

# Prevention of Primary ACL Injuries: A Novel, Innovative Approach

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## ABSTRACT

Anterior cruciate ligament (ACL) injuries are increasing amongst professional and recreational athletes, and creating prevention programs to reduce the occurrence of ACL damages is becoming a necessity. To prevent an ACL tear, it is necessary to comprehend the mechanisms and the risk factors of injury. Biomechanical and clinical studies try to understand these complex mechanisms in order to identify factors that can be improved and to develop training programs to prevent at least non-contact ACL injuries. There are several promising programs, but there are still many questions to answer. This paper analyzes the risk factors for ACL injuries and some aspects of the modern programs developed to decrease the rate of ACL tears.

**Keywords:** anterior cruciate ligament injury, knee, instability, prevention, risk factors

## INTRODUCTION

Anterior cruciate ligament (ACL) injuries are commonly encountered in professional and recreational athletes. There are many scientific projects aimed towards ACL injury treatment plans, but there is still a significant percentage of reconstruction failures with important long-term disabilities, reduced knee function, and significantly increased risk of developing knee osteoarthritis.<sup>1</sup> Analyzing the mechanism of ACL rupture, McNair and Boden found in 1990 and 2000 respectively, that around seventy percent of ACL tears take place as a non-contact injury and therefore might be, in theory, preventable.<sup>2,3</sup> Creating prevention programs to decrease the incidence of ACL injuries is a logical step. In 1996 Caraffa *et al.* published for the first time a prospective study on the prophylaxis of ACL tears in soccer and showed that proprioceptive workout can meaningfully decrease the rate of ACL in these athletes.<sup>4</sup> Even if initially the notion of ACL tear prevention was debatable, in recent years important research has been undertaken to prove that prevention programs can reduce the incidence of ACL

injuries. An analysis of 7 studies on ACL injury prevention programs, carried out between 1999 and 2008, found that participation in a prevention program decreased the risk of non-contact ACL tear by 71% on average.<sup>5</sup> Prevention programs can also diminish the rates of other knee and ankle injuries.<sup>6</sup> To be effective, these programs must be followed throughout the season; this requires a combined effort from the athletes and their coaches.

The present paper aims to present an analysis of the risk factors involved in ACL injuries and the results of the prevention programs.

## RISK FACTORS

There are several studies showing an increased risk of up to six times for females to have an ACL tear.<sup>7,8</sup> This leads to the assumption that there are several gender-related factors that influence the risk of having an ACL tear.

Analyzing the factors that can influence the risk of ACL damage, we can describe non-modifiable and modifiable biological factors, and environmental factors. Non-modifiable factors cannot be influenced, therefore cannot be decreased by any prevention program. In 2007 Hewett *et al.* published a systematic review of studies analyzing the association between ACL injury and menstrual cycle.<sup>9</sup> Certain studies found a significant risk of ACL tear in the pre-ovulatory phase and a lower injury rate in females taking contraceptive pills, but no definite indication that hormonal changes are linked with ACL injury or the use of oral contraception. Ligamentous laxity is considered to be a risk factor for ligament injuries, as it has been demonstrated by published studies.<sup>3,10</sup> The increased posterior tibial plateau slope seems to be correlated with a significant risk for ACL tear due to the increased peak of ACL strain.<sup>11-13</sup> Notch width seems to be an important anatomic factor correlated with the risk of ACL tear, given that a minor notch invades the ACL.<sup>14</sup> Souryal *et al.* proposed the notch-width index and showed that notch-width narrowing was significantly correlated with non-contact ACL injuries.<sup>15</sup> Chaudhari *et al.* showed that ACL injured subjects had significantly lower ACL volumes compared with those measured in controls.<sup>16</sup> This can be correlated with the findings of Dienst *et al.*: a lower notch-width index is linked to a smaller ACL.<sup>17</sup> Another biological factor that correlates with ACL injury risk seems to be the maturation of the skeleton, muscles, and neurological function. There is no difference between pre-adolescent gender characteristics, but following maturation, males undergo an increase in strength and coordination, allowing an increased neuromuscular control with differences in jumping and landing.<sup>18,19</sup>

