysis?	Yes/ No / Don't Know

Table 2: Methodology quality criteria.

Study	Quality Score	A	B	C	D	E	F	G	H	I
Walden, 2012 [13]	7	Y	Y	Y	Y	N	NR	Y	Y	Y
Gilchrist, 2008 [14]	5	NR	N	Y	N	Y	Y	Y	Y	Y
Soderman, 2000 [15]	3	NR	NR	Y	NR	Y	Y	N	Y	NR
Heidt, 2000 [16]	2	NR	NR	NR	Y	N	NR	NR	Y	NR
Steffen, 2008 [17]	7	Y	N	Y	Y	Y	N	Y	Y	Y
Mandelbaum, 2005 [18]	5	N	N	Y	N	Y	Y	Y	Y	N
Kiani, 2010 [19]	5	N	N	Y	N	Y	Y	Y	Y	NR

Note: a, acceptable method of randomisation; b, concealed treatment allocation; c, similar group values at baseline; d, blinded assessor; e, avoided or similar cointerventions; f, acceptable compliance; g acceptable droupout rate; h, similar timing of the outcome assessment in all groups; i, intention-to-treat analysis; Y, yes, N; no; DK, don't know.

Table 3: Description of included studies.

	Subjects/ design	Training program Componenets	Programme Format	Targeted Risk Factor	Athletes (N)		Mean age	Results
Walden, 2012 [13]	4564 female football players, RCT	Neuromusclar warm up Knäkontroll, SISU Idrottsböcker, Sweden, 2005 Exercises focusing on knee control and core stability	15 min warm up program at 2 training sessions a week throughout 1 season	Improve landing technique and strength	Intervention	2479	14	64% reduction in the rate of ACL injury in intervention group.
					Control	2085	14.1	
Gilchrist, 2008 [14]	1,435 collegiate female players, RCT	PEP: stretching, strengthening, plyometrics, agility training, video education.	In-season warm-up program, before practice, each with 20 min, 3x a week for 12 weeks	Neuromuscular control & avoidance of improper biomechanical techniques	Intervention	583	19.88	Overall 41% reduction in ACL injuries
					Control	852	19.88	
Soderman, 2000 [15]	221 semi-professional and professional female football players, RCT	Balance Board Training : Balance, propioception training	10–15 mins per session, 3x a wk, over 7 months	Lower extremity proprioception and dynamic balance	Intervention	121	20.4	No reduction in ACL injury rates with training protocol.
					Control	100	20.5	
Heidt, 2000 [16]	300 female high school soccer players, RCT	Frappier Acceleration training programme: Treadmill and plyometrics	2 treadmill sessions and 1 plyometric session per week. Pre-season program	Avoidance of movements that increase risk of injury	Intervention	42	14-18 (mean age not reported)	No significant difference. Untrained group higher percentage of ACL injuries 3.1% vs 2.4%
					Control	258	14-18 (mean age not reported)	
Steffen, 2008 [17]	2020 female youth soccer players, RCT	The "11" exercises: exercises for core stability, lower extremity strength, agility, balance	Preseason (2 months) and in-season (6 months) warm-up program, before practice, each 15–20 min, every training session for 15 consecutive sessions, then once a week during the remainder of the season	Muscle co-activation imbalance, dynamic knee valgus collapse, increased activation time.	Intervention	1073	15.4	No differences between groups in ACL injury rates.
					Control	947	15.4	
Mandelbaum, 2005 [18]	5,703 female amateur players, CCT	PEP: stretching, strengthening, plyometrics, agility training, video educationPEP: stretching,	20 mins/session, 2-3x a week, sports specific on field warm up	Proper landing techniques, muscle co-activation imbalance, strength and increased activation time	Intervention	1885	14-18 (mean age not reported)	88 and 74% reduction on ACL injury in first 2 seasons, respectively
					Control	3818	14-18 (mean age not reported)	
Kiani, 2010 [19]	1506 female football players, CCT	The 'HarmoKnee' program: warm-up, muscle activation, balance, strength, core stability exercises.	Performed 2x a week preseason (three months), once a week during in-season training session (six months), total duration 20 to 25 minutes	Improve awareness of injury risk, technique, strength and improve motion pattern of knee joint	Intervention	777	14.7	no ACL injuries in the training group compared with 5 ACL injuries in control group
					Control	729	15	

implemented every training for 15 consecutive sessions and thereafter once a week for the rest of the season. The training program makes an emphasis on correct technique and includes core stability, balance, plyometrics and strength exercises. Four ACL injuries occurred in the intervention group and five ACL injuries in the control group with no significance difference between groups (p =0.73).

