

[Orthopaedic Surgery]

Anterior Cruciate Ligament Injuries in Pediatric Athletes Presenting to Sports Medicine Clinic: A Comparison of Males and Females Through Growth and Development

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Background: Limited data exist regarding the effect of the growth process on anterior cruciate ligament (ACL) injury risk in male versus female children.

Hypothesis: The proportion of ACL injuries/sports injuries presenting to clinic will vary by age, sex, and body mass index (BMI).

Study Design: Cross-sectional epidemiologic study.

Level of Evidence: Level 3.

Methods: The study group consisted of a randomly selected 5% probability sample of all children 5 to 17 years of age presenting to a sports medicine clinic from January 1, 2000 to December 31, 2009; 2133 charts were reviewed. Data collected included demographics, height and weight, injury mechanism, diagnosis, treatment, previous injury, and organized sports.

Results: A total of 206 ACL tears were analyzed (104 girls, 102 boys). Girls were slightly older than boys (15.1 ± 1.7 vs 14.3 ± 2.1 years; $P < 0.01$). Male-female comparison of ACL injury/total injury by age revealed that girls had a steeper increase by age than boys. Among 5- to 12-year-olds, boys had a higher ACL injury/total injury ratio than girls (all $P < 0.01$). Children 13 to 17 years of age showed no significant difference for sex in ACL injury/total injury ratio. As age advanced, the proportion of ACL injuries/total injuries increased for both girls ($P < 0.01$) and boys ($P = 0.04$). BMI was independently associated with an ACL injury ($P < 0.01$).

Conclusion: The proportion of ACL injuries/total injuries was similar for boys and girls aged 13 to 17 years. Girls showed a significantly steeper increase in ACL injury proportion versus boys through puberty.

Clinical Relevance: This study will increase clinician awareness of ACL injury occurrence in young male and female athletes 5 to 12 years of age. Injury prevention efforts should target young girls before the onset of puberty and before injury occurs.

Keywords: BMI; children; injury prevention; knee; ligament injuries; sports injury risk factors

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Sports participation often starts early in life, and many children are eager participants throughout their growing years. Historically, mid-substance tears of the anterior cruciate ligament (ACL) were considered rare events in children.⁴² However, the child athlete with a tear of the ACL is no longer an enigma. In a retrospective review of ACL injuries in adolescent soccer and basketball players, the frequency of ACL injuries over a 5-year time period correlated with an increase in the level of participation in sports over the same period. Girls were more likely to experience ACL injuries than boys.²³

In contrast to the high school athlete, analysis of ACL injuries sustained by younger children is limited, and injury profile of sex, age, and sport is much less clear. Notably, there is no demonstrable evidence to date that a sex difference in ACL injury rates exists in prepubescent athletes. Two small studies on ligament injuries in children younger than 14 years with open physes reported no male-female differences in injury incidence.^{4,27} More recently, insurance injury claims in children 5 to 18 years showed 31% of knee injuries were girls with an ACL injury. Both boys and girls ages 11 to 12 years demonstrated an increased frequency of ACL injury claims. The overall ratio of ACL injury claims to total injury claims was consistently higher for the girls as compared with boys, beginning at age 12 years.⁴³

The effect of the growth process, including the onset of puberty and the physiologic changes that accompany this process, on sports injury risk are under continued investigation.^{17,19} While knee injuries do occur in skeletally immature children, differences between sexes with regard to the incidence of ACL tears do not appear to be present in children prior to the pubertal growth spurt.³¹ The purpose of this study is to evaluate ACL injuries in pediatric athletes presenting to a sports medicine clinic with regard to sex and age.

METHODS

Institutional internal review board approval was obtained prior to the initiation of the research protocol.