The modifiable factors involved in ACL injury risk are represented by neuromuscular imbalances.<sup>20</sup> Hewett *et al.* named the neuromuscular disproportion that causes valgus collapse as the ligament dominance.<sup>20</sup> In case of ligament dominance, the supportive muscle groups that are adjacent to the knee joint do not contract, leading to the absorption of ground reaction forces by static tissues such as ligaments, cartilage, and bone. There are several studies demonstrating that ligament dominance is a risk factor for ACL tear, with demonstrated increased side-to-side differences in case of female subjects.<sup>21,22</sup> It seems that the posterior kinetic chain (gluteus, hamstrings, gastrocnemius-soleus) is of utmost importance in preventing ACL tears, even if all lower extremity muscular groups are responsible for dynamic knee steadiness. Improper dynamics of the muscles during landing leads to increased abduction times, thus increasing the load that is transmitted to the ACL.<sup>20</sup> Another neuromuscular imbalance creating a risk for ACL tear has been named as quadriceps dominance by Hewett.<sup>20</sup> This is described as a quadriceps-active landing technique; women activate their quadriceps muscular group more than men, resulting in a vertical extended landing posture rather than a flexed posture, with an increased protection for the ACL. Contraction of the quadriceps exerts a tension on the ACL, with a maximum in 0–30° of knee flexion. An upright landing position mainly contracts the quadriceps, applying an anterior shear stress to the knee joint.<sup>23</sup> Leg dominance is another face of neuro-muscular control, which refers to side-to-side asymmetry. Even if the majority of athletes have one dominant side for kicking or jumping, it seems that female athletes have increased side-to-side differences.<sup>20,24</sup> Hewett considered a sportsperson to be leg-dominant when the muscle asymmetry was measurable.<sup>20</sup> In a study published in 2003, Ford found that female basketball players landed with a significantly higher maximum valgus knee-angle on their non-dominant side in comparison with their dominant part, finding not valid for males.<sup>22</sup> The last neuromuscular misbalance described by Hewett is termed trunk dominance. This describes the lack of dynamic control of the trunk due to suboptimal core strength, generating larger movements in the lower extremity for compensation. Lateral trunk movement was the best predictor for ACL tear risk in a study published by Zazulak in 2007.<sup>25</sup>

Even if there might be not enough studies to definitively assign these factors as risk factors for ACL tears, the efficiency of preventing programs based on reducing neuromuscular imbalances support the importance of these factors. Fatigue might be a risk factor for ACL tears, described in a study published by Chappell in 2005, but there aren't enough data yet to firmly sustain the importance of

this factor.<sup>26</sup> There are many studies analyzing environmental factors as risk factors for ACL injury. These include the sport, weather conditions, and especially sports gear, the quality of equipment, footwear, surface, shoe-surface interface etc. The most studied sports that seem to have the highest potential for ACL injuries are: American football, Australian football, soccer, basketball, handball, and ski.<sup>27</sup> Several studies showed a high risk of ACL tears in dry compared to wet conditions, in hot compared to cold season, or in pre-season.<sup>28,29</sup> Orchard in 2005 issued the results of a prospective study on Australian footballers and showed that grass type, additionally to ground hardness or weather conditions, would be accountable for a higher risk of non-contact ACL tears.<sup>30</sup> An epidemiologic study conducted by Dragoo *et al.* in 2012 analyzing football players, found that the percent of ACL tears on artificial grass compared to natural grass was present in games, scrimmages, and practices, and across all divisions.<sup>31</sup> Olsen in 2003 published a retrospective study on the Norwegian handball team and found an increased ACL tear risk on rubber floors.<sup>32</sup> Ekstrand *et al.* did not find any differences between the use of natural or artificial grass when conducting a prospective study on injuries on elite footballers.<sup>33</sup> It seems that there is scarce evidence to sustain the fact that increased friction forces in the shoe and ground surface are an important risk factor for ACL tears. Bere *et al.* published in 2011 a video analysis showing that ski equipment was the most important risk factor for ACL injury, followed by changes in snow conditions;<sup>34</sup> icy conditions on the slope probably could be safer than aggressive snow conditions. There are many studies supporting the importance of environmental factors in ACL injuries, some specific for certain sports.

