ORIGINAL ARTICLE

Rye grass is associated with fewer non-contact anterior cruciate ligament injuries than bermuda grass

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Objective: To assess the contribution of ground variables including grass type to the rate of anterior cruciate ligament (ACL) injury in the Australian Football League (AFL), specifically which factors are primarily responsible for previously observed warm season and early season biases for ACL injuries.
Methods: Grass types used at the major AFL venues from 1992 to 2004 were established by consultation with ground managers, and ground hardness and other weather variables were measured prospectively.
Results: There were 115 ACL injuries occurring in matches during the survey time period, 88 with a non-contact mechanism. In multivariate analysis, use of bermuda (couch) grass as opposed to rye grass, higher grade of match, and earlier stage of the season were independent risk factors for non-contact ACL injury. Ground hardness readings did not show a significant association with ACL injury risk, whereas weather variables of high evaporation and low prior rainfall showed univariate association with injury risk but could not be entered into a logistic regression equation.
Discussion: Rye grass appears to offer protection against ACL injury compared with bermuda (couch) grass fields. The likely mechanism is reduced ''trapping'' of football boots by less thatch. Grass species as a single consideration cannot fully explain the ACL early season bias, but is probably responsible for the warm season bias seen in the AFL. Weather variables previously identified as predictors are probably markers for predominance of bermuda over rye grass in mixed fields.

Knee anterior cruciate ligament (ACL) injuries are generally considered to be among the most severe that regularly occur in many sports.[1–4] Our ability to prevent ACL injuries is limited because there are few known reversible risk factors. Risk factors can be divided into intrinsic (personal) and extrinsic (environmental). This study examines extrinsic risk factors for ACL injury in Australian football.

ACL injuries in the Australian Football League (AFL) have been shown to exhibit a strong early season bias, with the injury rate halving from the early season (late summer and autumn) to the mid-late season (winter).[5] This early season bias has been shown in other football competitions.[6 7] There is also a geographical (warm season) bias in the AFL (which to date has not been reported in other football competitions) whereby the rate of ACL injuries is higher in the northern states than in the more southern state of Victoria.[8 9] Player factors, such as age, weight, and height, and team factors, such as playing at home or playing away, have been shown not to be contributing factors to either the early season or geographical bias in the incidence of ACL injuries.[10] The aim of this study is to progress further from previous work in this cohort to assess the contribution of ground hardness, grass types, and other match and weather variables to the rate of ACL injuries. This may help to determine which of these ground and weather variables are primarily responsible for the previously observed warm and early season biases and eventually may lead to prevention of ACL injuries.

METHODS

Australian football is a sport played between two teams of 18 players (with an interchange bench of four players) on a very large field (usually 2 hectares). Tackling in the upper body region (but not below the waist) is allowed in Australian football. The methods for this study are very similar to those previously used for the same cohort in previously published work.[5 8 10]

The scope of this study was all AFL listed players in AFL competition matches (preseason competition, regular season, and finals) over the seasons 1992 to 2004 inclusive. This included the AFL first grade competition in all years and the AFL reserve grade competition over the years 1992–1999 inclusive. Since 2000, the AFL has not administered a reserve grade competition, with teams allowing players on their lists to compete in separate lower grade competitions in their states. Most games occurred in the cities of Melbourne and Geelong (in the southern state of Victoria) and Perth, Adelaide, Brisbane, and Sydney (in the more northern, warmer states), as shown in table 1. Generally each team has about 40 listed (contracted) players each season. The competing teams have changed over the years such that, in later years, a greater proportion of matches were played in the ''northern'' states compared with the earlier years covered in this study.

Injury definition

The definition of ACL injury for this study required a complete injury in an AFL player that necessitated a knee reconstruction. Very few (<5%) of all recorded ACL injuries in the AFL competition are considered partial, with the player able to resume participation without an ACL reconstruction,[10] and these cases have been excluded from this series.