Data and Participants

All unique patients 5 to 17 years of age cared for in the Division of Sports Medicine between January 1, 2000 and December 31, 2009, were identified, from which a 5% probability sample was drawn. All subjects were not included in the chart review because of the time constraints and funding limitations. Six research assistants performed a medical chart review from the identified subjects. Data on demographics, anthropometric measures (height and weight), injury mechanism, diagnosis, treatment, history of previous injuries, and organized sports were aggregated. All injuries sustained during organized sports participation and for which the medical record contained all variables under study (sex, body part injured, injury type [overuse vs acute/traumatic], and sport played at time of injury) were included. Body mass index (BMI) was calculated from the height and weight recording in the medical record as weight in

kilograms/square of the height in meters (kg/m^2). BMI categories were created using cutoffs for children and teens provided by the Centers for Disease Control and Prevention.⁶ We included multiple injuries in the data collection and analysis if more than 1 diagnosis existed at the time of the initial evaluation. In this case, the clinician who performed the evaluation was asked to identify the primary diagnosis for the presenting complaint and subsequently documented secondary and/or tertiary diagnoses as needed. Each injury was analyzed separately, so long as the data set was complete in all outcome measures within the scope of the current investigation. If the patients had a past history of injury, this was recorded in the database but not included in data analysis because of insufficient data for outcome measures under investigation.

We excluded cases where the final diagnosis was in question after further review of the medical records and diagnostic studies. We also excluded injuries that were sustained as a result of accidents that occurred during activities of daily living (eg, falling down the stairs or falling off a bike while riding recreationally), injuries for which the activity at the time of injury was not specified, and cases where the subjects had an underlying congenital disorder (eg, osteogenesis imperfecta or sickle cell disease). All patients with the diagnosis of ACL injury were included in the final analyses (Figure 1).

After data aggregation, all injuries that were coded as "ACL injury" underwent a second chart review to confirm the diagnosis and ensure that magnetic resonance imaging (MRI) was used to make the diagnosis and was reported as ACL tear. Partial ACL tears were included in the final data set.

Statistical Analysis

Continuous variables were assessed using the Student *t* test and are reported as mean \pm standard deviation. Categorical variables were assessed using the chi-square test. Two-way analysis of variance (ANOVA) was used to compare the proportion of ACL injuries with total injuries between girls and boys across the range of ages. Multivariate logistic regression analysis was performed using patient age, sex, BMI, and sport as covariates and the binary dependent variable being ACL injury versus non-ACL injury; the likelihood ratio test was used to assess significance. Intercoder reliability was assessed using Krippendorff alpha. ACL injuries for children aged 5 to 17 years were compared between girls and boys using a generalized linear model with a binomial distribution and logit link function since the data represent counts of ACL injuries to total sports injuries \times 100%.³⁵ Goodness-of-fit of the 2-way ANOVA model was judged by the Akaike information criterion (AIC), and the slope comparison was assessed by the sex-by-age interaction term using the Wald chi-square test on 1 degree of freedom.¹³ Age was treated as a covariate in the model, and 95% confidence intervals were calculated for the proportion of ACL injuries to total injuries based on age for each sex. Statistical analysis was performed using IBM SPSS Statistics (version 21.0; IBM). Statistical significance was established using a priori criteria at $P < 0.05$.

