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Risk Factors of ACL Injury

Nuthan Jagadeesh, Sachindra Kapadi, Venkatesh Deva and Ankur Kariya

Abstract

An anterior cruciate ligament(ACL) is one of the major stabilizers of the knee joint, injury to which can be quite dreadful even ending many sports careers if not properly treated. Knowledge of the risk factors contributing to ACL injury will help in identifying at-risk individuals and develop preventive strategies. The factors contributing to ACL injury are multi-factorial involving biomechanical, anatomical, hormonal, neuromuscular factors etc; and can be broadly classified as Intrinsic and Extrinsic factors. Intrinsic factors are mostly non-modifiable risk factors may be subdivided into anatomical, genetic, gender, previous ACL Injuries etc. Whereas Extrinsic factors are mostly modifiable risk factors include environmental factors, characteristic of surface and shoe, BMI and others. Anatomical risk factors can divided into tibial parameters like posterior tibial slope, medial tibial plateau depth etc; femoral parameters like notch width, notch index etc.

Keywords: risk factors of ACL injury, Notch index, posterior tibial slope, prevention of ACL injury

1. Introduction

The Anterior Cruciate ligament (ACL) is said to be one of the most important stabilisers of the knee preventing the anterior translation of the tibia over the femur. Injuries to the anterior Cruciate ligament commonly occur during sports and are caused usually by sudden stops or change in direction while running, jumping and landing [1–4]. These injuries are quite disabling and take a significant amount of time to recover and rehabilitate despite the surgery. Moreover, people with these injuries tend to end up with increased articular wear with time and end up with early post-traumatic arthritis even with the best of surgeries [5].

ACL injuries have been increasingly common in elite athletes who have ramifications in terms of contract/scholastic obligations, sponsorships and revenue-generating potential. Though the number of people returning to sports post ACL reconstruction has increased, most professional sportsperson face challenges of returning to preinjury level and performances expected of them. As most of them, do not return to a high level of performance, many careers have ended or shortened because of ACL injury when compared to those without the injury [6, 7]. Consequently, it's important to identify the risk factors which might lead to an increased probability of ACL injury so that preventive measures can be taken.

Risk factors of ACL injury could be divided into two major categories like intrinsic and extrinsic [8]. Intrinsic factors include those which are innate to the individual and are usually non-modifiable. These include factors such as anatomic

factors (Notch parameters, posterior tibial slope, lower extremity alignment etc.), neuromuscular factors, genetic factors, hormonal milieus and cognitive function. Extrinsic factors are those which surround the athlete and may include level and intensity of games or activity, playing surface and environmental conditions, as well as equipment used [9–12]. In this chapter, we have attempted to create a comprehensive yet exhaustive list of the risk factors contributing to ACL injury.

2. Material and methods

In this review of literature, the authors have used Pubmed database to search for various studies that factors that may contribute to ACL injury. The authors used the keywords anterior cruciate ligament, risk factors, extrinsic risk factors, intrinsic risk factors to search for articles. After eliminating the duplicates, the authors identified the trends and patterns in the risk factors and have summarised the findings in this article to create a concise review for readers and students.

3. Discussion

3.1 Intrinsic factors

3.1.1 Anatomical factors

The anatomic factors have been studied thoroughly these days as these factors could be picked up easily by investigations pertaining to the diagnosis of ACL injuries like knee radiographs and MRI. Establishing correlation with these anatomic factors could help us in establishing a reliable tool in screening individuals at risk of ACL injury. Variations in these anatomical features are well documented in individuals especially between men and women which may explain why women are maybe at more risk of ACL injury than men. Various anatomic factors commonly studied include those related to knee geometry, alignment of the lower extremity, knee laxity, and body mass index [12, 13]. Factors related to knee geometry can be divided into a) tibial parameters like posterior tibial slope, depth of medial tibial plateau b) femoral/ notch parameters like notch width, bicondylar width, notch width index.

