Prevalence of Concomitant Injuries by Sport in Pediatric Patients With ACL Rupture

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Background: Although the risk of concomitant injury with anterior cruciate ligament (ACL) tears as a function of specific sports participation has been studied in adults, the topic has not been examined in pediatric and adolescent patients.

Purpose/Hypothesis: The purpose of the study was to determine if certain sports were associated with a higher risk of concomitant injuries in the setting of an ACL tear. It was hypothesized that the risk of concomitant injuries with ACL tears will differ by type of sport participation in the pediatric population.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Patients ≤18 years old from 2 tertiary children's hospitals who had undergone primary ACL reconstruction between 2006 and 2018 were included. Sport at the time of injury, demographic factors, and injury pattern (medial meniscal [MM] tears, lateral meniscal [LM] tears, posterior cruciate ligament [PCL] tears, medial collateral ligament [MCL] tears, lateral collateral ligament [LCL] tears, and any concomitant injury) were identified.

Results: A total of 855 patients with a mean age of 15.5 ± 1.7 years (range, 7-22 years) met the inclusion criteria. Of the included patients, 353 (41.3%) had an isolated ACL tear. A concomitant MM tear was identified in 27.6% of patients, LM tear in 42.9%, PCL injury in 0.4%, MCL injury in 3.0%, and LCL injury in 0.5%. There was no difference in the likelihood of concomitant MM injuries by sex (29.3% for male patients vs 26% for female patients; P = .31) or by sex within basketball (29.3% for male patients vs 25.6% for female patients; P = .96) or soccer (32.3% vs 26.3%; P = .06). Boys had higher proportions of LM injuries overall (51.7% for male patients vs 34.6% for female patients; $P < .001$) but not within the basketball subgroup (50.5% vs 40.0%; P = .86) or the soccer subgroup (59.7% vs 40.0%; P = .19). No statistically significant associations were found between patient age and specific ACL concomitant injury patterns. When stratifying by body mass index, it was found overweight and obese individuals constituted a greater proportion of LM (49.6% vs 39.1%; P = .01) but not MM (29.4% vs 25.5%; P = .28) injuries when compared to normal-weight patients. Using basketball as the comparison group, soccer and football injuries were 18% more likely to result in any concomitant injury, including concomitant MM, LM, PCL, MCL, and LCL injuries.

Conclusion: In the pediatric population, soccer and football players were more likely to present with a concomitant injury in addition to ACL injury relative to basketball players. This study aids in understanding sport-associated ACL injury patterns and can help physicians with patient counseling and injury prevention.

Keywords: knee; ACL; ligaments; meniscus; epidemiology

Anterior cruciate ligament (ACL) injuries are common among high school and college athletes. In the United States, there are an estimated 200,000 ACL injuries annually, accounting for roughly one-third of all sport-related injuries.[7] The literature demonstrates that patients with ACL tears are at risk for concomitant injuries and that factors such as sport played and field surface have been associated with ACL and concomitant injury risk.[1,6,14]

Several studies have examined specific concomitant injury patterns stratified by sport in high school and adult-aged athletes.[1,3,6,14] Granan et al[6] analyzed sport-associated injury patterns in adults playing soccer,

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football, and basketball. Relative to soccer players, they found that basketball players were more likely to experience concomitant lateral meniscus (LM), cartilage, and combined meniscus plus cartilage injuries. The authors speculated that sport-specific differences were due to variability in injury mechanisms by sport. Several studies have demonstrated an increase in both ACL rupture and concomitant injury as individuals age.[2,10,11,13,14]

It is well established that concomitant injury patterns vary by sport in adults with ACL tears and that risk for concomitant injury rises with age at the time of injury.[6,11] However, to our knowledge, no study has examined the association between sport and concomitant knee injuries in the setting of ACL tears in pediatric and adolescent patients. The aim of this study was to assess the presence of concomitant injuries stratified by sport played during injury in pediatric and adolescent patients undergoing an ACL reconstruction (ACLR). We hypothesized that the risk of concomitant injuries with ACL tears within the pediatric population would differ by type of sport participation.