## PREVENTION PROGRAMS

Even if there are some contradictory results and more studies are needed, we can say that at least some of the described factors definitely have a significant role in producing non-contact ACL tears. Considering that some risk factors for ACL injury are modifiable, preventing programs have been developed with the purpose to reduce ACL tears. Most studies on preventive programs aimed to change risk factors for ACL tears rather than decrease injury incidence.<sup>28,29</sup> Even if male professional and recreational athletes comprise the biggest population of total ACL tears, the science behind prevention injury programs is based mainly on research conducted on female athletes, therefore researchers are not ready to offer optimal preventive plans for male sports players.<sup>35</sup> Prevention agendas center their attention on some key features of training: bal-

ance, proprioception, plyometrics, strengthening, endurance, and stability.<sup>36</sup> The first clinical research to examine the protecting mechanisms of a neuromuscular training schedule was carried out in 1999 by Hewett *et al.*<sup>37</sup> A group of athletes underwent a pre-season neuromuscular workout program focused on flexibility, plyometrics, and proper technique. They found an increased incidence of injuries in the untrained female group compared with the trained female group. In 2005 Mandelbaum *et al.* analyzed in a prospective study conducted on women soccer players the role of a prevention program they had developed, named Prevent injury and Enhance Performance (PEP), designed for ACL tear prevention.<sup>38</sup> The PEP program (Table 1) is a 20-minute exercise program that replaces the normal warm-up routine.<sup>38</sup> The study included 1,041 female athletes in the first year and 844 in the second year who underwent the program and were compared with matched athletes as control. There was an 88% decrease in ACL tearing within the 1st year, and a 74% decrease in the second one.

Using the PEP program Gilchrist *et al.* evaluated, in a randomized controlled trial, the incidence of non-contact ACL injury in women's soccer. They found that the incidence of non-contact ACL tears was 3.3 times lower in the PEP group compared to controls, and that players in the PEP group with a history of ACL tear had a significantly lower chance of suffering additional injuries.<sup>39</sup> Thompson *et al.*, in 2016, published a study investigating the effects of the F-MARC 11+ injury prevention protocol developed by Soligard in 2008, showing that the program may be effective in improving peak knee valgus moment, a risk factor for ACL injuries, during a double-leg jump in pre-adolescent athletes. Also, the program reduced overall injury rates, but it remained unknown if it reduced ACL injuries in particular.<sup>6,40</sup>

Many trials analyzed different neuromuscular training programs designed to reduce the risk for ACL tear in handball female players and showed to reduce in the incidence of overall ACL injury, even if the studies are underpowered.<sup>41</sup> The efficacy of prevention programs in decreasing the incidence of ACL tearing was sustained by the results of meta-analyses published by Hewett in 2010<sup>20</sup>, Yoo in 2010<sup>36</sup>, and Sadoghi in 2012.<sup>42</sup> There are several biomechanical and clinical studies and meta-analyses supporting the possibility of preventing ACL injury by using validated prevention training programs, but we need future research to determine the importance of neuromuscular imbalances and generate solutions to prevent non-contact ACL injuries. One significant difficulty in the implementation of prevention programs is compliance. Steffen *et al.* published a study in 2007, in which adherence to preventive programs was 24% of the number of teams, as a result

