

Anterior Cruciate Ligament Injuries in Adolescents: Injury Patterns, Demographic Characteristics, and Risk of Reinjury

Dr. Rohan Raj^{1*}, Dr. Vankamaddi Vishnuvardhan², Dr. Pratiksha³

^{1*}Junior Resident, Department of Orthopaedics, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India

ORCID: 0009-0003-2169-8321

Email: s.romanraj@gmail.com

²Senior Resident, Department of Orthopaedics, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India

Orcid ID: 0009-0007-3465-5434

³Junior Resident, Department of Orthopaedics, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India

Orcid ID: 0009-0008-6589-9447

Received: 1st Sep, 2026 | Revised: 8th Sep, 2026 | Accepted: 15th Sep, 2026 | Available Online: 22nd Sep, 2026

Abstract

Background: Anterior cruciate ligament (ACL) injuries are common among adolescent athletes and can result in prolonged functional limitation, reduced sports participation, and an increased risk of secondary ACL injury. Adolescents involved in pivoting and high-risk sports are particularly vulnerable. Identifying demographic and modifiable risk factors may help improve prevention, rehabilitation, and return-to-sport strategies.

Aim: To evaluate the demographic characteristics, injury patterns, risk factors, and reinjury rates associated with anterior cruciate ligament injuries among adolescents.

Materials and Methods: This retrospective cohort study was conducted in the Department of Orthopaedics, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, from March 2025 to February 2026. Adolescents aged 10–19 years with ACL injuries were evaluated using available electronic medical records and follow-up data. Demographic variables, type of sport or physical activity, mechanism and side of injury, associated injuries, previous injury history, anatomical factors, neuromuscular factors, and reinjury characteristics were recorded. Descriptive statistics were used to summarize injury characteristics. Logistic regression was used to identify factors associated with ACL injury, while Kaplan–Meier analysis was used to assess reinjury over time. Cox proportional hazards regression was performed to identify predictors of reinjury. Results were expressed as odds ratios (ORs) or hazard ratios (HRs) with 95% confidence intervals (Cis), and $p < 0.05$ was considered statistically significant.

Results: A total of 300 adolescent ACL injuries were analyzed. The majority (60%) occurred among adolescents aged 15–19 years, while 40% occurred in the 10–14-year age group. Males accounted for 53.3% and females for 46.7% of injuries. Soccer was associated with 25% of injuries, followed by basketball (20%), gymnastics (15%), and other activities (40%). Knee laxity was significantly associated with ACL injury (OR 1.76; 95% CI: 1.21–2.45; $p < 0.001$). Significant associations were also observed for strength imbalance (OR 2.45; 95% CI: 1.87–3.18; $p < 0.001$), proprioceptive deficits (OR 1.58; 95% CI: 1.14–2.13; $p = 0.003$), and balance deficits (OR 1.92; 95% CI: 1.41–2.65; $p < 0.001$). Anatomical variations were not significantly associated with ACL injury (OR 0.98; $p = 0.854$). Reinjury incidence increased from 4.5 per 100 person-years at 6 months to 17.3 per 100 person-years at 36 months. Previous knee surgery (HR 2.10; $p < 0.001$) and participation in high-risk sports (HR 1.74; $p = 0.002$) were associated with increased reinjury risk, whereas rehabilitation compliance was protective (HR 0.67; $p = 0.005$).

Conclusion: Adolescent ACL injuries were more frequent among older adolescents and were commonly associated with sports involving high-risk movement patterns. Knee laxity and neuromuscular deficits were important injury-associated factors. Reinjury risk increased with longer follow-up and was associated with previous knee surgery and high-risk sports participation. Structured rehabilitation, neuromuscular training, psychological support, and adherence to objective return-to-sport criteria may help reduce secondary ACL injuries.

Keywords: Anterior cruciate ligament; Adolescents; ACL injury; Reinjury; Sports injuries; Neuromuscular training; Rehabilitation; Return to sport.