METHODS

After obtaining institutional review board approval, we performed a retrospective cohort study of pediatric and adolescent patients who underwent ACLR at 1 of 2 participating tertiary children's hospitals in the Midwest. Patients aged 18 years and younger (mean age, 15.5 ± 1.7 years), undergoing primary ACLR between 2006 and 2018, were included. Patients undergoing revision ACLR were excluded.

The exposure of interest was patient-reported sport activity at the time of ACL injury. Sports in our cohort included basketball, soccer, football, lacrosse, volleyball, and softball. The outcome of interest was injury pattern at the time of ACLR as documented in the operative report. ACL tears were diagnosed on clinical examination and confirmed arthroscopically. All intra-articular concomitant injuries were confirmed arthroscopically. Injuries to extracapsular structures (lateral collateral ligament [LCL], medial collateral ligament [MCL]) were diagnosed on clinical examination and confirmed on magnetic resonance imaging. Injuries documented included any concomitant injury or associated medial meniscus (MM), LM, posterior cruciate ligament (PCL), MCL, and LCL injuries. Covariables assessed included patient demographic data: sex; age; body mass index (BMI); and race/ethnicity.

Statistical Analysis

Statistical analysis was performed by members of the research team with advanced statistical training (D.A.K.). Descriptive statistics were used to evaluate patient demographic characteristics by sport, including sex, age, BMI, and race/ethnicity. The frequency of injury, including isolated ACL, MM, LM, PCL, MCL, and LCL injury, was then analyzed by sport. To further evaluate the relationship between concomitant injuries and sport played, associations were also stratified by sex, age, and BMI. Finally, the adjusted relative risk (ARR) of concomitant injuries was calculated for sports with more than 100 participants, using the most played sport (basketball) as the reference. Relative risk calculations using Poisson regression were adjusted for age, sex, BMI, and clustering by registry. The 95% confidence intervals (CIs) were calculated using the method of robust standard errors, as traditional methods of calculating CIs are too conservative when calculating them for relative risk calculations. All analyses were performed using R software Version 4.0 (R Foundation for Statistical Computing).

RESULTS

Data from 855 primary ACLRs were collected and analyzed: 457 (53.5%) from Hospital A and 398 (46.5%) from Hospital B. Of the 855 patients, BMI was missing for 77 (9.0%). Only 2 (0.2%) patients were missing age data, and there were no missing data for the other baseline variables, including sex and race/ethnicity. Patients with missing data were included in the statistical analyses because the relatively low rates of missing data in the cohort were unlikely to bias our estimates. Data on concomitant injuries were complete for all patients in the cohort.

Girls comprised 51.3% of patients. The overall mean patient age was 15.5 ± 1.7 years (range, 7-22 years), and mean BMI was 24.4 ± 4.5 kg/m^2. Basketball (n = 224, 26.2%) was the most common sport played at the time of injury, followed by soccer (n = 199, 23.3%), football (n =

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TABLE 1
Patient Demographics[a]

	All Patients (n = 855)	Basketball (n = 224)	Soccer (n = 199)	Football (n = 165)	Lacrosse (n = 30)	Volleyball (n = 21)	Softball (n = 21)
Female sex	439 (51.3)	125 (55.8)	137 (68.8)	0 (0)	10 (33.3)	21 (100)	21 (100)
Age, y	15.5 ± 1.7	15.2 ± 2.0	15.2 ± 1.6	16.0 ± 1.5	15.1 ± 2.2	15.5 ± 1.4	15.0 ± 1.2
BMI, kg/m^2	24.4 ± 4.5	24.3 ± 4.5	23.7 ± 3.6	25.6 ± 4.6	22.1 ± 3.9	24.1 ± 4.6	24.4 ± 5.3
Race							
White	674 (78.8)	166 (74.1)	177 (88.9)	109 (66.1)	28 (93.3)	19 (90.5)	17 (81.0)
Black	154 (18.0)	48 (21.4)	17 (8.5)	51 (30.9)	1 (3.3)	2 (9.5)	3 (14.3)
Asian	9 (0.1)	6 (2.7)	2 (1.0)	1 (0.6)	0 (0)	0 (0)	0 (0)

[a]Data are reported as n (%) or mean ± SD. BMI, body mass index.