**TABLE 3.** Prevent injury and Enhance Performance designed for ACL injury prevention

Phase	Activity (Duration of Time To Complete Activity)	Time at which Activity Occurs During Workout	Purpose
Warm-up (purpose: preparation)	Jog line-to-line (30 sec)	0 to 0.5 min	Prepare for training session
	Shuttle run (side-to-side) (30 sec)	0.5 to 1 min	Engage hip abductors and adductors; promote speed; avoid inward caving of knee joint
	Backward run (30 sec)	1 to 1.5 min	Engage hip extensors and hamstrings
Strengthening (purpose: leg strength)	Walking lunges (1 min)	1.5 to 2.5 min	Strengthen quadriceps
	Russian hamstring (1 min)	2.5 to 3.5 min	Strengthen hamstrings
	Single toe raises (1 min)	3.5 to 4.5 min	Strengthen calf: improve balance
Plyometrics (purpose: power, strength, speed)	Lateral hops over cone (30 sec)	4.5 to 5 min	Increase power and strength: emphasise neuromuscular control
	Forward and backwards hops over cone (30 sec)	5 to 5.5 min	Increase power and strength: emphasise neuromuscular control
	Single leg hops over cone (30 sec)	5.5 to 6 min	Increase power and strength: emphasise neuromuscular control
	Vertical jumps with headers (30 sec)	5 to 6.5 min	Increase vertical jump
	Scissor jump (30 sec)	6.5 to 7 min	Increase vertical jump
Agilities	Forward run with 3-step deceleration	7 to 8 min	Increase dynamic stability of ankle-knee-hip complex
	Lateral diagonal runs	8 to 9 min	Encourage technique and stabilization of hip and knee; avoids "knock-knee" position
	Bounding rung (44 yd.)	9 to 10 min	Increase hip-flexion strength, power and speed
Stretching (can be performed after warm-up)	Calf stretch (30 sec × 2 repetitions)	10 to 11 min	Stretch calf; focus on lengthening muscle
	Quadriceps stretch (30 sec × 2 repetitions)	11 to 12 min	Stretch quadriceps; focus on lengthening muscle
	Figure four hamstring stretch (30 sec × 2 repetitions)	12 to 13 min	Stretch hamstrings; focus on lengthening muscle
	Inner thigh stretch (30 sec × 2 repetitions)	13 to 14 min	Stretch adductors; focus on lengthening muscle
	Hip flexor stretch (30 sec × 2 repetitions)	14 to 15 min	Stretch hip flexors; focus on lengthening muscle

of the fact that instructors and athletes choose to focus on their performance rather than preventing injuries.<sup>43</sup> This issue raises the question if prevention training programs should be applied to all athletes or just to the risk group. Myer *et al.* in 2013 conducted a screening study on women athletes divided into risk categories based on analyzing movement during a vertical jump and calculating knee abduction.<sup>35</sup> They showed that peak knee abduction angle, quadriceps-to-hamstring ratio, knee-flexion range of motion, body mass index, and tibial length were the best predictors for knee abduction moments, with a sensitivity of 77% to 85% and a specificity of 71% to 93%. In 2015, the American Academy of Orthopedic Surgeons published the Appropriate Use Criteria for ACL Injury Prevention programs in order to determine the usefulness of using a supervised program for preventing ACL tears.<sup>44</sup> Most votes were for an ACL injury prevention program that includes

appropriate instruction and supervision, dynamic warm-up, strength training, technique training, plyometrics, balance and proprioceptive training.

## CONCLUSIONS

An increase in ACL injuries has been seen in the past years due to the growing number of athletes today. Even if there is not one specific way to injure an ACL, there are several different factors that intensify the risk for a non-contact ACL tear. It is accepted that females have a four to six time higher risk of ACL injuries than males, due probably to many different intrinsic factors, such as anatomical, biomechanical, and hormonal. Understanding the neuromuscular factors and environmental factors of an ACL injury allows physicians and therapists to develop programs that help decrease the rate of such injuries.

## CONFLICT OF INTEREST

Nothing to declare.

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