0363-5465/101/2929-0196$02.00/0
THE AMERICAN JOURNAL OF SPORTS MEDICINE, Vol. 29, No. 2

Intrinsic and Extrinsic Risk Factors for Anterior Cruciate Ligament Injury in Australian Footballers*

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ABSTRACT

The aim of this study was to examine the interaction between intrinsic (player-related) and extrinsic (environment-related) variables as risk factors for anterior cruciate ligament injury in Australian football. Between 1992 and 1999, 100,820 player-match exposures were analyzed for risk of anterior cruciate ligament injury using logistic regression analysis. There were 63 surgically proven noncontact anterior cruciate ligament injuries. The strongest risk factors were a player history of anterior cruciate ligament reconstruction either in the previous 12 months (relative risk [RR], 11.33; 95% confidence interval [CI], 4.02 to 31.91) or before the previous 12 months (RR, 4.44; 95% CI, 2.46 to 8.01). Weather conditions that were associated with dry field conditions—high water evaporation in the month before the match (RR, 2.55; 95% CI, 1.44 to 4.52) and low rainfall in the year before the match (RR, 2.87; 95% CI, 1.30 to 6.32)—were also significantly associated with these injuries. The increased risk of injury in the first 12 months after reconstruction was associated with the reconstructed knee, whereas after 12 months there was an even distribution of new injuries to the reconstructed knee and contralateral knee. A history of anterior cruciate ligament reconstruction is a risk factor for further injury. Weather conditions of high evaporation and low rainfall before matches are associated with noncontact anterior cruciate ligament injury.

Anterior cruciate ligament injuries of the knee are the most costly injuries in sport. This is due to the worldwide popularity of the various football sports, in which ACL injuries are both common and severe. In a report of sports injuries resulting in permanent disability in Sweden between 1986 and 1990, 841 of 1312 cases (64%) involved the ACL.[5] Despite the severity and cost of these injuries, fewer than 1% of citations regarding the ACL focus on injury prevention.[20]

Risk factors for injury can be divided into intrinsic (personal) and extrinsic (environmental) categories. Female sex is a well-established intrinsic risk factor.[2,3,6,7] A narrowed intercondylar notch is considered by some authors to be a risk factor,[22–24] although it is not certain whether the reported associations relate to impingement, smaller ligament size, or confounding by other injury risk factors.

The most likely extrinsic risk factors postulated relate to the shoe-surface interface. It has been hypothesized for many years that increasing traction between a football shoe and the playing surface causes an increase in the rate of knee injuries.[25] A recent prospective study has shown that American football shoes with a greater number of cleats and higher torsional resistance are associated with an increased number of ACL injuries.[11] The grade of the match and the weather conditions before matches have been shown to affect the risk of noncontact ACL tears among Australian Football League players.[19] In a recent review of noncontact ACL injuries in American football, it was noted that almost all injuries on natural grass occurred in dry conditions,[21] but conditions on days when injury did not occur were not measured or controlled for.

Some controlled studies have shown a reduction in the rate of ACL injuries in groups undergoing a proprioceptive training program.[4,10] However, to date, these studies have not been randomized or blinded and have not measured "proprioception" in the individual subjects, so the results must be interpreted with caution.

*A preliminary account of the findings in this study was presented at the Fifth IOC Conference on Sports Sciences, Sydney, Australia, November 1999.

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No author or related institution has received any financial benefit from research in this study.

The establishment of reversible risk factors is an important step toward injury prevention.[26] Intrinsic and extrinsic risk factors can interact and, where possible, should be considered together to adjust for confounding. The aim of this study was to examine the interaction between extrinsic and intrinsic variables as risk factors for ACL injury in Australian football players.

Australian Rules Football

Australian football is a unique game played outdoors on natural grass. The regular season consists of 22 matches per team, with teams playing once weekly. There are 18 players on the field in each team, with up to 4 players on an interchange bench. All players (including those on the interchange bench) receive considerable game time on the field. Games are played over four quarters lasting 20 minutes each, with time added for breaks (average, over 7 minutes per quarter). The Australian Football League is the premier professional league of Australian football and it conducted two divisions (grades) over the period of this study. The major division was referred to as first or senior grade. Most clubs also entered a team into the second (or reserve) grade division. The teams for each grade were selected weekly, so that some players alternated between first and second grade during the season.

MATERIALS AND METHODS

The number of teams, seasons, and players selected for this study are detailed in Table 1. All regular season, official preseason, and finals matches for both the first and second grade divisions were included. The players included in the study were those on official team lists (rosters) for each team for that season.