TABLE 2
Injury at Time of Reconstruction by Sport Played[a]

	All Patients (n = 855)	Basketball (n = 224)	Soccer (n = 199)	Football (n = 165)	Lacrosse (n = 30)	Volleyball (n = 21)	Softball (n = 21)
Any concomitant injury[b]	502 (58.7)	129 (57.6)	123 (61.8)	115 (69.7)	16 (53.3)	12 (57.1)	10 (47.6)
Medial meniscus injury	236 (27.6)	61 (27.2)	56 (28.1)	51 (30.9)	8 (26.7)	7 (33.3)	6 (28.6)
Lateral meniscus injury	367 (42.9)	100 (44.6)	89 (44.7)	92 (55.8)	9 (30.0)	8 (38.1)	7 (33.3)
PCL tear	3 (0.4)	0 (0)	0 (0)	2 (1.2)	0 (0)	0 (0)	0 (0)
MCL tear	26 (3.0)	6 (2.7)	4 (2.0)	11 (6.7)	1 (3.3)	0 (0)	0 (0)
LCL tear	5 (0.5)	1 (0.4)	0 (0)	2 (1.2)	0 (0)	0 (0)	1 (4.8)

[a]Data are reported as n (%). LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.
[b]Any concomitant injury was defined as any of the following: concurrent medial meniscus, lateral meniscus, PCL, MCL, or LCL injury.

165, 19.3%), lacrosse (n = 30, 3.5%), volleyball (n = 21, 2.5%), and softball (n = 21, 2.5%). Compared with basketball, a greater proportion of female patients participated in soccer (55.8% for basketball vs 68.8% for soccer; *P* = .008). Comparisons of other characteristics between basketball and soccer players found no differences in age (15.2 ± 2.0 years vs 15.2 ± 1.6 years; *P* = .999) or BMI (24.3 ± 4.5 kg/m^2 vs 23.7 ± 3.6 kg/m^2; *P* = .13) (Table 1).

The most frequent concomitant injuries among all participants were LM injury (42.9%) and MM injury (27.6%). Basketball-related ACL injuries included concomitant LM injury in 44.6% and MM injury in 27.2%. Soccer-related ACL injuries consisted of concomitant LM tears in 44.7% of patients and concomitant MM injuries in 28.1% of patients (Table 2). More than half (55.8%) of football-related ACL injuries had concomitant LM injury, and approximately one-third (30.9%) of football-related ACL injuries had concomitant MM injuries. Other activities, such as unknown mechanism of injury/unspecified recreational activity (n = 46, 5.4%), field hockey (n = 18, 2.1%), track (n = 8, 0.9%), baseball (n = 4, 0.5%), dance (n = 3, 0.4%), and wrestling (n = 1, 0.1%), were included in the descriptive statistics but were not described by sport participation or assessed for sport-specific risk due to limited statistical power.

Overall, there was no difference in the likelihood of concomitant MM injuries by sex (29.3% for male patients vs 26% for female patients; *P* = .31). There was also no difference in the frequency of MM tears by sex for specific sports, including basketball (29.3% for male patients vs 25.6% for female patients; *P* = .96) and soccer (32.3% vs 26.3%; *P* = .06). Male patients had a significantly greater proportion of LM injuries overall (51.7% for male patients vs 34.6% for female patients; $P < .001$) but not within the basketball subgroup (50.5% vs 40.0%; *P* = .86) or the soccer subgroup (59.7% vs 40.0%; *P* = .19). We found no statistically significant associations between patient age and specific ACL concomitant injury patterns. When stratifying by BMI, we found overweight and obese individuals constituted a significantly greater proportion of LM (49.6% vs 39.1%; *P* = .01) but not MM (29.4% vs 25.5%; *P* = .28) injuries when compared to normal-weight patients (Tables 3-5).

