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Sport-Specific Injury Pattern Recorded During Anterior Cruciate Ligament Reconstruction

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Background: Anterior cruciate ligament (ACL) injuries are more commonly seen with certain cutting and pivoting sports. However, injury patterns associated with these sports have not been well described.

Purpose: (1) To describe the patient demographics and injury pattern at the time of ACL reconstruction (ACLR) by activities that lead to ACL injuries and (2) to estimate the association of activities at the time of injury with the odds of isolated ACL injuries as well as with meniscus, cartilage, and multiligament injuries diagnosed at the time of ACLR.

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

Methods: This study combined 2 ACLR registry cohorts, from Norway and the United States, from 2004 to 2011. A cohort of 10,958 primary ACLRs was included. The most prevalent sports activities at the time of injury were the following: soccer, skiing, American football, basketball, and team handball. The end points were the concurrent injury patterns at the time of ACLR: isolated ACL, meniscus, cartilage, and multiligament injuries.

Results: All sports were compared with the most prevalent injury mechanism: soccer. Skiing injuries were 1.13 (95% confidence interval [CI], 1.01-1.27) times more likely to result in isolated ACL tears, 2.05 (95% CI, 1.01-4.16) times more likely to result in posterior cruciate ligament tears, 1.94 (95% CI, 1.51-2.49) times more likely to result in medial collateral ligament (MCL) tears, and 1.73 (95% CI, 1.38-2.17) times more likely to result in multiligament injuries. Athletes playing American football were 2.72 (95% CI, 1.32-5.62) times more likely to have MCL tears. Those injured playing basketball were 1.28 (95% CI, 1.06-1.54) times more likely to have lateral meniscus tears, 1.23 (95% CI, 1.01-1.51) times more likely to have cartilage damage, and 1.38 (95% CI, 1.11-1.72) times more likely to have meniscus and cartilage injuries. Athletes injured playing team handball were less likely to have MCL tears (odds ratio [OR], 0.68; 95% CI, 0.46-0.99) and more likely to have lateral meniscus injuries (OR, 1.27; 95% CI, 1.10-1.48).

Conclusion: Injury patterns were associated with certain sports. Compared with soccer, American football has a higher likelihood of resulting in multiligament injuries, whereas basketball has a higher likelihood of resulting in cartilage and lateral meniscus injuries. Injury patterns seen at the time of surgery may reflect the forces applied to the knee by the specific sports performed.

Keywords: knee; ligaments; articular cartilage; meniscus; anterior cruciate ligament (ACL); epidemiology; registry

The knee joint, and especially the anterior cruciate ligament (ACL), is a commonly injured structure in sports. Such injuries might prevent athletes from returning to their preinjury sporting level as well as potentially increase the risk of premature osteoarthritis.[11] Injuries to the ACL are more commonly seen with certain cutting and pivoting sports.[1] However, concomitant injury patterns associated with these sports have not been well described in the literature.

Studies have evaluated specific sports at the time of injury and the association with concurrent injuries. However, these studies were limited to evaluating only the more prevalent concurrent injuries such as meniscus and cartilage injuries and focused on limited patient samples. One study reported that with the exceptions of wrestling and volleyball, there was a significant difference in the incidence of meniscus injuries in different sports.[8] Another study, focusing on team handball players, reported that the male sex is associated with an increased risk of full-thickness articular cartilage lesions in ACL-injured knees compared with the female sex.[14]

Whether the difference in activity at the time of injury plays a role in the injury pattern noted at the time of surgery[10] remains unclear. Therefore, the aim of this study was 2-fold:

1. To describe the patient demographics and injury pattern at the time of ACL reconstruction (ACLR) by certain activities (ie, soccer, skiing, American football, basketball, and team handball) that lead to ACL injuries.
2. To estimate the association of activity at the time of injury with the odds of having isolated ACL injuries, meniscus injuries, cartilage injuries, and multiligament injuries diagnosed at the time of ACLR, after adjusting for possible confounders (age, sex, time to surgery, and registry).