The mechanism of injury was provided by team doctors or physiotherapists, after speaking with the player and/or reviewing a video of the injury. Mechanisms were classified as ''contact'' and ''non-contact'' on the basis of whether there was direct contact to the injured knee or leg. In Australian football, tackling is only allowed to the upper body, although incidental lower body contact does occur. A mechanism such as a player being tackled to the upper body with the foot fixed in the turf, with the ACL injured by an indirect force, was

Abbreviations: ACL, anterior cruciate ligament; AFL, Australian Football League; NFL, National Football League

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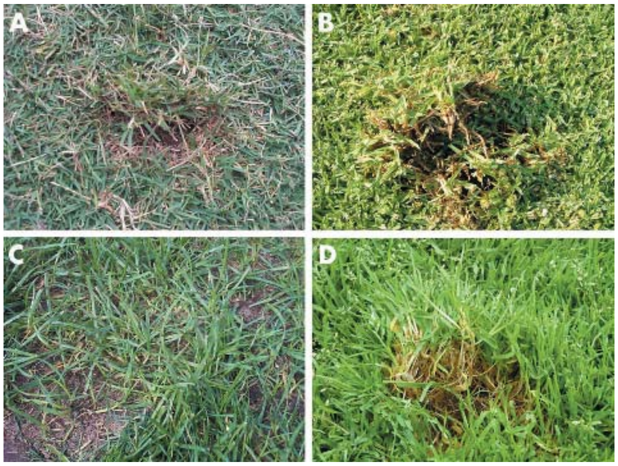

Figure 1 (A) Bermuda (couch) grass surface, showing thick thatch layer between grass leaves and soil. (B) Kikuyu grass, also showing thick thatch layer. (C) Rye grass surface, showing minimal thatch layer. This is probably a safer surface than the others, as the blades or cleats of the football boot are less likely to be ''gripped'' by the surface. (D) Annual blue grass surface, showing moderate thatch layer.

considered to be non-contact. Most of the ACL injuries were non-contact, and these are the main focus of this paper.

Ground, weather, and other match variables

Daily weather variables of rainfall and evaporation were obtained for cities where games had been played from the Bureau of Meteorology (Sydney, Australia). The composite variables of ''Previous month's evaporation'' and ''Previous year's rainfall'' were calculated from daily variables. These composite variables were chosen as they have been identified as predictors of ACL injury in this cohort previously, with similar methods used.[5 10] Rainfall in the previous 12 months was categorised as ''high'' and ''low'' based on whether there had been more or less than 600 mm of rainfall in the previous year. Generally the cities of Adelaide and Perth have low annual rainfall (<600 mm), the cities of Brisbane and Sydney have high annual rainfall (>600 mm), with the cities of Melbourne and Geelong varying depending on whether the previous year has been relatively wet or dry. Evaporation in the previous month was subdivided into ''high'' and ''low'' based on whether there had been more or less than 48 mm of water evaporation in the previous 28 days. Generally all cities in the study had high monthly evaporation in summer and early autumn (fall), with monthly evaporation becoming low in mid-autumn in the Victorian cities, but persisting as high in the more northern cities into late autumn.

Ground hardness was measured at the match venue by the penetrometer using the first drop technique, as previously described.[8] A first drop of 2.5 cm or less was considered to be a ''firm'' surface, 2.6–3.0 cm was considered to be a ''medium'' surface, and 3.1 cm or greater was considered to be ''soft''.

All AFL matches are played on a natural grass surface. Grass types used at the major AFL venues from 1992 to 1999 were retrospectively established in 1999 by consultation with ground managers at each venue. Thereafter they were recorded prospectively. Grass types for each ground season were subdivided as follows.

(1) Bermuda grass (couch), with *Cynodon dactylon* (or its hybrid species) making up more than 75% of the visible grass surface for the entire season (fig 1A)
(2) Kikuyu grass, with *Pennisetum clandestinum* making up more than 75% of the visible grass surface for the entire season (fig 1B)
(3) Rye grass, with *Lolium perenne* making up more than 75% of the visible grass surface for the entire season (fig 1C)
(4) Rye/annual blue grass mix, with a combination of rye grass (*Lolium perenne*) and annual blue grass (*Poa annua*) making up more than 75% of the visible grass surface for the entire season (fig 1D)

Bermuda and kikuyu grasses are warm season grasses, whereas rye and annual blue grass are cool season grasses.[11]

