


# Anterior cruciate ligament injury patterns and their relationship to fatigue and physical fitness levels – a cross-sectional study

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## Abstract

Anterior cruciate ligament (ACL) injury is one of the most common knee injuries that leads to many consequences such as early osteoarthritis and knee joint instability.

To explore the association of the types of ACL tear (complete and partial) and side of injury (dominant vs nondominate) with types of playing surfaces, sports, shoes, and mechanism of injuries as well as to determine whether higher levels of fatigue and physical fitness are risk factors for complete ACL tear.

This cross-sectional study used a questionnaire to collect information from young male adults with a confirmed ACL injury who were attending rehabilitation programs. The outcomes of interest were patterns of ACL injury, levels of fatigue before the injury on a 0 to 10 scale, and levels of physical fitness (hours per week). Mann–Whitney *U* and Kruskal Wallis tests were used to assess the differences between groups, while the odds ratios were calculated to evaluate risk factors for complete ACL tear.

One hundred thirteen young male adults with a confirmed ACL injury were enrolled. Most of the reported ACL injuries in this study were complete tear (80.5%) and occurred more frequently in the dominant leg (74.6%) due to noncontact mechanism (63.6%). More ACL injuries happened while playing soccer (97.2%) on artificial turf (53.3%). The level of fatigue before ACL injury was significantly higher in partial ACL tear injuries compared to complete ACL tear injuries ( $P = .014$ ). For every 1-point increase in the level of fatigue on a 0–10 scale, there was a 25% reduction in complete ACL injury risk ( $P = .023$ ).

The pattern of ACL types of tear and side of injury varies in different playing surfaces and mechanisms of injuries. Higher levels of fatigue seem to be associated with a partial tear of the ACL and reduction of a complete ACL tear risk factor.

**Abbreviation:** ACL = anterior cruciate ligament.

**Keywords:** anterior cruciate ligament, artificial turf, complete tear, fatigue and physical fitness

## Key Findings

- Most of the reported ACL injuries in this study were complete tear (80.5%) in the dominant leg (74.6%) while playing soccer (97.2%) on artificial turf (53.3%) due to non-contact mechanism (63.6%).

- Higher levels of fatigue before ACL injury seem to be more related to a partial tear of the ACL.

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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## 1. Introduction

Physical activities improve the efficiency of cardiovascular work, cognitive ability, quality of life,<sup>[1–3]</sup> and decrease the number of fall incidences.<sup>[4]</sup> However, in competitive sports, there is a possibility of several sports injuries that affect the athlete's career and may affect their daily life activities. Knee injuries are one of the most common sports injuries experienced by athletes,<sup>[5]</sup> and in many cases may require surgical intervention.<sup>[6]</sup> One of the most common knee injuries is anterior cruciate ligament (ACL) tear,<sup>[7]</sup> with about 200,000 injuries occurring annually in the United States.<sup>[8]</sup> The majority of those who have cruciate ligament injuries were between 15 and 25 years old.<sup>[6]</sup> ACL in most cases requires a surgical intervention followed by an intensive rehabilitation program for a long period. The injured athlete who underwent the ACL reconstruction and rehabilitation program took around 1 year to recover and about 82% of those were able to return to sports activity, and this percentage was much lower for those who have returned to competitive sports activities (44%).<sup>[9]</sup> In addition, ACL tear may cause further complications, such as the early onset of osteoarthritis, chronic pain, and may affect functional activities and quality of life<sup>[10]</sup> as well as complaints of instability.<sup>[11,12]</sup> Over the past 2 decades, an increase in ACL injury among young athletes has been reported.<sup>[13]</sup> Around 70% of soccer injuries are ACL injuries which ranked in soccer at the top compared to other sports.<sup>[14]</sup>