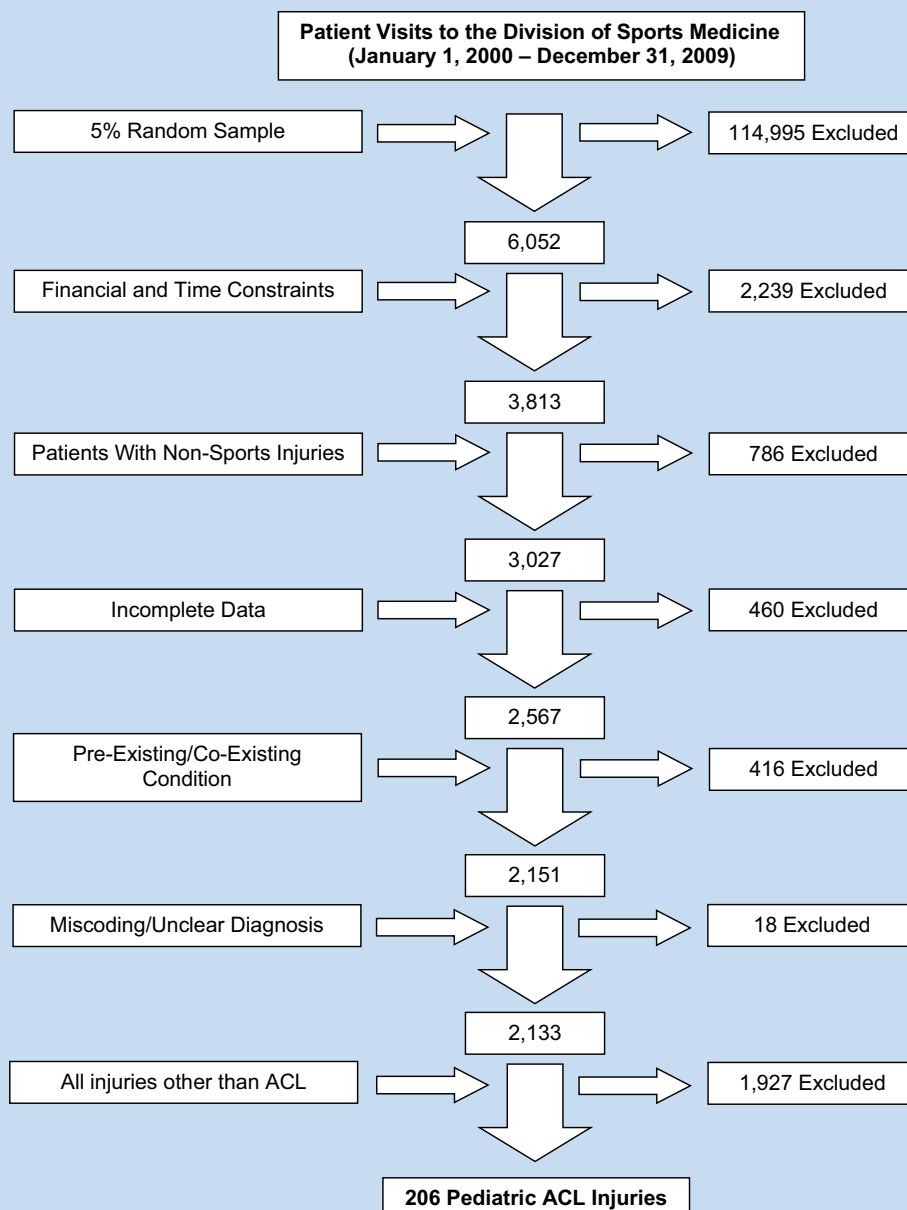


Figure 1. Flowchart of patient selection for anterior cruciate ligament (ACL) injuries in children aged 5 to 17 years.

RESULTS

There were 137,865 unique patients cared for in the Division of Sports Medicine from January 1, 2000 to December 31, 2009. There were 121,047 patients in the 5- to 17-year age range, from which a 5% probability sample was selected. A total of 3813 charts were reviewed, coded, and entered into a database. We excluded 1680 cases: 46.8% had an injury mechanism other than sports, 27.4% had incomplete data, 24.8% had a coexisting medical problem, and 1.1% had an incorrect medical record number or unclear diagnosis. Of the remaining 2133 patients, 206 had suffered ACL injuries and were included in the analyses.

Intercoder reliability was above the level of acceptability suggested by Krippendorff ($\alpha = 0.721$).²⁵ Of the 2133 patients, 54.5% were girls, and the majority (87.0%) were white. The mean age of the patients was 14.2 ± 2.3 years.

The sample of patients with an ACL tear contained nearly equal numbers of female and male athletes (104 and 102, respectively). Approximately 25% of patients in the ACL data set were 5 to 12 years old; the youngest patient with an ACL tear was 9 years old. The average age of female athletes with ACL tears was slightly higher compared with male athletes (15.1 ± 1.7 vs 14.3 ± 2.1 years; $P < 0.01$). For both boys and girls, the ratio of ACL injuries to total injuries seen in clinic increased with age, most notably after the age of 12 years (Figure 2).