Heidt et al. [16] examined the Frappier Program in high school female soccer players. 258 Participants were divided into a control group and 42 were randomised in the intervention group. The intervention was started prior to the start of the competitive season and consisted of 13 treadmill speed training sessions (two times per week) and 7 sessions of foot agility exercises completed within a 7-week period. Despite the intervention group having significantly fewer (14%) overall injuries than the control group (33.7%, $P = 0.01$), the incidence of ACL injuries did not reach statistical significance. Rupture of the ACL occurred in 2.4% of the trained group compared to 3.1% of the control group.

Walden et al. [13], studied 4564 adolescent female soccer players over one season. The groups were randomised into an intervention group and a control group, where the intervention group were instructed to do a 15 minute neuromuscular warm up program. The program targeted core stability, balance, and proper knee alignment

(Knakontroll, SISU Idrottbocker, Sweden 2005) to be carried out twice a week. Seven players (0.28%) in the intervention group, and 14 (0.67%) in the control group had an ACL injury. The absolute rate difference for non contact ACL injury did not reach statistical significance (p=0.1).

Kiani [19] used the HarmoKnee preventive program to provide a structured warm up and strengthening exercises program aimed at achieving an improved motion pattern that produces less strain to the knee joint. In this non randomised prospective controlled trial, 777 players in the intervention group and 729 in the control group were studied. The primary finding from this community based intervention trial among 13-19 female soccer players is the 77% reduction in acute knee injuries and there were no ACL injuries in the intervention compared to 5 ACL injuries in the control group.

Discussion

The goal of this review was to determine if neuromuscular and proprioceptive training programs reduce ACL injury rates. There are several limitations to this body of studies as a whole as well as to each individual study.

It is important to note that these results included both contact and noncontact injuries. Contact ACL injuries are often unavoidable and result from a different injury mechanism, and therefore in order to assess the adequacy of the prevention program one must focus on the rates of noncontact ACL injuries. This can be challenging when the ACL injury rate may not be high enough to be able to separate out contact vs non-contact rates. In this literature review, numerous ACL prevention programs [13-17,19] have not been as successful in significantly reducing ACL injury rates. One of the common problems with various ACL prevention programs that have failed to significantly lower ACL injury rates is that it is difficult for a study to be powered enough to reveal statistically significant differences in ACL injury. In order for a study to show statistical significance, a large enough sample is needed in order to have high enough ACL injury rates to be able to compare differences between the 2 groups. Also time of implementation varied, whether it begins pre-season [16,17,19] or upon start of the season [13-15,18].

The assessment of the studies' methodological quality has shown various weaknesses affecting their internal validity [22,23]. Compliance rates and methods of reporting injuries and exposures varied vary widely [24]. Injury incidence was reported by a coach [13,17,18], athletic trainer [14,16], and authors [19,15].

Other diverse factors included the components, frequency and duration of the prevention program. The duration of the prevention strategies were 7 weeks [16], 12 weeks [14,18], 7 months [13,15], 8 months [17] and 9 months [19]. All seven studies had participants between the 13 and 26 years and the applicability to other age groups is also limited. Results could also have varied depending on level of skill and age group.

The major benefit of proprioceptive and balance training is to improve the nervous system's ability to synchronize muscular activity around the knee, aiding dynamic knee joint stability [24-26]. It was recently presented that balance training produces reductions in peak valgus and internal rotation moments during anticipated sporting maneuvers, which could be an underlying mechanism for reduced ACL injury risk [27]. One should be aware, however, that balance training and unstable surfaces are often difficult to implement with the warm-up style programs due to time and equipment constraints. It is unclear if balance drills using unstable platforms alone may be sufficient to reduce ACL injury risk. In that context, only one of seven studies included in this review [15] demonstrated a higher incidence of ACL injuries in the intervention group. Soderman, et al. used a single component program consisting of balance exercises only. It could be hypothesized that, due to the home-based training intervention, compliance with the program was compromised. This might, together with the low number of athletes, large drop-out rates, and the fact that the authors did not report whether the ACL injuries were contact or noncontact in nature, explain rather interesting results. There was also a lack of supervision since the training was done at home. Balance and proprioceptive training may be useful to include in an ACL prevention program but on their own they are not sufficient. Neuromuscular and biomechanical adaptations need to be addressed [10,11].