3.1.1.1 Notch parameters

Notch parameters have been one of the widely researched risk factors related to an ACL injury but there are wide differences in the way these parameters are measured. The femoral attachment of ACL is in the medial aspect of lateral femoral condyle over lateral intercondylar ridge [14, 15]. It is observed that impinging of ACL at various knee positions are well documented especially in those with narrow notch width. But controversy exists whether it's due to geometry and size of notch itself, or due to volume of ACL or amalgamation of these characteristics [16]. It's proven that women are known to have smaller notches when compared to males and that the people with smaller notches tend to have thinner and weaker ACL compared to those with wider notch [17–19]. The stenotic notches cause ACL impingement over the lateral femoral condyle and if the knee is subjected to any anterior shear force or tibial rotational forces causing rupture of ACL ligament [20–23].

LaPrade et all demonstrated that there is an increased risk of ACL injury in people with a narrow intercondylar notch [24, 25]. Souryal et all in their study on

bilateral ACL injuries found narrow notch width to be associated but they used only the plain radiographs to calculate the Notch width. The major drawback of these studies was that they were done on plain radiographs where errors due to magnification were common. A notch width index was thus used to overcome these issues. Notch width index (NWI) can be measured using tunnel view radiographs or Coronal section MRI. The NWI was identified as the ratio of the width of the intercondylar notch to the width of the distal femur at the level of the popliteal groove. Souryal et al. used a tunnel view of radiographs and compared patients with unilateral and bilateral ACL injuries and found that patient with bilateral ACL ruptures have significantly smaller notch and NWI when compared to those with unilateral ACL ruptures. Moreover, they found no difference in NWI of unilateral ACL ruptures when compared to those with normal knees. Furthermore, they conducted a cohort study and reported that men athlete had higher NWI compared to female athletes who suffered ACL injuries when compared to those uninjured ones [26, 27]. S.M. Fahim et all in their randomised control study used MRI for the calculation for NWI, reported that there were no differences in NWI in either sex and the NWI was significantly lower in those with ACL injury [28]. Ashwini et al., in their MRI based comparative study, demonstrated that people with ACL injury had NWI of 0.29 ± 0.02 or lesser compared to those without an ACL injury, whereas Bhasukala et al., postulated the cutoff of NWI to be $0.28 \pm 0.06.21$. S.M. Fahim Et all reported cut off value of 0.29 with a sensitivity of 90% and specificity of 86.7%. However, Gormeli CA et al. In their study on bilateral knees with ACL injury demonstrated cut-off values of NWI of 0.22 ± 0.008 in bilateral injured knees and 0.24 ± 0.01 in the unilateral injured knee [29–31]. So the cut off varies depending on the ethnicity and the exact cutoff values are still controversial but most authors have concluded the critical value NWI ranging from 0.19 to 0.26.

The shape of the intercondylar notch is another parameter frequently studied with regards to the notch shape that is most associated with an ACL injury [32–34]. We could use a semi-quantitative approach to classify the various intercondylar notch shapes. It is classified into three shapes i.e. A, Inverse U, and Omega (U). Two parameters are calculated to ascertain the notch shape viz. notch width at the level of the popliteal groove(NWP) and notch width at the joint line(NWJ). If NWP equal to or near equal to NWJ, then the notch is of "U" shape. If NWP < NWJ then the notch is of "A" shape.If the NWP > NWJ then the notch shape is of Omega shape. 'A' shaped femoral notch is commonly associated with ACL injury whereas an inverted U shaped notch is more favourable to prevent ACL injury [29, 30, 35].

Overall, most authors found a positive relationship with an ACL injury and narrow notch and smaller NWI increased the risk of ACL injury I.e as intercondylar notch width decreases, an increase in ACL injury risk is observed.