Table 1 Major stadiums in the analysis

Ground name	Location	Predominant grass type(s)	Other notes
Telstra Dome	Melbourne, Vic	Bermuda and rye grass	Partially indoors, as stadium has a retractable roof; rye predominant from April
Skilled Stadium	Geelong, Vic	Rye and annual blue grass (1992–97); rye grass (1998–03)	
MCG	Melbourne, Vic	Bermuda and rye grass	Rye predominant from May
Optus Oval	Melbourne, Vic	Rye and annual blue grass (1992–96); rye grass (1997–03)	
Waverley Park	Melbourne, Vic	Annual blue grass and rye grass (1992–1995); rye grass (1996–2000)	
SCG	Sydney, NSW	Bermuda and rye grass	Rye predominant from June
Gabba (BCG)	Brisbane, Qld	Bermuda grass (1992–99), bermuda and rye grass (2000–2004)	Rye predominant from June (since 2000)
Football Park	Adelaide, SA	Bermuda, rye and annual blue grass (1992–1998), rye and annual blue grass (1999–2002), rye grass (2003–04)	Rye (± annual blue grass) predominant from May
Subiaco Oval	Perth, WA	Kikuyu grass (1992–1994); bermuda grass (1994–1998, 2001), bermuda and rye grass (1999–2000, 2002–04)	Rye predominant from June (since 1999)
WACA	Perth, WA	Bermuda grass	

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Table 2 Onset of anterior cruciate ligament (ACL) injuries by season

Season	AFL matches (non-contact*)	Other matches	Training sessions	Outside football	Total in matches
1992	12 (10)	4	2	0	16
1993	5 (4)	2	1	0	7
1994	7 (5)	6	2	0	13
1995	12 (9)	2	1	0	14
1996	12 (6)	7	3	0	19
1997	18 (15)	3	2	0	21
1998	11 (10)	4	2	0	15
1999	6 (5)	2	0	0	8
2000	4 (1)	4	0	0	8
2001	11 (8)	6	2	0	17
2002	6 (5)	9	3	1	15
2003	5 (4)	6	1	0	11
2004	6 (6)	3	2	0	9
1992–2004	115 (88)	58	21	1	173

The number of complete ACL injuries occurring to Australian Football League (AFL) players are shown. Values in parentheses are the number of ACL injuries in AFL matches that occurred with a non-contact mechanism.

When a grass profile was made up of a combination of warm season and cool season grasses, the warm season grass was considered to be the predominant species in the months when the average overnight minimum was >10℃. The cool season grass(es) were considered to be predominant in the months when the average overnight minimum was ⩽10℃. Therefore all combinations of warm and cool season grasses could be classified according to 1–4 above depending on the month of the year. Table 1 lists the months in which the cool season grasses were considered to have become predominant at each stadium. The only exception to the 10℃ rule cited above was at Telstra Dome in Melbourne, which uses bermuda and rye grass. Rye was considered to have been predominant from April (rather than May, which was the cut-off month for the other Victorian grounds). This is because Telstra Dome is a partially indoor stadium with a retractable roof, where bermuda grass becomes dormant earlier than it would otherwise in the same climate, because of the relative lack of sunlight.

The Sydney Cricket Ground (SCG) and ''Gabba'' ground (Brisbane Cricket Ground) have had a cricket wicket area in place during most of the years of this study, with the WACA ground in Perth and many of the Victorian grounds also having cricket wicket blocks before 1999. During the football season, the cricket wicket area is effectively a section of the field that is significantly harder than the surrounding regions. The grass cover on the cricket wicket section is usually good during the football season (as compared with the cricket season where it is deliberately mown very short to prepare cricket pitches). The presence or absence of a cricket wicket area is taken into account in the analysis.

Since 1999, the official statistical providers for the AFL, Champion Data (Melbourne, Australia), have kept records on match day as to whether there was rain during the actual match and whether the ground was wet or dry. In the presence of heavy dew, the ground can sometimes be wet even though it is not raining.

A match was considered a ''night'' match if artificial lighting was required by the start of the second half of a match and a ''day'' match if it was played mainly under natural light. The AFL season generally runs from February (preseason, in late summer) to September (finals, in early spring). For this analysis, a match was considered an early season match if it was played in the months before May and a late season match if it was played in May or later.

Data analysis

All ground, weather, and match variables were converted (where necessary) into discrete categories to allow risk comparison of categories to be presented with 95% confident intervals (CIs). Univariate comparisons were performed in Microsoft Excel using a Taylor Series expansion technique to calculate 95% CI.[12] To consider the effects of confounding, multivariate analysis was performed with the SPSS program[13] using a logistic regression forward stepwise technique, with a significance of 0.05 to enter the equation.