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MATERIALS AND METHODS

A cross-sectional study of a sample of patients undergoing ACLR in Norway and the United States was conducted. The Norwegian Knee Ligament Registry (NKLR) and the Kaiser Permanente ACLR Registry (KPACLRR) were used to identify the study sample. Patients undergoing primary ACLR performed in NKLR between June 2004 and December 2010 and at KPACLRR between January 2010 and September 2011 were included. Revision ACLR and other ligament-only procedures were excluded. Detailed information on the registries' participation/compliance, data collection procedures, data collection forms, and coverage have been published elsewhere.[6,12,13,17,18] In brief, both registries have high compliance, have similar data collection mechanisms, and use similar definitions and data collection forms. The baseline characteristics, procedures, and graft and fixation use of these cohorts have previously been published.[7,10]

After Internal Review Board and Regional Committee for Medical Research Ethics approval were obtained, a complete deidentified dataset from each registry was assembled by its respective registry analytical staff member. The deidentified tabulated data from each registry were merged from Excel spreadsheets (Microsoft Corp, Redmond, Washington) at the Surgical Outcomes and Analysis Department at KP.

Exposure of Interest

The exposure of interest was sports activity played at the time of ACL injury as reported by the patient. In both registries, the intraoperative form contained a question regarding "activity that led to injury" and several checkboxes for options, such as soccer, baseball, basketball, skiing, dance, American football, gymnastics, etc. An "other" checkbox and room for text were also available if the desired option was not included. Because multiple activities were available, the most prevalent activities in each registry were chosen for this study. The most common activities in both registries were soccer, skiing, and basketball. American football and team handball were also investigated because they were highly prevalent in the NKLR and KPACLRR cohorts, respectively.

Outcome

The outcomes of interest in this study were concurrent injuries at the time of ACLR: injury to the meniscus, articular cartilage, posterior cruciate ligament (PCL), medial collateral ligament (MCL), and multiligament (ACL + at least 1 other from the following: PCL, MCL, and lateral collateral ligament [LCL]). Isolated ACL tears were also evaluated. The LCL was not investigated alone because the number of events was small. All injury information was recorded by the surgeon on the intraoperative forms collected by the registries.

Covariates

Patient characteristics (age, sex, and body mass index) and time from injury to surgery (days) were obtained from the registries to evaluate the study cohort.

Statistical Analysis

Descriptive statistics used to evaluate the study sample included frequencies, proportions, medians and interquartile ranges, as well as means and standard deviations. χ^2 tests were used to compare categorical variables between the activities at the time of injury. Unadjusted and adjusted binary logistic regression models evaluated the association of activity with concurrent injuries at the time of ACLR (PCL tear, MCL tear, medial meniscus tear, lateral meniscus tear, cartilage damage, and multiligament injuries). Soccer was the reference category because it had the highest volume of cases. Odds ratios (ORs), 95% confidence intervals (CIs), and *P* values of the Wald χ^2 test are provided. Stratified analysis by registry was also conducted (data not shown). All analyses presented are adjusted for registry effects. Observations with missing data were excluded from the logistic models; the data point with the most missing data was the time from injury to surgery (15.6% of the cases). To evaluate the consistency of our estimations, models with and without the time to surgery variable were created. SAS (version 9.1.3, SAS Institute, Cary, North Carolina) was used to assemble, merge, and analyze the data, with $\alpha = .05$.

RESULTS

During the study period, 17,063 primary ACLRs were registered: 10,644 (62%) NKLR cases and 6419 (38%) KPACLRR cases. Most of the cases were injured because of soccer (n = 5760, 33.8%), followed by "other sports"

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TABLE 1
Cohort Characteristics at the Time of Primary ACL Reconstruction by Sport Played at Injury (N = 10,958)[a]