Several studies categorized the ACL injury in general into 2 categories: contact and noncontact injuries.<sup>[14,15]</sup> ACL injuries due to jumping, landing, or quick change of direction are considered noncontact injuries, whereas, contact injuries happen due to a direct hit to the knee or due to player-to-player contact. Several studies that analyzed the mechanism of injury, risk factors, and prevention methods of the ACL injuries have found that nearly 80% of ACL injuries are due to noncontact injuries.<sup>[15,16]</sup> Boden et al interviewed 89 athletes with 100 ACL injuries using a comprehensive standardized questionnaire about the events of their ACL Injuries. From those 100 injuries, 28 injuries were due to contact mechanism and 72 were a result of noncontact mechanism.<sup>[15]</sup> Several studies have proposed some risk factors to explain the mechanism of noncontact ACL injuries, including ACL impingement in the narrowing space of the intercondylar notch,<sup>[17]</sup> tibiofemoral compressive vector due to quadriceps contraction that leads to an anterior compressive force of the knee,<sup>[18,19]</sup> quadriceps-hamstring co-contraction imbalance,<sup>[20]</sup> and increased axial compressive force.<sup>[21,22]</sup>

The risk factors of ACL injury can be divided into intrinsic and extrinsic factors. Intrinsic factors are defined as factors originating from within the human body including the anatomical structure of knee bones, muscle power, endurance, proprioception, and muscle activation. Other intrinsic factors can include gender, body mass index, nutrition, and the physical properties of the ACL. On the other hand, extrinsic factors are factors outside the athlete's body including the type of shoes worn, type of field surface, and the type of sport and the player position.<sup>[23–25]</sup> There are many factors that remain controversial risk factors such as fatigue and level of physical fitness. While several studies indicated that fatigue is one of the risk factors that increases the possibility of ACL,<sup>[26,27]</sup> other studies reported that fatigued athletes tend to follow protective techniques while playing, especially during landing, that reduced strain load on the ACL.<sup>[28]</sup> However, to our knowledge, previous studies including meta-analysis and systematic reviews examined the effect of

fatigue resistance training protocols on the biomechanics of the lower extremities during some lab-based training tasks such as cutting and landing to determine whether these protocols increase the occurrence of factors that are believed to increase the risk of ACL injury such as increased hip internal rotation.<sup>[26,27]</sup> Whereas in this study, we will determine the level of fatigue during the sports activity in which the ACL injury occurred by indicating fatigue level using a perceived exertion scale.<sup>[29–31]</sup>

In this study, we aimed to assess the patterns and distributions of ACL injuries in different types of playing surfaces, sports, shoes, and mechanism of injury and the interactions between these variables. In addition, a secondary aim of the study was to determine whether higher levels of fatigue and physical fitness are risk factors for complete ACL injuries.

## 2. Methods

### 2.1. Study sample

In this observational study, we included 113 young adults with a confirmed ACL injury (complete or partial ACL tear) between the age of 15 to 55 years old. We excluded individuals suffering from any other ligament injuries of the knee joint. After informing the participants about the study procedures, each participant signed informed written consent. This study was approved by the Research Ethics Committee of the Physical Therapy and Health Rehabilitation Department, Prince Sattam bin Abdulaziz University (No. RHPT/018/003) on 24th of October 2020, and was conducted in accordance with the Declaration of Helsinki. Patients were not invited to comment on the study design and were not consulted to develop patient-relevant outcomes or interpret the results. Patients were not invited to contribute to the writing or editing of this document for readability or accuracy.

Sample size was determined by estimating a medium effect size of 0.5 of the difference between types of ACL injuries with an alpha level of 0.05 and a power of 0.80. Thus, the minimum required sample size was 106 participants. The estimated sample size was calculated using the G Power 3.1.7 software.<sup>[32]</sup>

### 2.2. Study design and data collection

A cross-sectional study design was adopted. A questionnaire was developed to determine the rates and patterns of ACL injuries as well as the levels of fatigue and physical fitness. The questionnaire was developed in the Arabic language and it was self-reported under the supervision of a certified physical therapist. Data collection took place in rehabilitation clinics in the city of Riyadh, Saudi Arabia from October 2018 to September 2019. Participants were asked to report information related to the latest ACL injury if they have had multiple ACL injuries. The questionnaire includes demographic information (age, weight, height, and level of education).

### 2.3. Primary outcomes

The questionnaire included information regarding the type of ACL tear (complete or partial), side of injury (dominant or nondominant), type of playing fields (artificial turf, natural grass, sand playground), type of sport (soccer or other), type of shoes, and mechanisms of injury (contact or noncontact). The dominant foot was determined by asking participants about their preferred foot to use to kick a ball with.