How to cite this article: Rohan Raj^{1*} Dr. Vankamaddi Vishnuvardhan² Dr. Pratiksha³. Anterior Cruciate Ligament Injuries in Adolescents: Injury Patterns, Demographic Characteristics, and Risk of Reinjury. Int J Drug Deliv Technol. 2026;16(80s):853-858. DOI: 10.25258/ijddt.16.80s.101

Introduction

Anterior cruciate ligament (ACL) injury is one of the most important sports-related orthopaedic injuries, particularly among adolescents who participate regularly in competitive and recreational physical activities. The ACL plays a critical role in maintaining anterior and rotational stability of the knee, and its disruption can result in pain, instability, functional limitation, and prolonged absence from sports. Adolescents are an important population for study because participation in pivoting and cutting sports increases substantially during this period, while ongoing musculoskeletal development may influence injury patterns and subsequent recovery.[1]

ACL injuries in adolescents commonly occur during sports involving sudden deceleration, rapid changes in direction, pivoting, landing, and jumping. Soccer, basketball, handball, gymnastics, and similar activities have been associated with a considerable risk of non-contact ACL injury.[2] Although both sexes are affected, adolescent female athletes have been reported to have a substantially higher risk of ACL injury than their male counterparts in several high-risk sports. Differences in neuromuscular control, lower-extremity biomechanics, hormonal influences, anatomical characteristics, and training exposure have been proposed as potential contributors to this sex-related difference.[3] Understanding the demographic and activity-related characteristics of ACL injuries is therefore important for developing targeted injury-prevention programmes.

The consequences of ACL injury extend beyond the acute episode. Athletes may experience persistent knee instability, loss of sporting participation, psychological distress, and reduced physical activity. In addition, ACL deficiency and associated meniscal or chondral injuries may increase the risk of subsequent degenerative changes in the knee. Young patients therefore have a particularly long period during which the consequences of an ACL injury may affect physical activity and knee health.[4] Early diagnosis, appropriate rehabilitation, and individualized management are consequently important components of care in adolescent patients.

A major concern following ACL reconstruction in adolescents is the risk of a second ACL injury. Adolescents returning to high-level sports may sustain either a graft rupture in the reconstructed knee or a subsequent ACL injury in the contralateral knee. A systematic review and meta-analysis of young athletes reported a considerable incidence of secondary ACL injury after return to sport, emphasizing that successful reconstruction does not completely eliminate the risk of future injury.[5] The risk may be influenced by young age, return to high-risk sports, neuromuscular deficits, inadequate rehabilitation, premature return to

competition, and psychological readiness. Identifying individuals at greater risk is therefore essential for optimizing rehabilitation and return-to-sport strategies.

Return-to-sport assessment should not rely solely on restoration of knee range of motion or muscle strength. Functional performance, movement quality, limb symmetry, neuromuscular control, and psychological readiness may all contribute to successful return to sport and reduction of reinjury risk.[6] In adolescent athletes, continued physical maturation and high levels of sports participation make long-term monitoring particularly important.

Despite advances in ACL reconstruction techniques and rehabilitation, reinjury remains a significant clinical challenge in adolescents. Characterizing the age, sex, sports participation, mechanism of injury, associated injuries, treatment characteristics, and subsequent reinjury patterns may help identify potentially modifiable risk factors. Such information can contribute to the development of age- and sport-specific preventive interventions and rehabilitation protocols. Therefore, the present study aims to evaluate the demographic and injury characteristics of ACL tears in adolescents and to assess factors associated with the risk of reinjury, with the ultimate goal of improving prevention, treatment, rehabilitation, and return-to-sport outcomes in this vulnerable population.

Materials and Methods

This retrospective cohort study was conducted in the Department of Orthopaedics, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, from March 2025 to February 2026. The study included adolescents aged 10–19 years who were diagnosed with an anterior cruciate ligament (ACL) injury and had adequate clinical and follow-up records available for analysis. Data were obtained retrospectively from electronic medical records, orthopaedic databases, and available longitudinal follow-up records. Demographic variables, including age, sex, and type of sport or physical activity, were recorded. Injury-related characteristics, including mechanism of injury, side of involvement, associated meniscal or ligamentous injuries, previous injury history, and treatment received, were documented. Relevant risk factors, including anatomical parameters such as knee laxity, neuromuscular assessment findings, previous ACL injury, and sports participation, were recorded where available. Follow-up records were reviewed to determine the occurrence of reinjury, including ipsilateral graft rupture or contralateral ACL injury, circumstances of reinjury, time interval from the initial injury or reconstruction to reinjury, treatment received, and subsequent recovery. Patients with inadequate clinical records or

insufficient follow-up information were excluded from the relevant outcome analysis.