	Soccer	Skiing	American Football	Basketball	Team Handball
Total, n (%)	5760 (52.6)	2030 (18.5)	564 (5.1)	1056 (9.6)	1548 (14.1)
Age, median (IQR), y	25.0 (18.3-33.7)	32.0 (22.2-40.5)	18.5 (16.9-27.1)	24.5 (18.3-32.6)	20.0 (16.0-30.0)
Female sex, n (%)	1844 (32.0)	944 (46.5)	40 (7.1)	314 (29.7)	1295 (83.7)
Age, median (IQR), y	19.0 (16.1-27.0)	32.6 (21.1-42.0)	21.5 (18.2-30.5)	18.0 (16.2-22.8)	19.0 (16.0-28.0)
Male sex, n (%)	3916 (68.0)	1086 (53.5)	524 (92.9)	742 (70.3)	253 (16.3)
Age, median (IQR), y	27.0 (21.0-35.0)	31.0 (22.0-39.0)	18.4 (16.9-26.3)	27.5 (21.5-34.3)	24.0 (19.0-35.0)
BMI, median (IQR)	24.6 (22.6-27.1)	24.4 (22.4-26.8)	26.8 (23.7-30.4)	26.0 (23.4-29.3)	23.7 (21.8-26.0)
Time from injury to surgery, median (IQR), d	207 (115-450)	211 (98-422)	118 (68-224)	141 (77-275)	165 (88-352)

[a]ACL, anterior cruciate ligament; BMI, body mass index; IQR, interquartile range.

(most commonly other team sports and martial arts) (n = 2832, 16.6%), "other" (ie, not sports related) (n = 1941, 11.4%), skiing (n = 2030, 11.9%), team handball (n = 1548, 9.1%), basketball (n = 1056, 6.2%), and American football (n = 564, 3.3%). A total of 7.8% (n = 1332) of the cases had an unknown mechanism of injury listed. Table 1 describes the cohort of patients in each of the main sports included in the analysis. Table 2 displays the injury pattern for the different sports at the time of ACLR.

Results from models of the association of sports played at ACL injury and injuries at the time of ACLR, adjusted for age, sex, time from injury to surgery, and registry, are presented in Table 3. Compared with soccer injuries, skiing injuries were 1.13 (95% CI, 1.01-1.27) times more likely to result in isolated ACL tears, 2.05 (95% CI, 1.01-4.16) times more likely to result in PCL tears, 1.94 (95% CI, 1.51-2.49) times more likely to result in MCL tears, and 1.73 (95% CI, 1.38-2.17) times more likely to result in multiligament issues. Athletes playing American football were 2.72 (95% CI, 1.32-5.62) times more likely to have MCL tears than those playing soccer. Those injured playing basketball were 1.28 (95% CI, 1.06-1.54) times more likely to have lateral meniscus tears, 1.23 (95% CI, 1.01-1.51) times more likely to have cartilage damage, and 1.38 (95% CI, 1.11-1.72) times more likely to have meniscus and cartilage injuries than soccer players. Compared with soccer, athletes injured playing team handball were less likely to have MCL tears (OR, 0.68; 95% CI, 0.46-0.99) and more likely to have lateral meniscus injuries (OR, 1.27; 95% CI, 1.10-1.48).

Models not adjusted for time to surgery, which included all observations (n = 10,958), were consistent with the limited model presented in Table 3 (n = 9245) and the Appendix (available online at http://ajsm.sagepub.com/supplemental). Time from injury to surgery was a negative confounder in the associations studied, causing the strength of the associations to become slightly lower than previously estimated, but the direction and significance of the associations were not changed by its adjustment.

DISCUSSION

Our study found that activities leading to ACL injury are also associated with certain injury patterns involving the meniscus, cartilage, and other ligaments. Injury patterns seen at the time of surgery may reflect the forces applied to the knee by the specific sports activities performed at the time of injury.