3.1.1.2 Posterior tibial slope

Several studies related to proven multiple times that the Posterior tibial slope could be the major factor contributing to the stability of the knee joint [35, 36]. Cadaveric studies have shown that an increased posterior tibial slope has resulted in an increased anterior translation of tibia over the femur, thus increasing stresses on the ACL ligament especially during active gait [37, 38]. The posterior tibial slope is traditionally measured on lateral knee radiograph, the tibial axis is to be drawn connecting midpoints of lines connecting anterior and posterior cortex 4-5 cm apart as caudally as possible from the joint line. The angle between tangent connecting anterior and posterior cortex at joint and line perpendicular to the tibial axis corresponds posterior tibial slope in lateral knee radiograph. But again controversies regarding errors due to magnification or lack of true lateral radiographs and

inability to measure lateral posterior tibial slope(LPTS) and medial Posterior tibial slope(MPTS) have resulted in calculating these parameters in an MRI. To measure the medial and lateral posterior tibial slope on MRI first is to determine the tibial axis. For this, a sagittal section at the centre of the knee which contains intercondylar eminence and PCL attachment is selected. Two lines joining anterior and posterior cortices was drawn approximately 4-5 cm apart as caudally as possible from the joint line, the line joining the midpoint of the above two lines corresponds to the tibial axis. (**Figure 1**) Now the sagittal section of the centre of the lateral tibial plateau is identified, a tangent connecting the anterosuperior cortex to the posteroinferior cortex is drawn. The angle between the above tangent and the line perpendicular to the tibial axis corresponds to the medial posterior tibial slope. A similar technique is to be used to measure Lateral posterior tibial slope by drawing tangent at the centre of the lateral tibial plateau (**Figures 2** and **3**). A detailed view of MRI have found lateral posterior tibial slope(LPTS) to be more involved with ACL injury than medial Posterior tibial slope(MPTS) [39] but a meta-analysis has shown that ACL injury was associated with

Figure 1.
MRI picture depicting calculation of Tibial Axis.