### 2.4. Secondary outcomes

The level of fatigue right before participants have gotten injured was reported using the Rating of Perceived Exertion scale that runs from 0 to 10,<sup>[29–31]</sup> where 0 indicates no exertion at all and 10 indicates extremely hard. Furthermore, the amount of usual physical activity in hours per week before the injury was reported to determine the physical fitness level.

### 2.5. Statistical analysis

Demographic data and study variables that are in the continuous form are summarized using mean and standard deviation. Percentage distribution of the types of tear, sport, field, and shoes, as well as the side of injury and its mechanisms of injury, are reported. The Shapiro-Wilks test was used to assess the distributions' normality of the continuous variables. As all the continuous variables were not normally distributed, nonparametric tests were used to evaluate the difference between variables. Mann-Whitney *U* test was used to assess the differences between the 2 groups, while the Kruskal Wallis test was used to assess the difference between three or more groups. Odds ratios and 95% confidence intervals were calculated to evaluate risk factors for complete ACL injuries. Data were analyzed using IBM SPSS Statistics software (Version 25.0; IBM Corp., Armonk, NY).

### 3. Results

A total of 125 young adults with a confirmed ACL injury were initially invited to participate in the study, and only 113 athletes met the inclusion/exclusion criteria and agreed to join the study. The demographic data and clinical characteristics of the participants are presented in Table 1. All participants were young male athletes with mean age of 32.2 ± 7.8 years.

The results of the questionnaire showed that most of the ACL injuries resulted in a complete tear of 80.5%, of which 72% were in the dominant leg and 28% were in the nondominant leg, while 19.5% of the ACL injuries were a partial tear, where injuries in the dominant side accounted for 92% of injuries, while 8% of partial ACL tear injuries were in the nondominant side (Fig. 1). Almost all the ACL injuries occurred while playing soccer, accounting for 97.2% of all injuries. The questionnaire results showed that most of the ACL injuries occurred during playing on artificial turf with 53.3% of the total injures, while 27.6% of ACL injuries occurred on natural grass and 19% occurred during playing on sand playground (Fig. 2). After looking more closely at the distribution of ACL injuries that occurred on artificial and natural turfs, we found that the percentages of complete tear injuries were very close by 80.3% and 79.3%, respectively, while all injuries that occurred on the sand playground resulted in a complete tear with a percentage of 100% (Fig. 2).

Many of the participants with ACL injuries, who accounted for 88%, reported that their injuries occurred while they were wearing sport shoes suitable for the game, while the other percentages were closely distributed on other types of shoes that are not suitable for the game (5.5%), nonsport shoes (2.7%), or without shoes (3.6%). Of those who reported ACL injuries while wearing sport shoes suitable for the game, 85.6% reported complete tear and 71.2% reported injuries in the dominant side.

In addition, ACL injuries due to noncontact injuries represent approximately two-thirds of the injuries (63.6%), while the other third of injuries represent contact injuries as a result of player-to-player contact or a direct hit on the knee. Figure 3 shows

**Table 1**  
**Demographic data and clinical characteristics of the Participants.**

Characteristics	Values
Age, mean ± SD (years)	32.2 ± 7.8
Weight, mean ± SD (kg)	77.2 ± 14
Height, mean ± SD (cm)	171 ± 7
Body Mass Index, mean ± SD (Kg/m <sup>2</sup> )	26.4 ± 4
Education (years)	14.7 ± 2.3
Physical fitness (hours per week)	3.3 ± 1.7
Level of fatigue prior to injury (maximum score = 10)	5.1 ± 2.5
ACL reconstruction (%)	
- Yes	77 (70)
- No	33 (30)
- Missing data	3
Smoking (%)	
- Smokers	30 (28.6)
- Non smokers	75 (71.4)
- Missing data	8
Type of tear (%)	
- Complete tear	91 (80.5)
- Partial tear	22 (19.5)
Side of injury (%)	
- Dominant side	62 (74.6)
- Non dominant side	21 (25.4)
- Missing data	30
Type of sport (%)	
- Soccer	105 (97.2)
- Others	3 (2.8)
- Missing data	5
Type of playing surfaces (%)	
- Artificial turf	56 (53.3)
- Natural grass	29 (27.6)
- Sand playground	20 (19)
- Missing data	8
Type of shoes (%)	
- Sports shoes suitable for the type of sport	97 (88.2)
- Sports shoes are not suitable for the type of sport	6 (5.5)
- Non-athletic shoes	3 (2.7)
- Without shoes	4 (3.6)
- Missing data	3
Mechanism of injury (%)	
- Pivoting (noncontact)	51 (47.7)
- Jumping and landing (noncontact)	17 (15.9)
- Player-to-player contact (contact)	28 (26.1)
- Direct hit to the knee (contact)	11 (10.3)
- Missing data	5

the distribution of the mechanism of injury, in addition to the distribution of types of ACL injury, the side of injury, and the type of playing field.