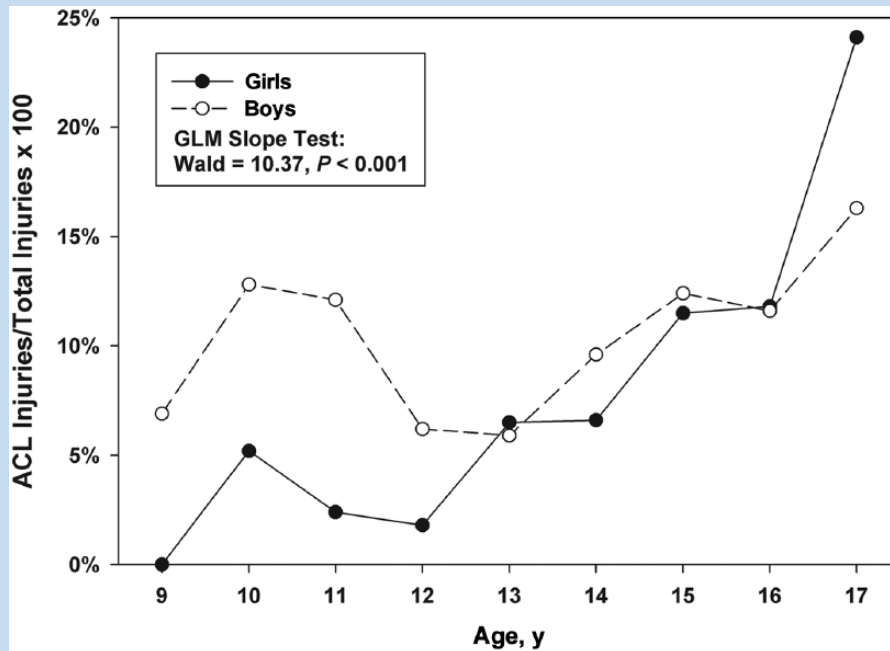


Figure 2. Male-female comparison of anterior cruciate ligament (ACL) injury/total injury ratio by age. The generalized linear model (GLM) indicated a difference in the slope of ACL injury proportion with age for girls when compared with boys (sex-by-age interaction test Wald $\chi^2 = 10.37$ on 1 degree of freedom, $P < 0.001$).

The generalized linear model indicated a difference in the slope of ACL injury proportion with age for girls when compared with boys (Wald $\chi^2 = 10.37$ on 1 degree of freedom, $P < 0.01$). The change in the slope of ACL injury/total injury ratio as age increases shows that girls have a steeper increase than boys (Figure 2). Age comparison revealed that for younger athletes (5-12 years of age), boys have a significantly higher ACL injury proportion than girls (all $P < 0.01$). After the age of 12 years, however, children in the older age group (13-17 years) show no significant sex difference for ACL injury proportion. Moreover, at age 17 years, girls had a higher ratio of ACL injuries to total injuries presenting to clinic than boys. This statistical analysis approached, but did not reach, statistical significance (24.1% vs 16.3%, $P = 0.06$). In further interaction analysis of patients with ACL injuries, age and sex revealed that as age advanced the proportion of ACL injuries/total injuries increased for both girls (Wald $\chi^2 = 28.57$, $P < 0.01$) and boys (Wald $\chi^2 = 4.17$, $P = 0.04$).

Multivariate logistic regression analysis was performed using 2133 patients with sports injuries in the study population, of which 206 (9.7%) had ACL injuries. The analysis, based on this population of sports injuries, indicates that BMI is associated with an ACL injury (likelihood ratio test = 6.81, $P = 0.01$) independent of age, sex, and sport. The ratio of ACL injuries to total injuries was lower for patients with lower BMIs (eg, from roughly 10% for BMI of 20 kg/m² to 15% for BMI of 30 kg/m²) (Figure 3).

The sports most commonly played by patients who tore their ACLs were soccer, basketball, football, and skiing. Female athletes who suffered ACL injuries were most commonly participating in soccer, basketball, and skiing at the time of injury, while male athletes sustained their ACL injuries most commonly in football and soccer (Table 1).