The occurrence of ACL injuries was determined by the ongoing injury surveillance program that included a register for ACL injuries. The definition of ACL injury for this study required a complete injury that necessitated a knee reconstruction to allow continued play at the elite level. Injuries that were managed nonoperatively were excluded, as the diagnosis for these was not consistently established by a standard methodology, such as MRI scan. The diagnosis for all complete tears was proven at the time of arthroscopy or reconstruction. As can be seen from Table 1, the majority of ACL injuries were treated surgically. The standard management at all teams was that only partial tears involving a minor degree of ligament damage, with no functional instability, were treated nonoperatively. Injuries that occurred during training sessions or unofficial matches were excluded.

The mechanism of injury was provided by team doctors after speaking with the player or reviewing a video of the injury. Mechanisms were divided into contact and noncontact based on whether there was direct contact to the injured knee or leg. Therefore, a mechanism such as a player being tackled to the upper body with the foot fixed in the turf, with the ACL injured via an indirect force, was considered to be noncontact. The majority of the noncontact injuries were caused by pivoting (cutting) or landing from a jump.

The Australian Football League statistical database was used to determine intrinsic player characteristics such as age, height, and weight, and to verify the location, dates, and players competing in each match.

Daily weather variables were measured during the period of study by the Australian Bureau of Meteorology (Sydney, Australia) for the cities of Adelaide, Brisbane, Canberra, Darwin, Geelong, Hobart, Melbourne, Perth, and Sydney at central locations in each city. Only six matches during the study period were played outside these cities, and these were excluded from the analysis. Two composite weather variables—28-day evaporation and 365-day rainfall—were considered for analysis as they had been found previously to be the best predictors of ACL injury in this cohort.[19] Water evaporation is a meteorological variable measuring the change of surface water into water vapor—it is affected by temperature, sunshine, humidity, and wind.[12] The 28-day evaporation measured the sum total of water evaporation in the city over the

TABLE 1
Scope of Study and Injuries

Variable	Number
Number of seasons	8
Number of teams (total)	17
Number of teams in competition per season	15 (before 1995); 16 (after 1995)
Number of team seasons	125
Number of players (total)	1643
Average height (cm)	185.2 ± 7.1
Average weight (kg)	83.9 ± 8.3
Average age (years)	23.6 ± 3.8
Average number of first grade matches per team per season	24.0
Average number of second grade matches per team per season	15.1
Number of matches	2594
Number of player matches	100,820
Number of ACL injuries during the study period	120
ACL injuries excluded because of onset in training or unofficial match	32
ACL injuries excluded as partial tears that did not require reconstruction	5
Number of ACL injuries included	83
Number of included ACL injuries with mechanism not involving direct contact	63

previous 28 days, while the 365-day rainfall measured the total rainfall in the city over the previous year.

Statistical analysis was performed using the SPSS program.[16] Student's *t*-tests (after variances assessed using Levene's test) were performed in the initial stages of the analysis. Multivariate analysis was performed using a logistic regression forward stepwise technique, with a significance level of 0.05 to enter the equation. Continuous variables in the logistic regression were redefined into binary variables based on group median values to calculate risk ratios adjusted for confounding.

RESULTS

There were 100,820 athlete-exposures (match) over the study period that had all data available for analysis. Within this cohort there were 83 surgically proven ACL tears that resulted in reconstruction, of which 63 had a noncontact mechanism (Table 2). This is an injury incidence of 0.82 ACL injuries per 1000 athlete-exposures, and 0.62 noncontact ACL injuries per 1000 athlete-exposures.

A logistic regression model was created to predict ACL injury occurrence (from all mechanisms and from noncontact mechanisms only) based on both intrinsic and extrinsic risk factors.

The extrinsic factors considered in the model were evaporation, rainfall, and grade of the match, all of which had been found to be associated with ACL injury in a previous study.[19] Evaporation was converted into a binary variable according to whether it was greater than 48 mm in the previous 28 days. Rainfall was converted into a binary variable according to whether it was less than 449 mm in the previous 365 days. These values were chosen because they were group medians.

Intrinsic factors were subjected to *t*-tests and correlation studies to determine their possible validity in the logistic regression model. Increased age ($t_{100570} = 2.73$, $P = 0.006$), increased weight ($t_{100818} = 3.28$, $P = 0.001$), and body mass index ($t_{100460} = 2.28$, $P = 0.023$) were significantly associated with noncontact ACL injury. There was a trend but no significant relationship between increasing height and noncontact injury ($t_{100389} = 1.87$, $P = 0.062$).