medial and lateral PTS [40]. Hashemi et all [41], in their study of 104 patients, both MTPS and LTPS were increased, injured group. Though females had higher LTPS than males they concluded that increased lateral posterior-directed tibial plateau slope is one of the major risk factor irrespective of gender. Whereas MPTS was significantly increased only in men. Stijak et all, in their utilised both knee radiographs and the MRI, to determine the correlation between PTS and lateral plateau and concluded that increased lateral PTS was seen among the ACL injury cohort compared to the ACL intact cohort but they found increased MPTS in the uninjured group when compared to the injured cohort. They suggested that an increase in LTPS would influence the rotation of the knee joint causing pivoting of the knee. In our study, Both MPTS and LTPS had a positive correlation with ACL injury they were significantly increased in the ACL tear group when compared to uninjured group irrespective of the gender. Females had higher MPTS and LTPS when compared to males in both groups but the difference was statistically significant in either sex.
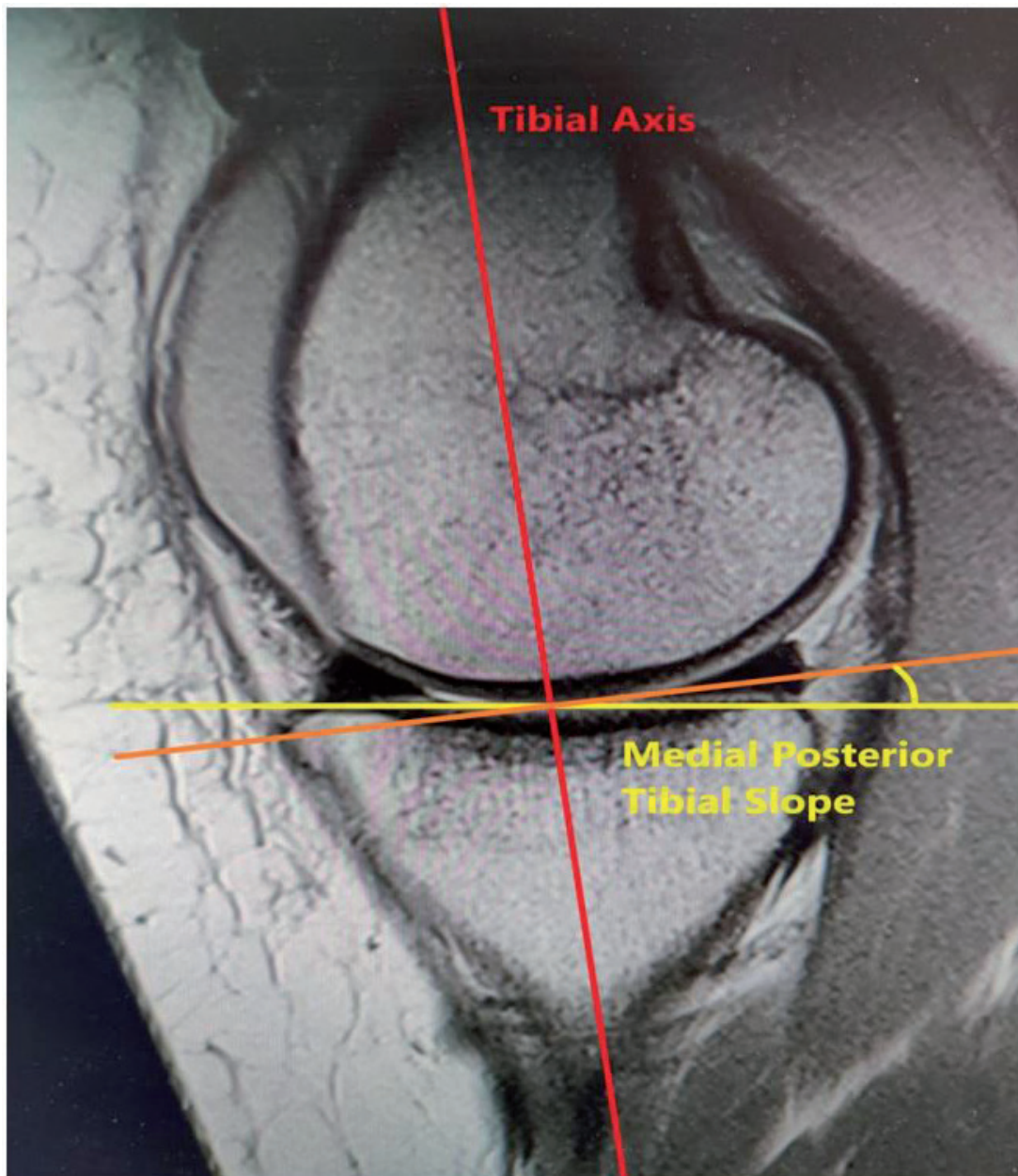