DISCUSSION

The surge in sports participation by young girls and concurrent increase in sports-related injuries to both male and female children has generated an increase in public awareness and interest. There are clear differences in sports injury incidence patterns between female and male athletes. Female athletes have an increased relative incidence of ACL injury compared with male athletes.^{1,12,29,37} While the etiology of this elevated risk has been investigated, no definitive explanation has been identified. The medical literature indicates a variety of factors that may contribute to male-female discrepancies in ACL injury incidence, including differences in strength, flexibility,^{3,7,23,24} physiology, and anatomy.^{18,20-22,26,37,44}

By showing that ACL injuries account for a higher proportion of total injuries seen as children age and progress through puberty, particularly for female patients, these data lend support to the concept that the pubertal period of rapid growth and development in children may be a significant factor in injury patterns in sport. These data are consistent with a recent

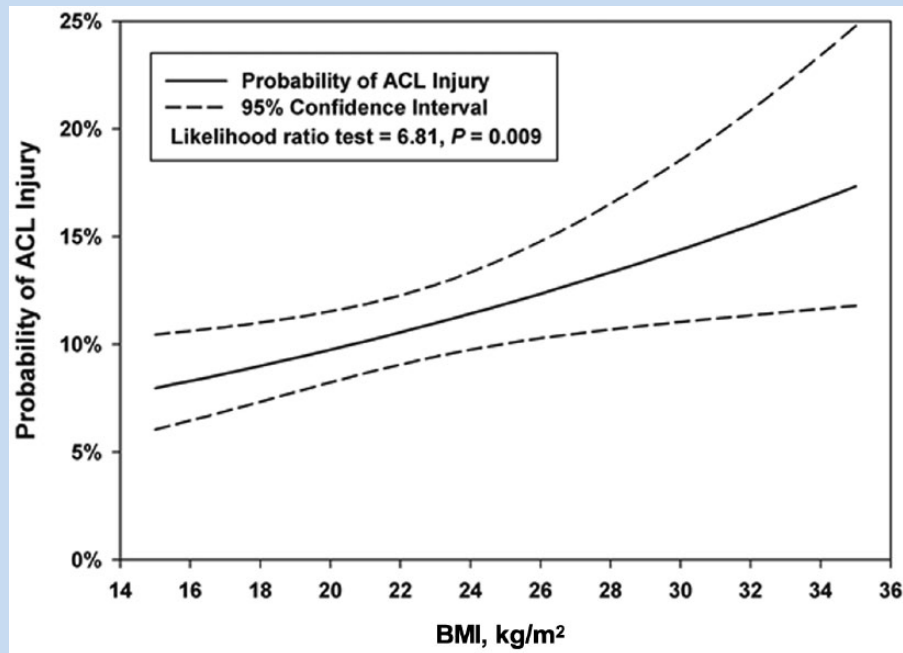


Figure 3. Multivariate logistic regression analysis depicting a body mass index (BMI)-specific relationship with anterior cruciate ligament (ACL) injury in children independent of age, sex, and sport.

Table 1. Sports played by male and female patients presenting to clinic with ACL tears

Sport ^a	All ACL Injuries, % (n)	Girls, % (n)	Boys, % (n)
Football	14.5 (30)	—	29.0 (30)
Soccer	24.7 (51)	30.7 (32)	18.6 (19)
Basketball	16.5 (34)	21.1 (22)	11.7 (12)
Skiing	13.1 (27)	14.4 (15)	11.7 (12)
Baseball/softball	6.8 (14)	4.7 (5)	8.7 (9)
Lacrosse	5.8 (12)	7.6 (8)	3.9 (4)
Cheerleading	1.9 (4)	3.8 (4)	—
Track and field	1.9 (4)	1.9 (2)	1.9 (2)

ACL, anterior cruciate ligament.