As the most frequently played sport among patients was basketball, basketball was used as the comparison group for multivariable analyses when calculating risk ratios adjusted for age, sex, BMI, and registry for sport-associated injuries (Table 6). Compared with basketball participants, those playing soccer at the time of ACL tear were 18% (ARR, 1.18; 95% CI, 1.00-1.39) more likely to present with any concomitant injury of the knee, defined as concurrent MM, LM, PCL, MCL, or LCL injury. For soccer, there was no difference in risk for MM (ARR, 1.19; 95% CI, 0.86-1.64) or LM (ARR, 1.08; 95% CI, 0.86-1.35) injuries. Football injuries demonstrated a similar association

TABLE 3
Type of Injury by Sex[a]

	All Patients (n = 855)		Basketball (n = 224)		Soccer (n = 199)	
Sex	Female	Male	Female	Male	Female	Male
Medial meniscus injury	114 (26.0)	122 (29.3)	32 (25.6)	29 (29.3)	36 (26.3)	20 (32.3)
Lateral meniscus injury	152 (34.6)	215 (51.7)	50 (40.0)	50 (50.5)	52 (40.0)	37 (59.7)

[a]Data are reported as n (%).

TABLE 4
Type of Injury by Age[ab]

	All Patients (n = 855)		Basketball (n = 224)		Soccer (n = 199)	
Age, y	<16	≥16	<16	≥16	<16	≥16
Medial meniscus injury	100 (26.5)	136 (28.6)	28 (24.6)	33 (30.0)	31 (31.3)	25 (25.2)
Lateral meniscus injury	160 (47.3)	206 (43.4)	51 (44.7)	49 (44.5)	46 (46.5)	42 (42.4)

[a]Data are reported as n (%) unless otherwise indicated.
[b]Count discrepancies for LM and MM between Tables 2 and 4 represent missing data for Age and BMI.

TABLE 5
Type of Injury by BMI[ab]

	All Patients (n = 855)		Basketball (n = 224)		Soccer (n = 199)	
BMI, kg/m^2	<25	≥25	<25	≥25	<25	25
Medial meniscus injury	129 (25.5)	80 (29.4)	34 (25.2)	18 (24.7)	34 (24.8)	19 (38.0)
Lateral meniscus injury	198 (39.1)	135 (49.6)	54 (40.0)	36 (49.3)	54 (39.4)	29 (58.0)

[a]Data are reported as n (%) unless otherwise indicated. BMI, body mass index.
[b]Count discrepancies for LM and MM between Tables 2 and 5 represent missing data for Age and BMI.

TABLE 6
Adjusted Risk Ratios of the Association of Injury Type and Sport Played at Injury[a]

	Basketball (Reference)	Soccer	Football
Any concomitant injury[b]	1.0	1.18 (1.00-1.39)	1.18 (1.00–1.40)
Medial meniscus injury	1.0	1.19 (0.86-1.64)	1.02 (0.73-1.44)
Lateral meniscus injury	1.0	1.08 (0.86-1.35)	1.20 (0.97-1.50)

[a]Data are reported as risk ratios (95% CI) except for reference. Risk ratios were adjusted for age, sex, body mass index, and registry for evaluations of soccer. For evaluations of football, risk ratios were adjusted for age, body mass index, and registry, as all football players were male.
[b]Any concomitant injury was defined as any of the following: concurrent medial meniscus, lateral meniscus, posterior cruciate ligament, medial collateral ligament, or lateral collateral ligament injury.

with the presence of any concomitant ACL injury (ARR, 1.18; 95% CI, 1.00-1.40). For football, there was also no association with risk of MM (ARR, 1.02; 95% CI, 0.73-1.44) or LM (ARR, 1.20; 95% CI, 0.97-1.50) injuries.

DISCUSSION

This study demonstrates several key findings. First, pediatric athletes who experienced an ACL tear during soccer and football were more likely to have a concomitant injury than basketball players. Likewise, we found that boys had a higher proportion of LM injuries overall. Lastly, overweight and obese individuals had a higher proportion of LM injuries. This information is helpful to physicians and parents alike in better understanding sport-associated injury patterns and risks.

The literature demonstrates ACL tears in male athletes are more likely to result from direct blows to the knee compared to their female counterparts.[14] Likewise, direct contact increases the risk of concomitant injury to the knee cartilage, femoral condyles, and collateral ligaments.[12]

Age has also been shown to be a risk factor for concomitant injury, with athletes aged 14 years or older having an increased prevalence of concomitant knee injury compared to their younger cohort.[11] Last, previous research has demonstrated that both weight and BMI increase the risk for ACL injury and concomitant injury in the pediatric population.[3,8,10]

These increased proportions were observed in some focused comparisons within our patient sample. For instance, male patients demonstrated an overall increased proportion of LM injury compared to female patients among all patients (51.7% vs 34.6%; $P < .001$), basketball (50.5% vs 40%; $P = .86$), and soccer (59.7% vs 40%; $P = .19$). Although all subgroups did not demonstrate statistical significance, differences between groups are large—particularly soccer—and likely clinically significant. Failure to demonstrate statistical significance is possibly due to underpowered subgroups. Likewise, patients with a BMI >25 kg/m^2 demonstrated an overall increased proportion of LM injury among all patients (49.6% vs 39.1%) and those playing soccer (58% vs 39.4%). However, these findings were not consistent across all subgroups.