Figure 2.
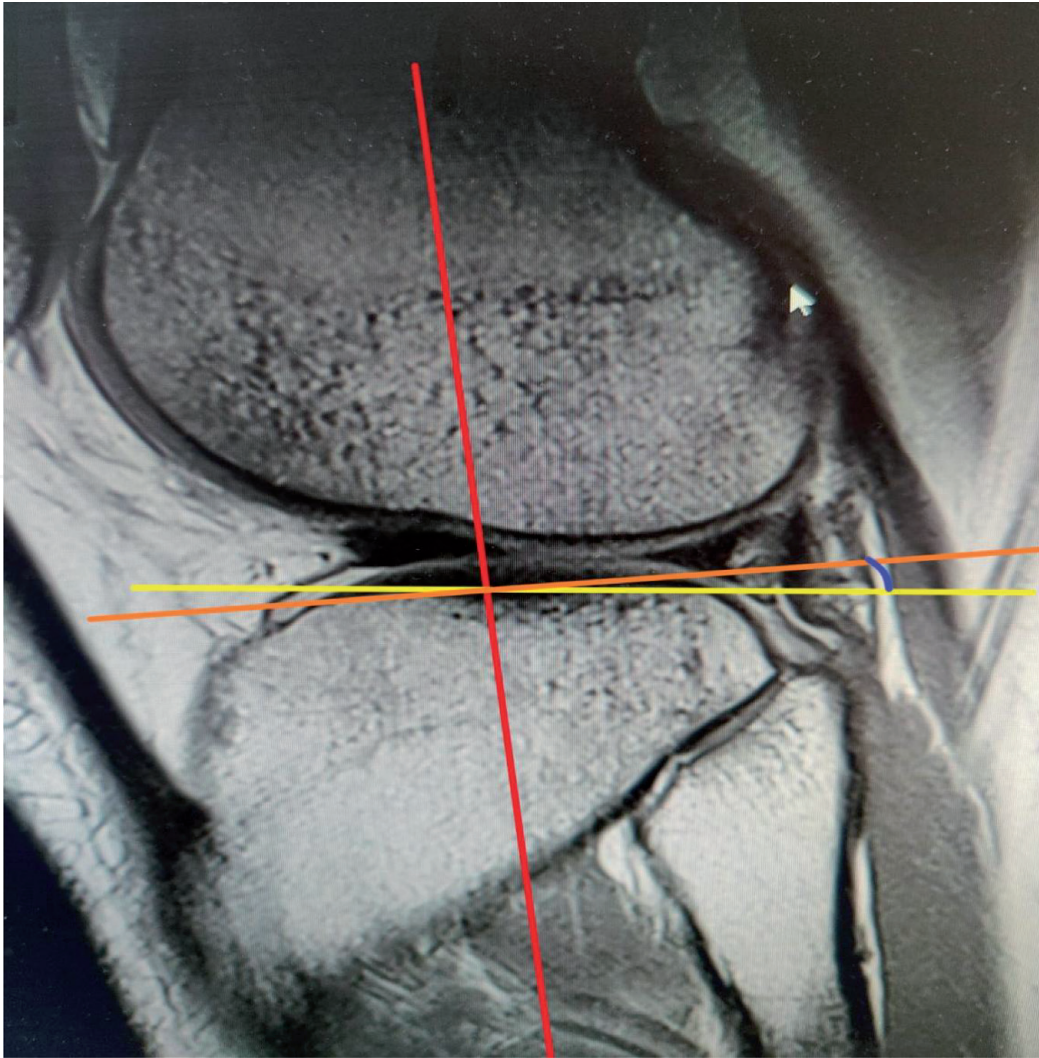*MRI picture depicting calculation of medial posterior Tibial slope(MPTS).*

Figure 3.
MRI picture depicting calculation of lateral posterior Tibial slope (MPTS).

3.1.1.3 Medial tibial plateau depth

Other tibial medial parameters assessed are with the correlation of medial and lateral tibial plateau depth with an ACL injury but the evidence in this regard is very limited. It is measured with two parallel lines line drawn, one connecting the highest point of anterior and posterior points of the medial tibial plateau and the other line is tangent drawn at the deepest point of the medial tibial plateau, the distance between these two lines corresponds to medial tibial plateau depth. Hashemi et al. suggested that deepening of the surface of the medial tibial plateau leads to better joint congruity and prevents anterior translation of the tibia. In their study, they concluded that decreased MTD is associated with a greater risk of ACL injury. They found MTD to be a bigger risk factor than LPTS or MPTS whereas Blanke F et all suggested there is no correlation of medial tibial plateau death with an ACL injury [41–44]. More research in this area is required to come to a proper consensus on the influence of MTPD in ACL injury.

3.1.1.4 Other factors

Other parameters said to be associated with ACL injury are subtalar pronation, knee recurvatum, quadricep angle but the mechanism of how these parameters affect and evidence regarding its association is very limited.

3.1.2 Neuromuscular risk factors

In Contrast to anatomical risk factors which non-modifiable without surgical intervention, neuromuscular deficit are often modifiable risk factors. Intervention could reduce the risk of ACL injuries. Better control over the core body and improved proprioceptive control over the lower extremity have said to be associated with reduced risk of ACL injury. Proprioceptive performance can be improved by exercises improving muscle strength, synergistic coordination etc. which in turn help to reduce the risk of ACL injury. The mechanism of ACL injury occurs when the athlete takes off from valgus positioned knee, during which the knee is typically in 10–30° of flexion and tries to internally rotate the externally rotated foot aiming to suddenly change the direction.