Both, Mandelbaum et al. [18] and Gilchrist et al. [14] investigated the same warm up strategy, the PEP. Although Mandelbaum [18], showed a highly significant reduction in ACL injuries, Gilchrist et al. [14] showed only a trend toward risk reduction with a significance in the injury rate only in the second half of the study. The different results are likely the result different study designs and methodologies. Mandelbaum [18] used a CCT design with intrinsic methodological limitations while Gilchrist et al. [14] performed the gold standard RCT. The CCT introduces a potential for subject and allocation bias as there is no blinding or randomisation. The voluntary enrolment of athletes serves a potential selection bias recruiting athletes with a greater interest in ACL injury prevention. Moreover other limitations of this study were poor compliance measures and inadequate measures of exposures. However, the PEP used in both studies was an on-the-field warm-up program that required only traditional soccer equipment (cones and soccer ball) making it a practical and cost-effective way to address the incidence of ACL injury. Moreover, it was a 2-3 times a week program with a duration of 20 min per session over the course of the 12-week soccer season, what made this program suitable to fit with the already existing training programs in each soccer team. The significance in injury rate in the second half of the study suggests that the program takes some time to have an effect, thus arguing for implementing ACL prevention programs earlier, prior to the season, to have an effect on ACL injury rates.

The 'HarmoKnee' [19] programme significantly reduced the risk of knee injuries. However, findings did not indicate a significant reduction in the risk of specific injuries including ACL injuries despite the intervention group sustaining no ACL injuries. This is due to the very low number of 5 ACL injuries identified in the control group. Until larger studies are completed evaluating the 'HarmoKnee' [19] programme, these results must be interpreted with caution.

The Heidt et al. [16] study also had low numbers to examine injury epidemiology, and compliance also was not well documented. In addition, these authors did not detail the training method in a useful way. They used a commercial training program, without giving details of the exercises used. Heidt [16] argues that if there had been a higher number of athletes in the study then there would have been higher ACL injury rates, resulting in greater differences between the 2 groups. This highlights a common challenge in studying ACL prevention programs - low overall ACL injury rates require high numbers of athletes to participate in prevention studies to be able to assess significant differences between trained and untrained athlete populations [10].

The 11' intervention program [17] may have been too general to address the ACL injury rates identified in female football players. The lack of effectiveness could also be explained by the poor compliance; only used in 52% of training sessions with a seven week summer break during the study. This may have lead to a detraining effect during this period. As they further discuss, individual data were not recorded and subgroup analyses were not possible in this low power study. With 4 ACL injuries and 5 ACL injuries in the intervention and control group respectively, the author did not report whether they were contact or non contact, thus limiting the applicability of this study for the present review. The authors concluded that better compliance was needed for sufficient training effects to reduce injuries.

Walden [13] well designed randomised control trial included a cluster randomisation design to avoid contamination, blinded assessors with careful monitoring of exposure data and compliance. The principal finding of this study was that a 15 minute neuromuscular warm up reduced the overall rate of ACL injury by 64%. Although this was the largest RCT in the review, there was a lower than expected incidence of ACL injuries which could have lead to the non-significant difference in the rate of non-contact ACL injury. A possibility of selection bias could have existed as clubs initially chose to participate. The authors also highlight that the cut off for compliance was a least one intervention session a week. This may have allowed other warm up strategies to confound the benefits of the intervention and conversely for optimal results to be realised.

Conclusion

Female football players on average have a 3.5 times higher risk for sustaining non-contact ACL injuries compared with males. This gender discrepancy stems from maladaptive neuromuscular recruitment patterns and poor jumping/landing biomechanics that lead to greater risk for ACL tears in women [10]. Approximately 80% of ACL injuries are noncontact, making prevention strategies focusing on neuromuscular control, balance, and resistance to muscular fatigue attractive targets for clinical intervention [10].

A number of conclusions could be elicited from the literature review. First, there is no universally, standardised neuromuscular and proprioceptive intervention program established for female football players to reduce the ACL injury risk. Second, programs with multi-component exercises showed better results than single component preventive programs. Third, ACL prevention program incorporating exercises and drills that emphasize plyometrics, neuromuscular training, and muscle strengthening, as well as education and feedback regarding body mechanics and landing technique may be advocated. Fourth, programs should ideally begin in the pre-season combined with a maintenance program during the in-season [3].

Of the seven studies, ACL injury risk was decreased in five studies. Therefore, more than half of the interventions were effective in reducing ACL injury incidence. Although the exercises included differed between studies, there appears to be a measurable effect of neuromuscular and prioprioceptive training interventions on the risk of ACL injury [11] Wide scale implementation of ACL prevention programs may hopefully one day narrow the gender gap in injury rates in female football players [10].

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