The results of Mann-Whitney *U* test showed that the level of fatigue before injury was significantly higher in injuries that resulted in a partial tear of the ACL compare to complete tear of the ACL (*P* = .014). However, the other comparisons did not show any significant differences between the side of the ACL injuries or the mechanism of the injury in terms of the level of fatigue before injury or level of physical fitness (hours per week) (Table 2).

The results of univariate binary logistic regression analysis demonstrated that only the level of fatigue (*P* = .023) was significantly associated with the chance of complete ACL tear (Table 3). For every 1-point increase in the level of fatigue on a scale from 0 to 10, there was a 25% reduction in the risk factor of

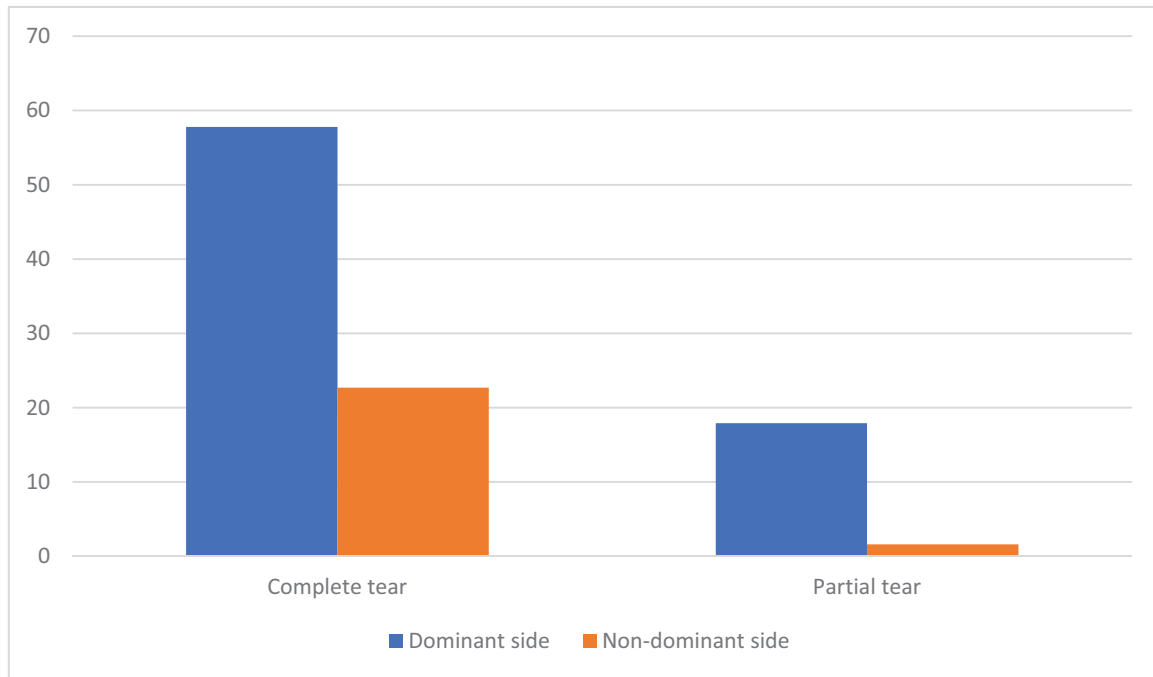


Figure 1. Distribution of ACL tears types and side of injury.

complete ACL injury (odds ratio=0.75; 95% CI=0.58, 0.96;  $P=.023$ ) (Table 3).