RESULTS

Table 1 lists the major stadiums at which matches were played in this series, along with their locations and predominant grass types.

There were 115 ACL injuries occurring in matches during the survey time period, 27 with a mechanism involving direct contact with the knee or leg, and 88 with either no player to player contact or an indirect contact mechanism, which were designated non-contact injuries (table 2).

Table 3 details univariate associations of ground, match, and weather variables with the risk of a non-contact ACL injury. There were fairly strong associations with injury risk for grade of match (higher grade having greater risk), location of match (northern venue having greater risk), grass type (bermuda grass having greater risk), previous month's evaporation (higher values having greater risk), and stage of season (early season matches having greater risk). Low previous year's rainfall exhibited a trend towards increased ACL injury risk which was bordering on significant.

There were strong correlations between many of these variables, and therefore multivariate analysis was performed. Using a multivariate technique, only grade of match, grass type, and stage of season were significant predictors, with the match location and weather variables no longer being significant predictors (tables 4 and 5). When this analysis was repeated for all 115 ACL injuries (and not just the 88 non-contact injuries), only grade of match and grass type were significant predictors of ACL injury, with stage of season not significant. In this analysis, bermuda grass type has a stronger association with injury (relative risk 1.87, 95% CI 1.26 to 2.77) with stage of season not in the equation, as there is an internal correlation between bermuda grass and stage of season ($r = 0.406$, $p<0.001$). In the non-contact logistic regression analysis, after step 2 (before stage of season has been entered into the equation), bermuda grass has a stronger association with non-contact injury (relative risk 2.13, 95% CI 1.37 to 3.31). This naturally weakens after the stage of the season is entered into the equation because of their internal correlation.

Table 3 Univariate analysis of risk factors for non-contact anterior cruciate ligament (ACL) injuries

Risk factor	Matches played	Non-contact ACL injuries	Non-contact ACL rate per 1000 team games	Relative risk	95% CI
Location					
Victorian	2622	50	9.5	Ref	
Northern	1013	38	18.8	1.97	1.28 to 3.02
Grade					
First grade	2581	78	15.1	Ref	
Reserve grade	1054	10	4.7	0.31	0.16 to 0.61
Cricket wicket area					
Yes	1538	37	12.0	Ref	
No	2097	51	12.2	1.01	0.66 to 1.55
Enclosed roof					
Yes	252	6	11.9	Ref	
No	3383	82	12.1	1.02	0.44 to 2.36
Time of game					
Night	978	29	14.8	Ref	
Day	2657	59	11.1	0.75	0.48 to 1.18
Previous month's evaporation					
High (>48 mm)	1891	63	16.7	Ref	
Low	1530	19	6.2	0.37	0.22 to 0.63
Unknown	214	6			
Previous year's rainfall					
High (>600 mm)	2010	40	10.0	Ref	
Low	1410	42	14.9	1.50	0.97 to 2.32
Unknown	215	6			
Ground hardness					
Firm	263	7	13.3	Ref	
Medium	355	9	12.7	0.95	0.35 to 2.59
Soft	335	8	11.9	0.90	0.32 to 2.51
Unknown	2682	64			
Rain during match					
None (dry ground)	1144	34	14.9	Ref	
None (wet ground)	65	3	23.1	1.55	0.46 to 5.19
Heavy rain	36	1	13.9	0.93	0.12 to 7.02
Light rain	98	2	10.2	0.69	0.16 to 2.90
Unknown	2292	48			
Primary grass type					
Bermuda	758	34	22.4	Ref	
Kikuyu	23	1	21.7	0.97	0.13 to 7.39
Rye	1725	34	9.9	0.44	0.27 to 0.71
Rye/annual blue grass mix	700	15	10.7	0.48	0.26 to 0.88
Unknown	429	4	4.7		
Stage of season					
Early (Feb–Apr)	996	40	20.1	Ref	
Late (May–Sept)	2639	48	9.1	0.45	0.30 to 0.69

DISCUSSION

This study progresses further from previous work on the same cohort, showing that the grass types used on stadium fields, more so than ground hardness, are most likely to be responsible for the early season and warm season biases for ACL injuries that were previously noted. The variable for grass type is a stronger predictor of injury than the weather variables of previous evaporation and rainfall, suggesting that these weather variables are not true predictors of injury but merely indicators of the grass profile. High rainfall and low evaporation favours the promotion of rye over bermuda grass in the climates generally found in Australia.