History of ACL injury was subdivided into recent history of ACL injury (within the previous 12 months) and past history of injury (greater than 12 months ago), to try to further isolate the effect of incomplete healing of the ACL reconstruction. The range of time to return to sport after ACL reconstruction in this study was 4 to 16 months, with the decision to return based on both clinical grounds and the demands of the competition (many players returned at the start of the season after their injury, at whatever time period from reconstruction that may have been).

There were four ACL injuries that occurred within 12 months of a previous injury, and all of these were noncontact injuries to the recently reconstructed side. There were 17 ACL injuries that occurred in players with a past history of injury (more than 12 months earlier); 7 were to the reconstructed knee and 10 to the contralateral knee.

Variables considered significant in the logistic regression equations were recent history of ACL injury, past history of ACL injury, low rainfall in the city of the match, high evaporation in the city of the match, and higher grade of match (Table 3). Age, weight, and body mass index could not be entered into the equations when the other variables were taken into account. Taller players were found to have a greater risk of noncontact ACL injury in the multivariate equation, even though there was not a significant relationship on univariate analysis. Height was also not significant in the multivariate equation when all ACL injuries were considered (Table 3).

DISCUSSION

This study reveals that players who have sustained a previous ACL injury are at much greater risk of further injury, to both the reconstructed and contralateral knee. Although few players in this study sustained an ACL injury within 12 months of an initial ACL injury, such players were approximately 10 times more likely to suffer a noncontact ACL injury in this period and in all cases (4) the injury was to the same knee. The confidence intervals for risk when the previous injury was recent (within 12 months) slightly overlapped those for old injuries (see Table 3), so it is likely but not certain that there is an increased risk of graft rerupture in the first 12 months. Any increase in risk could be partially attributed to either technical (surgical) failure or graft immaturity. Laboratory studies suggest that an ACL graft is still maturing at 12 months.[14,15] The risk per match exposure was approximately 1 in 100 for those players returning within 12 months, which may be an acceptable risk in some circumstances for a player competing in important games. Even though a very large number of athlete-exposures formed part of this study, there were insufficient cases of early graft rerupture to adequately compare the risks at 4, 6, 8, 10, and 12 months. When enough data become available to statistically compare the risks at these time periods, cli-

TABLE 2
Raw Numbers of Exposures by Injury History (Not Adjusted for Other Risk Factors)

Injury history	Not injured	Injured		All exposures
		Contact	Noncontact	
No previous history	94,609	18	44	94,671
History of ACL reconstruction within 12 months	441	0	4	445
History of past ACL reconstruction (>12 months ago)	5687	2	15	5704
All players	100,737	20	63	100,820

TABLE 3
Analysis of Significant Variables in Logistic Regression Equations

Mechanism	Variable	Analysis[a]			
		B	SE	Risk ratio	95% CI
Noncontact ACL injuries	ACL injury within 12 months	2.43	0.53	11.33	4.02–31.91
	Past ACL injury	1.49	0.30	4.44	2.46–8.01
	Low rainfall in past year	1.05	0.40	2.87	1.30–6.23
	High evaporation in past month	0.94	0.29	2.55	1.44–4.52
	First grade match	0.86	0.35	2.36	1.19–4.68
	Taller player	0.60	0.27	1.83	1.09–3.07
All ACL injuries	ACL injury within 12 months	2.23	0.52	9.32	3.35–25.90
	Past ACL injury	1.29	0.28	3.63	2.12–6.23
	Low rainfall in past year	1.12	0.34	3.06	1.58–5.94
	High evaporation in past month	0.65	0.24	1.91	1.20–3.05
	First grade match	0.92	0.31	2.50	1.38–4.54

[a] B, regression coefficient; SE, standard error; Risk ratio, exp (B); 95% CI, 95% confidence interval.

nicians may be able to recommend a minimum time of return to sport for athletes.

One year or more after ACL reconstruction, players with knee reconstructions still had a greater than fourfold increased risk of noncontact ACL injury compared with players who never had an ACL injury. This increase in risk was divided fairly evenly between the reconstructed side and the contralateral knee (overall there were 11 ipsilateral injuries [4 early, 7 late] and 10 contralateral injuries [all late]). This suggests that there are perhaps genetic or anatomic factors that predispose athletes to recurrent and bilateral injuries, in addition to graft failure. It is possible that players with a history of ACL reconstruction often injured the contralateral knee because they were more likely to pivot using this knee or land on this knee, in preference to their previously reconstructed knee.