There is a greater risk of injury to ACL injury when the knee is in abduction, there are intersegmental abduction movements and increased ground reaction force with decreased stance time. A study by Hewett et al. showed that when landing from jump in double leg stance, increased knee abduction angle and intersegmental forces, greater ground reaction force and shorter stance time caused increased ACL injuries [44–48].

A small knee flexion angle coupled with strong quadriceps contraction during sports activity will cause increased posterior loading on the knee. As a result, this increases ACL injury risk.

In female athletes, while landing from heigh during a jump, they perform cutting and pivoting manoeuvres with less knee flexion and hip flexion, increased valgus at the knee, increased internal rotation of the hip coupled with increased external rotation of the tibia and increased quadriceps muscle activation caused increased ACL injury due to increased strain on the knee.

Females have poor neuromuscular control of hamstrings and weaker gluteus medius strength, weaker hip abductors which coupled with poor landing mechanism increases the risk of ACL injury.

Balance training, core strengthening, jump training, dynamic joint stability and plyometric exercises training increased core stability and improved proprioception, which reduced the risk of ACL injury.

When the knee is in valgus loading the medial collateral ligament becomes taut and lateral compression occurs. This as well as the anterior force vector caused by quadriceps contraction causes the lateral femoral condyle to shift posteriorly and the tibia shifts anteriorly and internally rotates, resulting in ACL rupture.

3.1.3 Sex differences

Anterior cruciate ligament tears vary in incidence by gender being more common among women. In fact, studies have shown that the rate of ACL tears could be 9 times more common in women as compared to men [49]. Many studies have tried to study the exact reason for this sex-based discrepancy in ACL injuries. Though the exact reason still remains unclear, it appears there are various intercalated intrinsic factors that lead to this. The possible factors could be due to their unique effects of sex hormones, anatomic differences in the female ACL s and/or neuromuscular control variations among the sexes [50].

Female athletes have been found to have different movement and muscle activation patterns [51, 52]. Females while jumping, due to their increased quadriceps activation coupled with decreased hip and knee flexion increases the load on the ACL, thus injuring it [53]. A study conducted by Anderson et al. have found that the lack of stiffness and strength in the quadriceps and hamstrings in females along

with anatomically smaller ACLs predispose them to injuries [52]. Furthermore, female athletes displayed greater knee laxity values as compared to their male counterparts [54].

Anthropometric studies on ACL have shown Intercondylar notch is an anatomic factor that has links to the risk of ACL injuries [55, 56]. Subjects with a narrow/ stenotic intercondylar notch have a higher incidence of ACL injury. Therefore, females by the virtue of having smaller intercondylar notch and notch width index, have an increased likelihood of sustaining an ACL injury [57].

3.1.4 Hormonal risk factors

There is wide variations in hormonal milieu over the course of menstrual in females. The occurrence of ACL injuries has been found to have an association with the menstrual cycle phase. The reason for this may be because of the presence of progesterone and oestrogen receptor sites on the ACL [58–60]. However, all the studies on this have been either in vitro or in animal models and the presence of these receptors on human ACLs have not been proved. The hypothesis is that oestrogen has an effect on the synthesis and breakdown of the matrix components of ACL. The rate of occurrence of ACL injuries is more during the ovulatory phase of the menstrual cycle, which is hallmarked by high concentrations of serum oestrogen [58, 59]. What's perplexing about these injuries in women is that they have been found to occur during non-contact event usually due to deceleration or a change of direction manoeuvre rather than a direct impact injury [61]. Oestrogen decreases the rate of proliferation of fibroblast and synthesis of types I procollagen whilst progesterone promotes the same [62]. Hence this variation in the concentration of oestrogen and progesterone in the various phases of menstruation influence the materialistic properties of ACL. Thus, ACL injuries in women are more common during the pre-ovulatory phase of menstruation, when the serum oestrogen levels are high [63].