#### 4. Discussion

This study describes the rates and distributions of ACL injuries among young athletes in regards to the type of ACL tears (complete versus partial), side of injury, types of sport, type of

shoes, and mechanism of the injury in addition to the interaction among those variables. In addition, this study examined a number of potential factors as risk factors for ACL injuries. A complete tear of ACL accounted for 80.5% of all cases included in this study. This percentage is similar to what was reported in several studies as the percentage of complete tear ranges between 73% and 90%.<sup>[33,34]</sup> The reason for this high percentage at least in this study might be because the sample included in this study

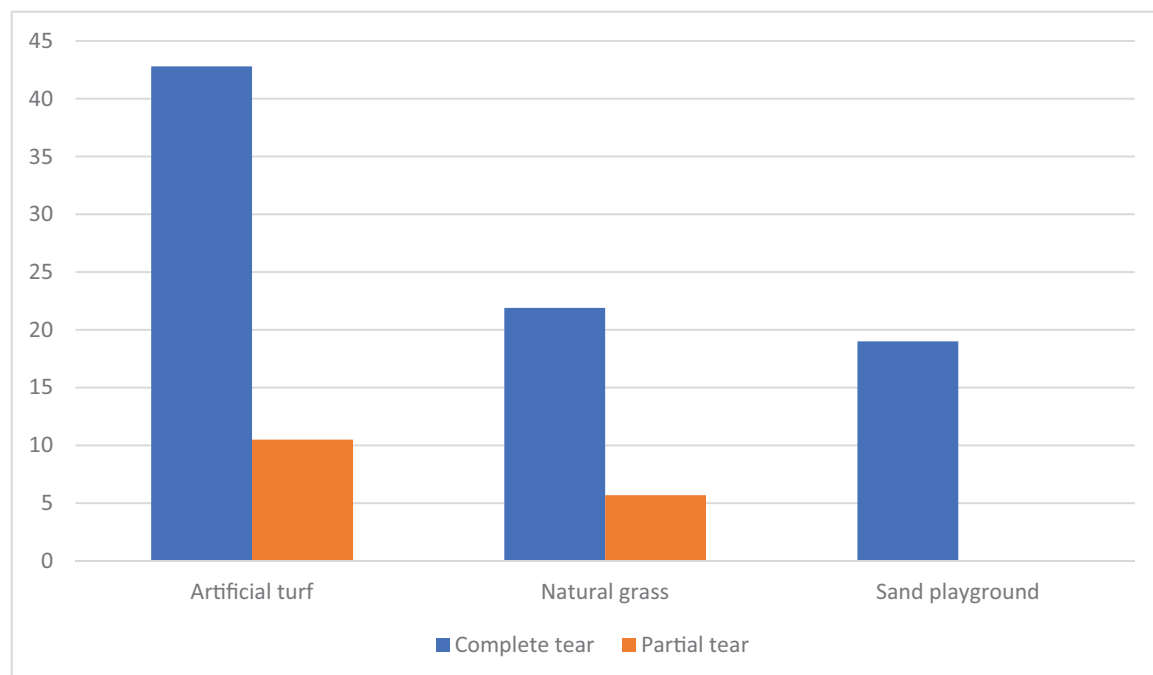
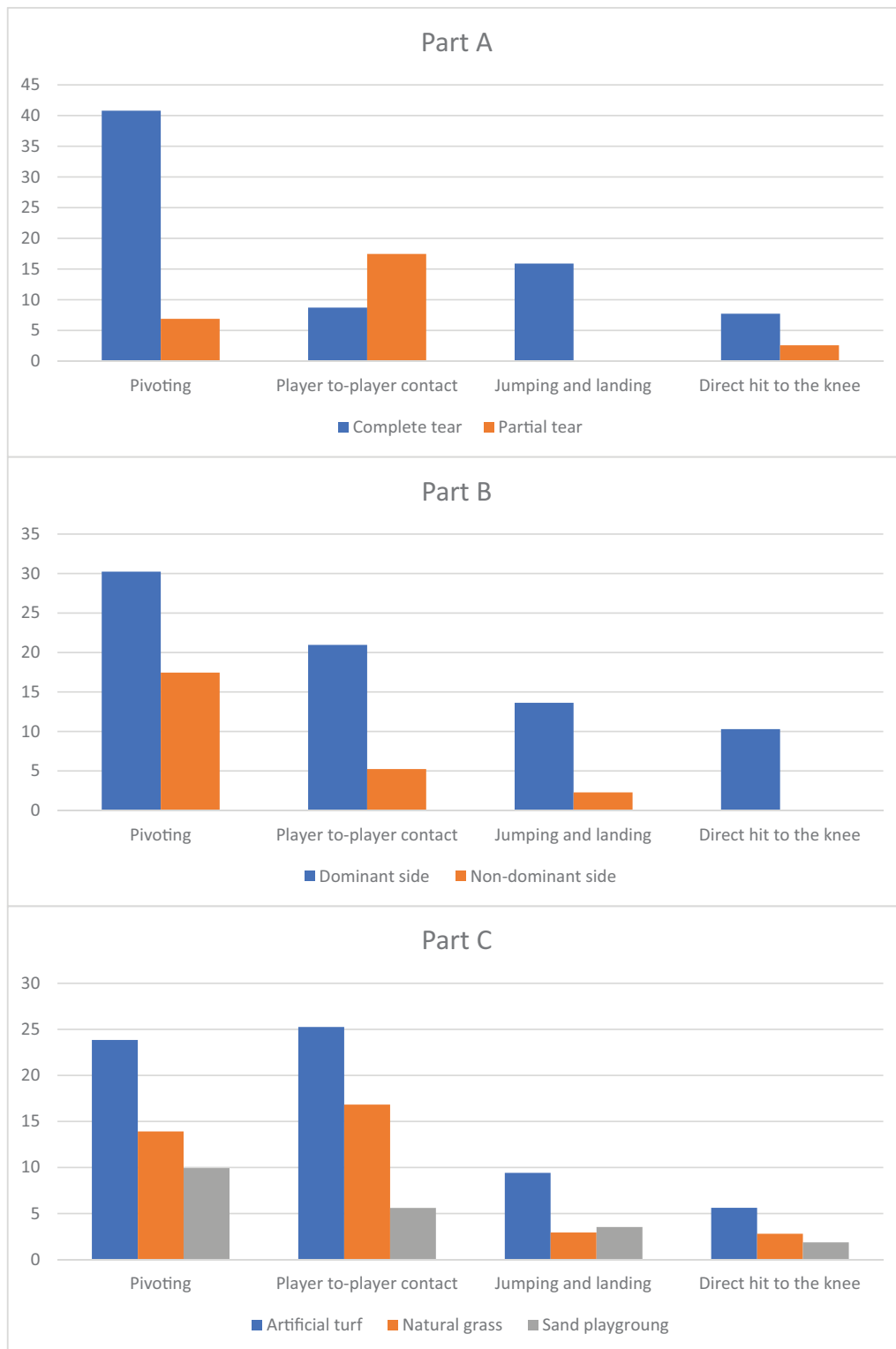