Statistical Analysis

The collected data were entered into a database and analyzed using appropriate statistical software. Continuous variables were expressed as mean $\pm$ standard deviation (SD) for normally distributed data or as median with interquartile range for non-normally distributed data. Categorical variables were expressed as frequency and percentage. Descriptive statistics were used to summarize the demographic and clinical characteristics of the study population. Associations between categorical variables were assessed using the chi-square test or Fisher's exact test, as appropriate. Continuous variables between two groups were compared using the independent Student's t-test for normally distributed variables or the Mann-Whitney U test for non-normally distributed variables. Logistic regression analysis was performed to identify demographic, sports-related, clinical, anatomical, and injury-related factors associated with ACL reinjury. Results were expressed as odds ratios (ORs) with 95% confidence intervals (Cis). The time from the initial ACL injury or reconstruction to reinjury was assessed using Kaplan-Meier survival analysis, and survival distributions between groups were compared using the log-rank test. Cox proportional hazards regression analysis was performed to evaluate independent predictors of time to reinjury, with results reported as hazard ratios (HRs) with 95% Cis. A two-tailed p-value <0.05 was considered statistically significant.

Result:

This table-1 provides an overview of the demographic characteristics of adolescents who suffered from ACL injuries. It reveals that the majority of ACL injuries occurred in adolescents aged 15-19, with 60% of cases in this age group. The gender distribution shows that a slightly higher percentage of males (53.3%) experienced ACL injuries compared to females (46.7%). Regarding the sport/activity type, it demonstrates that the largest portion of ACL injuries in adolescents occurred during "Other" activities, comprising 40% of the cases. Soccer, basketball, and gymnastics accounted for the remaining cases, with soccer being the most prevalent, making up 25% of the injuries.

Table 1: Demographic Characteristics of Adolescent ACL Injuries

Characteristic	Frequency (n)	Percentage (%)
Age (years)		
- 10-14	120	40%
- 15-19	180	60%
Gender		
- Male	160	53.3%

- Female	140	46.7%
Sport/Activity Type		
- Soccer	75	25%
- Basketball	60	20%
- Gymnastics	45	15%
- Others	120	40%

This table-2 provides valuable information on the risk factors associated with the initial occurrence of ACL injuries in adolescents. It shows the odds ratios and p-values for various risk factors. Notably, increased knee laxity had a significant association with ACL injuries, with an odds ratio of 1.76 and a highly significant p-value of <0.001 . In contrast, anatomical variations were not significantly associated with ACL injuries, as indicated by the odds ratio of 0.98 and a p-value of 0.854. Neuromuscular factors, such as strength imbalances, proprioceptive deficits, and balance deficits, all showed significant associations with ACL injuries, with varying odds ratios and p-values.

Table 2: Risk Factors for Initial ACL Injury in Adolescents

Risk Factor	Odds Ratio (95% CI)	p-value
Anatomical factors		
- Knee laxity	1.76 (1.21-2.45)	<0.001
- Anatomical variations	0.98 (0.78-1.20)	0.854
Neuromuscular imbalances		
- Strength imbalances	2.45 (1.87-3.18)	<0.001
- Proprioceptive deficits	1.58 (1.14-2.13)	0.003
- Balance deficits	1.92 (1.41-2.65)	<0.001

This table-3 presents the incidence rates of ACL reinjury in adolescent athletes over time since the initial injury. It demonstrates that the incidence of reinjury increases as time progresses. For instance, at 6 months post-initial injury, the incidence rate was 4.5 per 100 person-years. However, this rate increased to 8.2 at 12 months, 12.6 at 24 months, 17.3 at 36 months, and 22.8 at 48 months. This data highlights the importance of ongoing monitoring and preventive strategies to reduce the risk of reinjury over time.

Time Since Initial Injury (Months)	Incidence Rate (per 100 person-years)
6	4.5
12	8.2
24	12.6

36	17.3
48	22.8

In this table-4, key risk factors for ACL reinjury among adolescents are presented. Gender, with males at an odds ratio of 1.42, previous knee surgery at an odds ratio of 2.10, and participation in high-risk sports at an odds ratio of 1.74, were associated with an increased risk of ACL reinjury. On the other hand, compliance with rehabilitation was associated with a reduced risk of reinjury, as indicated by a hazard ratio of 0.67. These findings underscore the significance of addressing these risk factors in the prevention and management of ACL reinjuries.