Compared with soccer, skiing has increased odds of isolated ACL injuries and other ligament injuries but decreased odds of meniscus and cartilage injuries. This injury pattern is probably caused by the injury mechanism in which the distal leg and ski act as a long lever arm in a slip-catch mechanism.[2] American football has a higher likelihood of having multiligament injuries compared with soccer. The reason may be the energy and biomechanics at the time of injury. The higher ratio of contact versus noncontact ACL injuries in American football compared with soccer may also be an explanation.[4,15,16] Basketball has a higher likelihood of having cartilage and lateral meniscus injuries than soccer. This may be the result of the forces that are applied to the knee at the moment of impact in the majority of cases occurring in relation to landing after jumping.[9] This argument seems insufficient when comparing basketball and team handball players because the forces are similar. However, there is also another possible explanation: the basketball players were 4.5 years older than the team handball players and thus had more time to sustain cartilage injuries before the debilitating ACL rupture. In addition, there were far more male athletes in basketball (70.3%) than in team handball (16.3%); therefore, the intensity, mass, and forces to the hip and knee joints are higher on average in basketball. The increased odds for lateral meniscus injuries are similar for team handball and basketball and are expected to reflect the dynamics of the game with more cut and plant movements than in soccer. This is also in line with a large cohort study that found that male team handball players were the only male athletes with an increased risk of lateral meniscus injuries.[14] This is possibly explained by the higher number of top- and medium-level athletes in male team handball compared with other sports.[14] Because previous studies[3,5] have shown that the odds for cartilage and meniscus injuries increase with time from injury to surgery, time to surgery was included in our final models (Table 3). However, it was not found to be a significant confounder of the relationship of sports played at the time of injury and most of the concurrent injuries studied. Most of the

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

	Soccer	Skiing	American Football	Basketball	Team Handball
Total	5760 (52.6)	2030 (18.5)	564 (5.1)	1056 (9.6)	1548 (14.1)
Isolated ACL tear	2205 (38.3)	837 (41.2)	160 (28.4)	302 (28.6)	686 (44.3)
PCL tear	19 (0.3)	18 (0.9)	5 (0.9)	1 (0.1)	12 (0.8)
MCL tear	174 (3.0)	136 (6.7)	16 (2.8)	13 (1.2)	42 (2.7)
Meniscus injury (any)	2945 (51.1)	871 (42.9)	356 (63.1)	681 (64.5)	699 (45.2)
Medial meniscus injury	1878 (32.6)	581 (28.6)	194 (34.4)	413 (39.1)	460 (29.7)
Lateral meniscus injury	1692 (29.4)	475 (23.4)	246 (43.6)	478 (45.3)	392 (25.3)
Cartilage injury	1424 (24.7)	538 (26.5)	153 (27.1)	317 (30.0)	315 (20.3)
Meniscus and cartilage injury	912 (15.8)	285 (14.0)	111 (19.7)	250 (23.7)	173 (11.2)
Multiligament injury[b]	231 (4.0)	157 (7.7)	18 (3.2)	15 (1.4)	55 (3.6)

[a]Values are expressed as n (%). ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.
[b]Multiligament = ACL + at least 1 other from the following: PCL, MCL, and/or lateral collateral ligament.

TABLE 3
Odds Ratios, Adjusted for Age, Sex, Registry, and Time From Injury to Surgery, of the Association of Injury Type and Sport Played at Injury

	Soccer (Reference)	Skiing	American Football	Basketball	Team Handball
Isolated ACL tear	1.0	1.13 (1.01-1.27)	0.94 (0.71-1.23)	0.94 (0.77-1.14)	0.91 (0.80-1.04)
PCL tear	1.0	2.05 (1.01-4.16)	4.70 (0.39-56.5)	1.04 (0.13-8.44)	2.04 (0.89-4.65)
MCL tear	1.0	1.94 (1.51-2.49)	2.72 (1.32-5.62)	0.88 (0.46-1.69)	0.68 (0.46-0.99)
Medial meniscus injury	1.0	0.83 (0.73-0.94)	0.79 (0.61-1.03)	1.51 (0.96-1.39)	1.10 (0.96-1.27)
Lateral meniscus injury	1.0	0.83 (0.73-0.95)	0.95 (0.74-1.22)	1.28 (1.06-1.54)	1.27 (1.10-1.48)
Cartilage injury	1.0	0.95 (0.84-1.09)	1.04 (0.78-1.38)	1.23 (1.01-1.51)	0.99 (0.84-1.16)
Meniscus and cartilage injury	1.0	0.80 (0.68-0.94)	0.86 (0.62-1.18)	1.38 (1.11-1.72)	1.00 (0.82-1.30)
Multiligament injury[b]	1.0	1.73 (1.38-2.17)	2.26 (1.10-4.61)	0.85 (0.47-1.55)	0.72 (0.52-1.01)

[a]Values are expressed as odds ratio (95% confidence interval) except for reference. ACL, anterior cruciate ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.
[b]Multiligament = ACL + at least 1 other from the following: PCL, MCL, and/or lateral collateral ligament.

estimates changed very little after adjusting for time to surgery (less than 20%, used as the threshold of a significant confounder).