3.1.5 Familial predisposition

There is some evidence to prove that ACL injuries do have a familial predisposition. A study conducted by Flynn et al. showed that people with anterior cruciate ligament tear were twice as likely to have a relative who has an anterior cruciate ligament tear as compared to the controls [64]. They concluded from this study that there is a familial predisposition to an anterior cruciate ligament tear. Another study by Harner et al. found that the incidence of anterior cruciate ligament tear was higher in the patients who have had a family history of ACL injury [65]. However, these studies have not looked into the similarities between the patients and their family. A study by Goshima et al. looked into the mechanism, situation and the types of sports played between patients and their family members to avoid bias [66]. They found that there was a strong familial predisposition to ACL injuries. Furthermore, individuals with FH of ACL injury had an increased risk of repeat ACL injuries and thus require prevention programs.

3.1.6 Genetic risk factors

Mutation in the specific genetic sequence variants of genes that code for the extracellular matric of the ACL are found to predispose such individuals to ACL injury. These genes include COL1A1, COL5A1 and COL12A1. The COL1A1 gene codes for the primary subunit of type 1 collagen which I the primary constituent of the ACL matrix. The TT genotype of the COL1A1 gene was found to be

underrepresented in patients with ACL ruptures as compared to those with control. These studies concluded that individuals with TT genotype of COL1A1 gene are less prone to ACL tears [67]. The COL5A1 gene codes for a major subunit of type V collagen which is a minor constituent of the ACL. A recent study showed that mutation of this gene was associated with ACL ruptures in these individuals [68]. The COL12A1 gene codes for collagen XII which is involved in the fibrillogenesis of ACL. In a recent study by Posthumus et al., it was found that COL12A1 AluI RFLP was found to be associated with ACL ruptures [69].

Matrix metalloproteins that are physiological mediators of collagen cleavage and removal are located on chromosome 11q22. A study done by Posthumus et al. this found that underrepresentation of the AG and GG genotypes caused an increased incidence of ACL injuries [70]. However, these factors are usually associated with other intrinsic and extrinsic factors and their independent association is difficult to determine. It is important that genetic variants be determined in various at-risk population and their phenotypes identified.

3.1.7 Cognitive function risk factor

Neurocognitive performance is one risk factor that has been understudied, though it is potentially a modifiable risk factor. Researchers have been looking into the association of loss of neuromuscular control and noncontact ACL injuries. They hypothesised that reduced baseline neurocognitive functions predispose an individual to ACL injuries. Athletes who had suffered ACL injuries were demonstrated significantly slower reaction time and processing speed. Furthermore, they performed poorly on visual and verbal memory composite scores as compared to the controls. Poor neurocognitive performance is associated with reduced neuromuscular control and coordination issues thereby causing ACL injuries [71].

3.1.8 Previous injury

Previous ACL injury and reconstruction is in itself a risk factor for injury of the contralateral ACL and reinjury of the reconstructed ACL as well [72]. It was found that football players with an old ACL injury and/or reconstruction were predisposed to an ACL injury in either the contralateral knee ACL or the reconstructed ACL graft [73]. Patients who have had ACL reconstruction in the past 12 months have 11 times the risk of sustaining a new / re-injury of the ACL. Some researchers have looked into the incidence of ACL injury in patients who have had other musculoskeletal injuries. It was seen that previous ankle injuries had a correlation to the likelihood of sustaining an ACL injury [74]. However, the site of previous injury and the recovery from the same dictates the risk of having an ACL injury. For example, patients with injuries of the lower limb and trunk have a greater predilection of sustaining an ACL injury as compared to those of the upper limb. Rehabilitation from the injury to pre-injury levels also reduces the risk of sustaining an ACL injury in the future.