Figure 2. Distribution of ACL injuries in different playing surfaces.



**Figure 3.** Frequency of different mechanism of injuries in relation to the distribution of types of ACL injury (part A), the side of injury (part B), and the type of playing field (part C).

were those who were attending rehabilitation programs and we believe that most of them have a complete ACL rupture due to their high need for rehabilitation programs to strengthen their muscles and increase joint stability, whether before or after the reconstruction surgery. The high incidence of ACL injuries in the

dominant leg recorded in this study is in line with the results of many studies that indicated that most ACL injuries in male athletes are in the dominant limb, while ACL injuries in female athletes are more frequent in the nondominant side.<sup>[35,36]</sup> Our study results showed that ACL injuries occurred on artificial turf

**Table 2**  
Impact of fatigue and physical fitness on different types of ACL tears, side of injury, and mechanism of injuries.

Variables	Fatigue level (0–10)	P-value	Physical fitness (hours per week)	P-value
Type of tear				
- Complete	4.76 ± 2.5	0.014*	3.23 ± 1.7	.355
- Partial	6.35 ± 1.9		3.7 ± 1.7	
Side of injury				
- Dominant	4.84 ± 2.6	0.888	3.48 ± 1.7	.406
- Non-dominant	5.1 ± 2.0		3.1 ± 1.7	
Mechanism of injury				
- Pivoting	4.83 ± 2.23	0.785	3.31 ± 1.72	.869
- Jumping and landing	5.19 ± 2.73		3.40 ± 1.87	
- Player to-player contact	5.33 ± 2.53		3.31 ± 1.57	
- Direct hit to the knee	4.83 ± 3.97		2.85 ± 1.69	

\* Significance level <0.05.

are more frequent compared to other playing surfaces. One study stated that the stiffness of artificial turf, as well as the increased friction between the shoes and the surface of the artificial turf, compared to other playing surfaces, maybe the reason for the higher injury rate.<sup>[37]</sup> A study by Dragon et al assessed the effect of the artificial playing surface (artificial grass) on ACL injury and how it threatens the athletes. The results of their study indicated that the frictional force to the shoe-surface interface created by artificial grass increases the risk of getting ACL injury compared to natural grass.<sup>[38]</sup>

It was remarkable that almost all the injuries reported in this study were during the practice of soccer and this can be justified as soccer is the most popular sport where this study was conducted. Similarly, soccer has the highest ACL injuries rate amongst all other popular sports in different countries due to the nature of this competitive game that requires high continuous physical effort, cutting movements, or landing techniques for about 1 hour and a half, which places a high load on muscles and ligaments.<sup>[14]</sup> We were unable to draw a conclusion regarding the impact of the types of shoes on ACL injury as most of the participants in this study were wearing athletic shoes appropriate to the type of sport when their ACL was injured.

It has appeared in this study that the most common mechanism of injury of the ACL was a noncontact mechanism of injury such as cutting movements or landing on one leg after a jump, which accounted for 63.6% of the total cases. The results, reported in this study, is close to that reported in previous studies, where ACL injuries due to non-contact mechanism accounted for 70% to 80% of the ACL injuries.<sup>[15,16]</sup>

The results of this study showed that participants with partial tears reported significantly higher levels of fatigue before injury compared to participants with complete tears. Although a

number of studies reported varying results as to whether fatigue is a risk factor for ACL injury,<sup>[26,27]</sup> studies that analyze athletes' behavior during physical activities when they reach high levels of fatigue showed that fatigued athletes tend to land with more knee and hip flexion and less landing forces compared to less fatigued athletes and all these mechanisms are considered protective mechanisms and appropriate strategies to reduce the possibility of ACL injuries.<sup>[28]</sup> Following those protective strategies by fatigued athletes may explain the fact that most of the participants in this study who reported higher levels of fatigue had a partial tear of the ACL, while most of those who reported lower levels of fatigue had a complete tear. Less fatigued athletes may be less cautious during competitive sports, which makes them more vulnerable to develop a complete ACL injury.

### 5. Limitations

This study had a number of limitations. First, our study included only young male athletes from one region, which reduces the ability to generalize the results of this study on a larger population, especially female gender. Second, this study was of a cross-sectional nature, which gives more credibility to the results of associations rather than the results of causal relationships.

### 6. Conclusion

This study revealed that most of the ACL injuries are a complete tear in the dominant foot, and most injuries occur in playing field with artificial turf. In addition, this study showed that higher levels of fatigue are more associated with a partial ACL injury than with a complete ACL injury. This finding may direct

**Table 3**  
Participant demographics and clinical measures (N= 113).

	Complete Tear n=91 (80.5%)	Partial Tear n=22 (19.5%)	P-value	Odds ratio (95% CI)	P value
Age (years)	32.2 (7.8)	32.1 (8.1)	.945	1.01 (0.94–1.06)	.944
Height (cm)	170.8 (7.0)	172.2 (5.1)	.393	0.97 (0.90–1.04)	.389
Weight (Kg)	76.3 (10.7)	81.2 (22.6)	.142	0.98 (0.94–1.01)	.158
Body Mass Index	26.2 (3.7)	27.2 (6.8)	.338	0.95 (0.86–1.05)	.341
Education (yrs)	14.9 (2.3)	13.9 (2.3)	.097	1.18 (0.97–1.45)	.102
Fatigue Level (0–10)	4.8 (2.5)	6.4 (1.9)	.014*	0.75 (0.58–0.96)	.023*
Physical Fitness (hours per week)	3.2 (1.7)	3.7 (1.7)	.342	0.85 (0.61–1.19)	.341



prevention programs to focus more on the initial times while practicing sporting activities of a competitive nature when athletes are less cautious.

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