In this analysis, grade of match appeared to be the strongest predictor of injury. However, previous multivariate analysis on this cohort taking intrinsic factors into account showed that confounding was partially responsible for this finding.[10] Previous ACL injury is a very strong risk factor for both ipsilateral and contralateral ACL injury, and players who are in first grade matches were more likely to have had a past history of injury than players in reserve grade matches (who are generally younger). Being a first grade match had a risk ratio of 2.36 (95% CI 1.19 to 4.68) in this cohort when intrinsic variables had been accounted for.[10] There is also a potential bias that there may have been a small number of non-AFL listed players who were participating in AFL reserve grade matches that may have suffered ACL injuries which were not captured by this surveillance system. These problems with analysing grade of match as a risk factor are not critical, as it is a relatively unimportant injury risk given that it is completely non-reversible. By contrast, attrition of injury prone players from the cohort through early season injuries did not appear

Table 4 Logistic regression risks for non-contact anterior cruciate ligament injury

Variable	p Value	Relative risk	95% CI low	95% CI high
First grade game	0.003	2.805	1.436	5.481
Bermuda grass predominant	0.037	1.679	1.031	2.734
Early stage of season	0.025	1.722	1.072	2.768

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Table 5 Non-significant variables with respect to non-contact anterior cruciate ligament injury

Variable	p Value
Hard surface	0.307
Victorian match	0.173
Enclosed stadium	0.593
Night match	0.871
Low rainfall in past year	0.234
High evaporation in past month	0.259

to be a major cause of the early season bias in the previous analysis.[10]

Although only a minority of matches in this analysis had a measurement of ground hardness available, and notwithstanding criticisms of the use of the penetrometer as a device to measure hardness,[8 14 15] the relation between ground hardness and ACL injury risk appears to be weak in the AFL competition. Where penetrometer readings have been taken on AFL grounds, most first drop readings have been between 2.0 and 4.0 cm.[8] Hardness readings taken at AFL grounds using a Clegg hammer (with a 2.25 kg mass dropped from 45 cm) have been between 40 and 120 gravities.[16] In recent seasons, Clegg hammer readings have shown trends towards being higher at Victorian venues than northern venues and being higher later in the season, which are the opposite to what would be expected if hardness were a significant risk for ACL injury.[16] Furthermore, there was also no relation seen in our study between the presence of a cricket wicket area and ACL injury risk, which would have been expected if hardness was a major risk factor.

Despite the fact that hardness may not be highly relevant to ACL injury risk in the AFL competition, grounds in this competition only display a limited range of hardness measurements. Astroturf, very dry natural grass fields in relative droughts which have not been watered, and frozen natural grass fields may all be significantly harder than 120 gravities as measured by the Clegg hammer.[17–19] Football matches of various types are played on these sorts of fields on various occasions, although none of these field types are relevant to the AFL competition. It is beyond the scope of this study to exclude an increased risk of ACL injury on a surface with hardness greater than 120 gravities.

Rye grass appears to offer protection against ACL injury compared with bermuda grass, and this factor appears to be chiefly responsible for the previously observed northern bias for ACL injury in the AFL competition. Grass species as a single consideration may not be able to fully explain the ACL early season bias, as stage of season appears to still be relevant as a risk factor even when grass type is taken into account. It may be possible that intrinsic factors are relevant to the early season bias—for example, in the early season players have had more recent weight training in the gym than football specific drills. It is also possible that, within grass species, characteristics of the turf that are relevant to injury risk, such as thatch depth, change over the course of the season.[16 20] This may be related to a higher incidence of ACL injuries at the start of the season when greater depths of thatch may "trap" players' boots preventing free rotation of the foot and placing more stress on knee ligaments. This hypothesis may also explain the early season bias observed in other football codes where different grass profiles are used.