4. Extrinsic risk factors

Extrinsic risk factors are the environmental factors, which predispose a person to ACL injury [75–79]. Firstly, weather plays a role wet and rainy days have an increased risk of Anterior cruciate ligament injury as they decrease friction in-between shoes and field. As a result, there is a greater risk of ACL injury. In addition, there is more risk of ACL injury in hot weather as heat increases ligament

extensibility predisposing the patent to ACL injury. Orchard et al. prospective study showed increased risk with hot climate for ACL injury [76–79].

Secondly, the type of Cleats on shoes play a role in ACL injury. Cleats that have higher torsion such as edge cleats have higher resistance and will increase the risk of Anterior cruciate injury. Lampson et al. prospective study showed that cleats with higher torsional resistance have a significant risk of ACL injury. Their study was conducted on 3119 athletes which showed that 42 Athletes with edge cleats had ACL injuries which showed a higher predisposition to ACL injury with Edge cleats. Cleats design such as flat cleats, small cleats and fewer cleats had a fewer ACL injury [75].

Another factor that can contribute to the risk of ACL injury is the surface of the field. The field which has Bermuda grass have a higher risk of ACL injury compared to the field with Ryegrass due to cleats getting trapped in Bermuda grass. Orchard et al. prospective study show an increased risk of trapping in Bermuda grass compared to the field with Ryegrass, but this study did not take into account the different cleats used by the players [76–79].

Another study by Olsen Et al, compared ACL injuries in handball players in synthetic and wooden courts. They have found that the incidence of ACL injuries was 2.35 times higher in synthetic courts compared to the wooden courts [49]. There is usually an interplay between the foot ware and surface of which indoor games take place which increases the ACL injury risk and similar interplay could play in outdoor activities as well in combination with the weather conditions.

5. Conclusion

Several intrinsic and extrinsic risk factors contribute to ACL injury. Focus must be on modifiable risk factors in order to mitigate the risk of ACL tears. In depth knowledge and understanding of these risk fators can help surgeons and physiotherapists to educate patients and sportspersons on prevention of ACL tears.and identify at risk individual (**Table 1**).

Intrinsic risk factors		
Anatomical risk factors		
Tibial Parameters		
Posterior tibial slope	Increased posterior tibial slope associated with increased translation of tibia over femur	
Medial tibial plateau depth	Increased MTD prevents tibial translation. Increased congruence of tibial plateau reduces the risk of ACL tear	
Notch parameters		
Notch width index	Narrow notch area associated with thinner ACLs Stenotic notch is associated with impingement of ACL	Notch width index <0.29 associated with high risk
Shape of intercondylar notch	Three shapes based on notch width at the level of patellar groove (NWP) and at the level of joint line (NWJ)	'A' shaped femoral notch is commonly associated with ACL injury
Other factors	subtalar pronation knee recurvatum quadricep angle, neuromuscular factors	

Intrinsic risk factors		
Gender	More common in females	
	Hormonal effects	
	Anatomical variations in ACL	
	Neuromuscular variation	
	Differences in movements and muscle activation patterns	
	Greater knee laxity	
	Smaller intercondylar notch	
Hormonal risk factors	ACL injury more common in pre- ovulatory phase due to high oestrogen	
Familial and genetic risk factors	Two times higher risk with family history	
	Mutations in COL1A1, COL5A1 and COL12A1	
	chromosome 11q22	
Cognitive function	Poor neurocognitive performance is associated with reduced neuromuscular control and coordination issues thereby causing ACL injurie	
Previous injury	11 times higher risk of ACL injury on same side after reconstruction or opposite side	
	Previous ankle injury	
Extrinsic risk factors		
Weather	Wet and rainy days – reduced friction with surface	
	Hot weather – increased ligament extensibility	
Type of cleat on shoes	Edge cleats – higher risk of torsion – higher risk of injury	
Type of grass	Higher risk with Bermuda grass as compared to ryegrass due to trapping of cleats in Bermuda grass	
Type of courts	2.35 times higher in synthetic courts compared to the wooden courts.	

Table 1.
Summary of all the risk factors of ACL injury.

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