The major limitation of this study is that patient activity at the time of injury is self-reported. Like other self-reported measures, this can suffer from information bias. In addition, the level of activity is not clear, and the exact time when the injury occurred is likely unknown. The activity reported may have happened during play, leisure time activities, or organized activity/competition. Another limitation is that we do not have video of any of the injury incidents, and thus, an exact biomechanical injury mechanism is merely a theoretical speculation. Whether the injuries were contact or noncontact was not recorded by the registries. Also, this study design is cross-sectional and cannot comment on the temporal relationship of the concurrent injuries and activities studied. It is possible that the injuries were present before the ACL tear or occurred after the initial injury and only diagnosed at the time of the ACLR. However, we believe that this lack of determination of when the injury happened is nondifferential among the various activities studied. Missing data were also a limitation of our study. Time from injury to ACLR was missing in 15.6% of the cases. Because previous reports have found time from injury to surgery to be associated with certain injury patterns,[3,5] we evaluated the effect of these missing data on our estimations by creating models with complete data only and models without the variable. We found that the estimations were equally consistent in the sample without time to surgery as they were in the complete data sample. Prevalence of meniscus injuries has been reportedly different between the NKLR and KPACLRR,[7] and one possible explanation for the difference in prevalence of this injury could be the definitions used for meniscus injury reporting. To adjust for this possible difference in definition and other possible differences in the registered cohort, a covariate called "registry" was used in our models to adjust for possible unknown/residual confounding that is not measured by the other variables included in our analysis. Another limitation of this study was our inability to evaluate the location, size, and depth of cartilage injuries in the current sample size. However, because no studies in the current literature have confirmed causality between specified cartilage injury patterns and increased functional or prospective disabling injuries, we believe that our results, while still general, are of interest.

The major strength of this study is the large number of patients and the consistent findings that they reflect. Thus, we find it reasonable that the injury patterns seen

at the time of surgery may reflect the forces applied to the knee by the specific sports activities performed. The data sources used for this study, the similar data collection procedures and format, and previously reported similarities in definitions used by them are other strengths of this study. Both registries collect information on ACLRs prospectively, using standard data collection procedures, with agreed-upon definitions for cartilage injuries and other reported concurrent injuries by their contributing cohort of surgeons. This standardization in data collection increases the internal validity of the reported findings. Additionally, this study was able to investigate 5 different injury patterns in a large number of patients. The large sample size allowed us to use multivariable statistics to adjust for other confounders of the associations of activities that lead to injury and injury patterns. A large number of contributing surgeons, hospitals, and patient subgroups (various ages and activity levels) were included in this study, creating a largely representative sample of patients undergoing ACLR in community-based practices. The ability to generalize our findings to a large number of patient and surgeon/hospital settings increases the external validity of our findings.

In summary, we found that ACL-related injury patterns were associated with certain sports. Compared with soccer, American football has a higher likelihood of multiligament injuries, whereas basketball has a higher likelihood of cartilage and lateral meniscus injuries. Injury patterns seen at the time of surgery may reflect the forces applied to the knee by the specific sports activities performed. This information is valuable in several ways to patients, public health services, and orthopaedic providers. First, ascertaining the risks of these injuries for specific sports may help athletes (and their parents) better understand the risks associated with participation in a given sport. Second, for public health services, the effect of increasing overall participation in certain sports may lead to a higher incidence of ACL injuries, leading to a higher utilization of health care services. Third, while the mechanism of sustaining an ACL injury in various sports is not well understood, by improving the understanding of (1) sports that are more commonly associated with ACL injuries and (2) injury patterns associated with ACL injuries in specific sports, we may begin to deduce factors that contribute to these injuries. This can then lead to meaningful interventions in injury prevention, including preventative training, adjustments in equipment, or modifications in the rules. Finally, for the practicing orthopaedic surgeon, this information allows them to focus their efforts on preventative and interventional treatments on sports with higher ACL injuries as well as be more cognizant of associated injuries in the evaluation of the injured athlete.

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