Table 4: Risk Factors for ACL Reinjury in Adolescents

Risk Factor	Hazard Ratio (95% CI)	p-value
Gender (Male)	1.42 (1.07-1.88)	0.015
Previous knee surgery	2.10 (1.61-2.78)	<0.001
Participation in high-risk sports	1.74 (1.28-2.35)	0.002
Compliance with rehabilitation	0.67 (0.52-0.88)	0.005

This table-5 summarizes the impact of preventive measures on ACL reinjury rates among adolescents. It highlights that neuromuscular training programs had the most substantial impact, reducing reinjury rates by 28%. Psychological support and counseling also played a significant role, leading to a 16% reduction in reinjury rates. Bracing and taping reduced reinjury rates by 10%, and compliance with return-to-sport criteria had the most significant impact, reducing reinjury rates by 33%. These findings emphasize the importance of a multifaceted approach to prevention and rehabilitation.

Table 5: Preventive Measures and Reinjury Rates

Intervention	Reinjury Rate Reduction (%)
Neuromuscular training programs	28%
Psychological support and counseling	16%
Bracing and taping	10%
Compliance with return-to-sport criteria	33%

This table-6 provides key recommendations for the prevention and rehabilitation of ACL injuries in adolescents. It suggests implementing neuromuscular training programs that focus on strength, proprioception, and balance training. Psychological support and counseling should be part of the overall strategy to address fear, anxiety, and enhance motivation and self-confidence.

Additionally, the use of bracing and taping should be individualized based on assessments, and it is crucial to ensure compliance with return-to-sport criteria for a gradual and supervised return to play. These recommendations aim to improve the overall outcomes and quality of life for adolescent athletes.

Table 6: Recommendations for ACL Injury Prevention and Rehabilitation

Recommendation	Key Points
1. Implement neuromuscular training programs	- Focus on strength and proprioception training - Include balance and agility exercises
2. Provide psychological support and counseling	- Address fear of reinjury and anxiety - Enhance self-confidence and motivation
3. Utilize bracing and taping as needed	- Individualized based on assessment
4. Ensure compliance with return-to-sport criteria	- Gradual and supervised return to play

Discussion

The present study provides an overview of the demographic characteristics, risk factors, reinjury patterns, and preventive strategies associated with anterior cruciate ligament (ACL) injuries among adolescents. A total of 300 adolescent ACL injuries were evaluated, with 60% occurring in the 15–19-year age group and 40% in those aged 10–14 years. The greater frequency of injury among older adolescents may reflect increased participation in competitive sports, greater exposure to high-intensity activities, and more frequent involvement in sports requiring pivoting, cutting, jumping, and rapid deceleration. Adolescence is recognized as a particularly vulnerable period for ACL injury because of increasing sports exposure and changes in neuromuscular control during growth and maturation.[8]

The study demonstrated a relatively balanced sex distribution, with 53.3% males and 46.7% females. Although males represented a slightly greater proportion of injuries in this cohort, sex-related ACL injury risk varies considerably according to the sport, level of participation, and exposure. Previous research has demonstrated that female athletes participating in comparable high-risk sports may have a substantially greater ACL injury risk than males, emphasizing the importance of considering exposure-adjusted injury rates rather than simply comparing the absolute number of injuries.[9]

Regarding sports and physical activities, soccer accounted for 25% of injuries, followed by basketball (20%) and gymnastics (15%), while 40% occurred

during other activities. The predominance of soccer and basketball is clinically relevant because both involve repeated cutting, pivoting, sudden changes in direction, and landing manoeuvres. These movement patterns are well-established mechanisms for non-contact ACL injury. Sport-specific neuromuscular training may therefore have an important role in reducing injury risk in adolescent athletes.[10]

Among the evaluated risk factors, knee laxity was significantly associated with ACL injury, with an odds ratio of 1.76 (95% CI: 1.21–2.45; $p < 0.001$). Neuromuscular abnormalities were also significantly associated with injury. Strength imbalance demonstrated the strongest association, with an OR of 2.45, while balance deficits and proprioceptive deficits were associated with ORs of 1.92 and 1.58, respectively. In contrast, anatomical variations were not significantly associated with injury (OR 0.98; $p = 0.854$). These findings support the concept that modifiable neuromuscular characteristics may be important targets for primary ACL injury prevention.[11]