Previous literature has examined sport-associated ACL injury patterns; however, understanding the cause of such differences is not as clear. Granan et al[6] found football to be associated with multiligament injury, while basketball had a higher association with cartilage and LM injury compared to soccer. The authors speculated that differences in injury patterns could be due to the mechanisms of injury experienced during different sporting activities. For instance, basketball injuries typically arise from jumping-landing mechanisms compared to cutting and pivoting movements seen in soccer.[6,9] Conversely, it has been reported that football players have increased odds of experiencing multiligament injuries compared to soccer players, which authors speculate is due to higher rates of contact injuries.[4,6,15]

Our study conflicts somewhat with those findings in that when adjusting for age, institution, and BMI—soccer and football, not basketball—demonstrated an increased risk for concomitant injury patterns in the ACL-injured adolescent population. Our findings are also interesting in that football showed higher overall proportions of concomitant injury, although when adjusting for demographic factors, soccer and football had a similar risk.

The authors speculate that the differences in our findings compared with previous studies could, at least in part, be due to differences in the age of our sample. In the study by Granan et al,[6] the mean age for soccer, football, and basketball participants was 25, 18.5, and 24.5 years, respectively, compared with 15.5 years across all sports in our sample. With this younger age comes differences in joint flexibility, ligament laxity, and neuromuscular factors, which may interact with how mechanism-specific ACL injury patterns manifest themselves.[3] In addition, mechanisms used to explain the increase in concomitant injury with football and basketball (direct contact vs jumping-landing movements, respectively) may not exist to the same degree in younger populations. In contrast, pivoting movements seen in soccer might be consistent across ages. These are just speculation, however, and more research is needed on both sport-associated injury risks and mechanisms of injury in the pediatric population.

Limitations

Our study has several limitations. First, given its retrospective nature, we lacked complete data on the time to surgery, precluding formal analysis of this variable. Because of this omission, we cannot account for the effect of a delayed ACLR on a concomitant injury.[5] However, there was unlikely a differential rate of delay to ACLR among sports, so we do not feel that this potential limitation would change the results of the current study. Second, the activity at the time of injury was gathered from patient-reported data. Although this information is likely accurate, the patient's level of activity or details regarding the exact mechanism of injury may not be precise given the potential for recall bias. On the contrary, an ACL injury is a psychologically traumatic event, and details surrounding the injury (ie, sport being played or timing) are unlikely to be forgotten or confused. Third, the data used in this study consisted of 855 patients from 2 tertiary children's hospitals in the Midwest. Although the climate and patient demographics at these 2 locations are comparable enough to allow for intrasample validity, there is the potential that the results would not be generalizable to other regions with a different mix of sport participation. Last, all available participants were used in the analysis, and therefore an a priori power analysis could not be performed. There is some concern for underpowered subgroups when considering the large proportional differences found without statistical significance; specifically, examining the proportion of LM injury in male patients versus female patients by sport. However, given the study's large number of participants and positive findings, there is minimal concern for type 2 error for most findings.

CONCLUSION

Pediatric and adolescent athletes sustaining an ACL injury during soccer and football were more likely to present with a concomitant injury compared with those participating in basketball. Treating surgeons can use these data in their preparation for surgery, knowing to examine patients more carefully during arthroscopic surgery as a function of their sport at the time of injury and the potential likelihood of associated injuries. In addition, as parents consider the risks and benefits of participation in certain sports for their children, it is important to understand the associated injury patterns and their sequelae. This study demonstrates 1 such consideration, as additional injuries to other knee structures accompanying ACL injuries are associated with increased risk of early osteoarthritis and decreased function associated.

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