It is worth comparing these results with those of a recently published series of skiing ACL injuries.[17] That study found a threefold increase in the risk of injury for a reconstructed knee compared with a never-injured knee, an increase similar to that seen in our current study. Of skiers who had undergone an ACL reconstruction and suffered a new ACL injury, three had injury to the contralateral knee whereas six had injury to the ACL graft. The number of new injuries was not large enough to determine whether there is a different pattern of risk for the contralateral knee in skiing compared with Australian football. Both the Oates et al.[17] study and the current study included very large cohorts but had a small number of ACL reinjuries, highlighting the difficulty of comparing ACL reinjury rates using a prospective method.

We found higher grade of match to be a significant risk factor for ACL injury. This relationship was not as strong as that found in a previous study with the same cohort that considered only extrinsic variables.[19] First-grade players were older (24.7 ± 3.6 years) than second-grade players (21.7 ± 3.3 years) and were more likely (7.0% compared with 3.5%) to have previously undergone an ACL reconstruction, a strong risk factor for reinjury. Increasing player age and weight were significantly associated with ACL injury using univariate analysis (*t*-tests), but not when past injury was taken into account in a logistic regression analysis. In contrast, according to logistic regression analysis there was a weak but probably valid relationship between taller players and risk of noncontact ACL injury. These differences between univariate and multivariate analyses show that as many factors as possible should be considered in analyses to best understand the relationship between risk factors and injury.

Harmon and Dick[8] found no relationship between collegiate division and risk of ACL injury in soccer and basketball players. They did confirm the previous findings of many authors that women have a much higher risk of ACL injury than men when playing the same sports. In Norwegian handball, a higher risk of ACL injury was found in first division players compared with lower division players,[13] and an analysis of Swedish insurance data showed that ACL injuries are much more common at the elite level of sports than at lower divisions.[5] At this stage it is not clear whether a higher level of play is a universal risk factor for ACL injury. No studies to date have found that lower skill and experience increase the risk for noncontact ACL injury, which was previously thought to be a possible reason why women suffer more ACL injuries than do men.

In this study we found a relationship between ACL injury and weather conditions that would be expected to cause a drier playing surface. Increased speed of the game on dry grounds may also be relevant. These results are in keeping with the theory that high shoe-surface traction is a risk factor for noncontact ACL injury. Friction and torsional resistance between football shoes and natural grass has been shown to be higher in dry conditions than in wet conditions.[9]

Analysis of the association between weather conditions, ground conditions, and noncontact ACL injury in other sports is encouraged. We reported an ACL injury incidence of 0.82 per 1000 athlete-exposures during matches, which is higher than that of American football (0.25 per 1000 athlete-exposures during games)[21] and collegiate soccer in the United States (0.33 per 1000 athlete-exposures for women and 0.12 athlete-exposures for men).[1] Most of Australia is in a subtropical climate zone, meaning that dry, hard ground conditions may be more common and a more significant factor in ACL injuries than for

countries in more temperate zones. Prevailing climatic conditions may be partially responsible for the high rate of ACL injury observed in Australian football. In most of the southern USA, Africa, Latin America, and Asia various forms of football are played on natural turf in climates where grounds may be expected to be hard during periods of the season. The review of noncontact ACL injuries in American football was of interest, as it was noted that almost all injuries on natural grass occurred in dry conditions.[21]

Low water evaporation and high rainfall (over a long-term period) significantly lower the risk of noncontact ACL injuries in Australian footballers. The mechanism is likely to be lower shoe-surface traction forces and consequently lower force transmission to the knee in movements such as pivoting (cutting). Consistent extra watering and perhaps covering of grounds during times of high water evaporation (sunny, windy periods with no rain) as well as sowing grass types that result in lower traction may all possibly lower the rate of these devastating and costly injuries. A study is in progress to directly measure ground conditions in the Australian Football League, and it is interesting to note that since ground conditions have been objectively monitored by the ground managers there has been a marked reduction in ACL injuries in the Australian Football League competition.[18]

Previous injury to the ACL is also a strong risk factor for further injury, both to the injured knee and the contralateral knee. The risk for the grafted knee is highest in the first year after reconstruction, but further study is required to determine the safest time to return after such surgery.

ACKNOWLEDGMENTS

The authors thank the Australian Football League, which funds injury surveillance for its competitions, and the medical staff of all Australian Football League teams for collecting data used in this study.

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