The results of this study can be compared with the results of a similar study involving the National Football League (NFL) competition of American football.[6] In the NFL, there is an early season bias for ACL injuries on natural grass fields and on astroturf surfaces in the open air. There is little or no early season bias for ACL injuries in domes (astroturf surfaces in indoor stadiums, where the temperature is constant throughout the year). This correlation between ACL injury risk on astroturf and warmer temperatures, along with the observation from another study that shoe-surface traction on astroturf is greater in warmer conditions,[21] suggests that increased shoe-surface traction leads to an increased ACL injury risk.[6 7 21]

It is notable that in the NFL competition, on natural grass fields, there is no warm season (or southern) bias for ACL injuries.[6] Most NFL stadiums in the southern states use bermuda grass oversown with rye grass, whereas in the northern states most stadiums use primarily Kentucky blue grass (*poa pratensis*), which has superior ability to withstand frozen conditions over rye grass. It is a confounding factor that, in the north, the natural grass grounds may become frozen during the later months of the season. This lack of correlation of temperature on natural grass (by location rather than by month) with ACL injury risk in the NFL suggests that on natural grass surfaces, grass types are more relevant than just raw temperature variables. It also suggests that perhaps Kentucky blue grass may have a higher ACL injury risk than rye grass.

McNitt *et al*[22] have reported that perennial rye grass is associated with lower shoe-surface traction than Kentucky blue grass. This is probably because Kentucky blue grass has a lateral growth habit and forms a significant thatch layer, compared with rye grass, which has a "bunch-type" growth and produces relatively little thatch.[11] Rye grass is considered to lead to lower shoe-surface traction than bermuda grass[8 9 23] because it creates less thatch and does not have a lateral growth habit, which may create excess traction between the shoe cleats and grass layer.

A confounding factor could be the operation of oversowing of rye grass, which usually involves the scarification of the bermuda grass to create a suitable seedbed. It is possible that this scarification activity is on its own reducing the risk of bermuda grass by reducing the thatch and by cutting the lateral growth into smaller segments.

Although there are other potential confounders, it appears that rye grass generally offers a safer surface with respect to ACL injuries for Australian football than bermuda grass and perhaps some other grasses. The likely mechanism is a

What is already known on this topic

- Increased shoe-surface traction is a potential risk factor for non-contact ACL injury
- Warmer and drier weather conditions can lead to increased shoe-surface traction and hence may be associated with greater ACL injury risk

What this study adds

- Grass type and characteristics probably have a greater effect on ACL injury risk than ground hardness. In particular, bermuda grass may lead to higher shoe-surface traction and higher ACL injury risk, whereas rye grass may lead to lower injury risk
- The characteristic that most differentiates these grass types is the extra production of thatch by bermuda grass

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shallower thatch layer leading to lower shoe-surface traction on more occasions (fig 1).

Unfortunately, reducing the ACL injury rate is not simply a matter of mandating that all Australian football grounds use rye grass. Rye grass is poorly tolerant of heat, drought, and extreme cold, and pure rye grass is less tolerant of wear than a combination of bermuda and rye grass. There may possibly be other injuries that could be increased by use of rye grass (although none of these have been noted to date), and the spectacle of the game may be affected by increased slippage of players on rye grass surfaces. However, turf managers should be aware of the trends observed in this study and should consider promoting rye grass and trying to reduce the amount of thatch where possible. As can be seen from tables 1 and 2, there have been trends towards the increased use of rye grass on AFL grounds since 1999 and also a slight decrease in the numbers of ACL injuries since 1999.

Because the interactions of grass type, player choice of boot, and shoe-surface traction are not well understood, it is still premature to make any strong recommendations about acceptable ground conditions with respect to safety in preventing ACL injuries. A randomised controlled trial would be the best method to determine conclusively whether changing ground conditions can prevent injury. This is not practical within the framework of a professional competition such as the AFL, and would be very expensive to conduct in an amateur competition. The AFL will continue to monitor ground conditions and report injury rates. Hopefully there will be a sustained decrease in the incidence of ACL injuries, in association with a historical non-randomised change in the way that grounds were prepared. This ongoing link would give stakeholders good reason to invest in a randomised control trial to further assess the relation between grass type and injury. It would also hopefully lead to further developments in turfgrass technology, such as improved cultivars of rye grass better able to withstand extremes of temperature and cultivars of bermuda grass that produce less thatch.

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