^aThe remaining sports/activities played by patients with ACL tears included in this cohort: field hockey (3), gymnastics (3), snowboarding (3), ice hockey (3), gym class (3), skateboarding (2), trampoline (2), dance (2), wrestling (2), bicycling (2), rugby (1), horseback riding (1), flag football (1), ultimate frisbee (1), and volleyball (1).

investigation showing that young female athletes had a consistently higher ACL injury ratio when compared with male athletes, beginning at age 12 years.⁴³

Micheli²⁸ has singled out the growth process of young athletes as a risk factor for sports injury, stating that children may be more susceptible to overuse injury than adults because of growth tissue, growth cartilage, and the growth process itself.³⁶

After rapid growth and development, female athletes sustained a higher rate of sprains than male athletes, and this trend continued into maturity.⁴⁶ Likewise, there is a higher injury rate in peripubertal female gymnasts (Tanner stages 2 and 3) compared with gymnasts at either higher or lower stages of development, regardless of competitive level.² Adolescent gymnasts between 10 and 14 years of age are more likely than

older gymnasts to have chronic wrist pain, even after adjusting for intensity of training, age of initiation of training, years of training, and sex.⁵

Sex-based anatomic and physiologic changes may explain the more rapid increase in proportion of ACL injuries/sports injuries among adolescent female athletes. In general, female athletes appear to have greater ligamentous laxity than male athletes.^{40,41} Cyclic changes in the hormonal milieu of young girls may also play a role in injury patterns.⁴⁷ Sex differences in joint laxity are noted between puberty and postpuberty.³⁸ In contrast to boys, girls may have greater generalized joint laxity after the onset of puberty.^{8,38} Increased laxity (alterations in passive joint restraints) combined with the physiologic changes (ie, neuromuscular control) that occur during puberty may affect the type, severity, and incidence of injuries in the maturing adolescent population.^{33,38} In female athletes, increased general joint laxity, as well as decreased anterior/posterior tibiofemoral passive restraints, are associated with increased ACL injury risk.³³ ACL laxity has been shown to increase at peak levels of estrogen and progesterone when compared with baseline.¹⁴ Furthermore, ACL injury seems to occur more frequently during the ovulatory phase of the menstrual cycle, suggesting a relationship between a surge in estrogen to ACL laxity and peak timing for injury.⁴⁸ Peak ACL injury occurrence on days 1 and 2 of the menstrual cycle has also been reported.⁴⁵

After the onset of puberty and the initiation of peak height velocity, increased tibia and femur length, increased overall body mass, and increased height of the center of mass lead to decreased core stability.³⁰ A key tenet of this decrease in core stability for female athletes in particular is the absence of increases in strength and muscle recruitment at the hip and trunk.^{9,31}

The identification of patterns of ACL injury in young children according to age and sex may help explain the observed incidence of ACL injuries beginning at puberty and continuing through maturation. A recent meta-analysis of 14 ACL injury prevention studies concluded that greater success in knee injury reduction in female athletes was achieved when preventive neuromuscular training commenced before the onset of neuromuscular deficits and peak knee injury incidence, optimally during early adolescence.³⁴ Neuromuscular training conducted during preadolescence or earlier increases neuromuscular function related to improved movement biomechanics that may lead to a reduction of ACL knee injuries as the young female athlete progresses through growth and sport.^{10,11,15,16,17,39}

Targeting children early and effectively with school or team evidence-based ACL injury prevention protocols may ultimately promote safe and successful physical activity into adulthood.³²

The results of this research must be considered in light of several limitations. The retrospective chart review methodology of this study limited the precise collection of data related to mechanism of injury. Furthermore, time of maturation is variable among children. Without athletic exposure data we cannot estimate the

incidence of ACL injury in the pediatric population. Finally, these results lack generalizability given the narrow spectrum of the patient population from which the data set was obtained.

CONCLUSION

With advancing age, the ratio of ACL injuries/total injuries increased for both boys and girls. Female athletes showed a steeper increase in the ACL injury/total injury ratio than boys as they aged. BMI was associated with an increased likelihood of ACL injury independent of age, sex, and sport.

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