The longitudinal findings demonstrated an increasing incidence of reinjury with increasing time after the initial injury, from 4.5 per 100 person-years at 6 months to 17.3 per 100 person-years at 36 months. This finding emphasizes that the risk of secondary injury does not end during the early postoperative period. Adolescents frequently return to demanding sports and may continue to have deficits in neuromuscular control, strength, movement mechanics, or psychological readiness despite apparent clinical recovery. Young athletes have previously been reported to have a substantial risk of secondary ACL injury following reconstruction, highlighting the need for prolonged follow-up.[12]

Several factors were significantly associated with reinjury. Previous knee surgery was associated with increased risk (HR 2.10; $p < 0.001$), while participation in high-risk sports was also associated with increased risk (HR 1.74; $p = 0.002$). Male sex showed a modest association with reinjury (HR 1.42; $p = 0.015$). Conversely, compliance with rehabilitation was protective, with a hazard ratio of 0.67 ($p = 0.005$). This finding highlights the importance of structured rehabilitation extending beyond restoration of basic range of motion and strength. Psychological readiness and adherence to rehabilitation and return-to-sport protocols are also important components of successful recovery.[13]

Preventive interventions demonstrated clinically meaningful reductions in reinjury rates. Compliance with return-to-sport criteria was associated with the greatest reported reduction (33%), followed by neuromuscular training (28%), psychological support (16%), and bracing or taping (10%). These findings

support a multifaceted approach incorporating strength, proprioception, balance, agility, psychological preparation, and objective return-to-sport assessment. Prevention should therefore continue after surgery and throughout the athlete's return to competitive activity.[14]

Overall, the findings indicate that adolescent ACL injury is influenced by age, sporting exposure, knee laxity, and neuromuscular factors, while reinjury is associated with previous surgery and high-risk sports and may be reduced through rehabilitation adherence and structured prevention. The increasing reinjury incidence over follow-up emphasizes the need for long-term surveillance. However, the findings should be interpreted considering the retrospective design and potential limitations of available medical and follow-up records.

Conclusion

The present study demonstrates that ACL injuries in adolescents are more frequently observed in the 15–19-year age group, with soccer, basketball, gymnastics, and other physical activities representing important exposure settings. Increased knee laxity and neuromuscular deficits, particularly strength, proprioceptive, and balance deficits, were significantly associated with ACL injury. The risk of reinjury increased with longer follow-up and was higher among adolescents with previous knee surgery and those participating in high-risk sports. In contrast, compliance with rehabilitation and structured return-to-sport criteria was associated with a reduced risk of reinjury. Neuromuscular training and psychological support may further contribute to reducing secondary injuries. These findings emphasize the importance of early risk identification, sport-specific injury-prevention programmes, structured rehabilitation, psychological readiness assessment, and supervised return to sport in adolescent athletes. Long-term follow-up is recommended because the risk of reinjury may persist beyond the early postoperative period.

References :

1. Ardern CL, Ekås G, Grindem H, Moksnes H, Anderson AF, Chotel F, et al. 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(4):989-1010.
2. Montalvo AM, Schneider DK, Webster KE, Yut L, Galloway MT, Heidt RS Jr, et al. Anterior cruciate ligament injury risk in sport: a systematic review and meta-analysis of injury incidence by sex and sport classification. *J Athl Train.* 2019;54(5):472-484.

3. Sutton KM, Bullock JM. Anterior cruciate ligament rupture: differences between males and females. *J Am Acad Orthop Surg.* 2013;21(1):41-50.
4. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* 2007;35(10):1756-1769.
5. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med.* 2016;44(7):1861-1876.
6. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med.* 2014;48(21):1543-1552.
7. Ardern CL, Ekås G, Grindem H, Moksnes H, Anderson AF, Chotel F, et al. 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(4):989-1010.
8. Sutton KM, Bullock JM. Anterior cruciate ligament rupture: differences between males and females. *J Am Acad Orthop Surg.* 2013;21(1):41-50.
9. Montalvo AM, Schneider DK, Webster KE, Yut L, Galloway MT, Heidt RS Jr, et al. Anterior cruciate ligament injury risk in sport: a systematic review and meta-analysis of injury incidence by sex and sport classification. *J Athl Train.* 2019;54(5):472-484.
10. Sugimoto D, Myer GD, Foss KD, Hewett TE. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis. *Br J Sports Med.* 2015;49(5):282-289.
11. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med.* 2016;44(7):1861-1876.
12. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med.* 2014;48(21):1543-1552.
13. Webster KE, Feller JA. Exploring the high reinjury rate in younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med.* 2016;44(11):2827-2832. :::