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Incidence, Mechanisms, and Severity of Game-Related College Football Injuries on FieldTurf Versus Natural Grass

A 3-Year Prospective Study

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Background: Numerous injuries have been attributed to playing on artificial turf. More recently, FieldTurf was developed to duplicate the playing characteristics of natural grass. No long-term studies have been conducted comparing game-related collegiate football injuries between the 2 playing surfaces.

Hypothesis: Collegiate athletes do not experience any difference in the incidence, mechanisms, and severity of game-related injuries between FieldTurf and natural grass.

Study Design: Cohort study; Level of evidence, 2.

Methods: Twenty-four universities were evaluated over 3 competitive seasons for injury incidence, injury category, time of injury, injury time loss, player position, injury mechanism, primary type of injury, grade and anatomical location of injury, type of tissue injured, trauma (head, knee, and shoulder), and environmental factors.

Results: In sum, 465 collegiate games were evaluated for game-related football injuries sustained on FieldTurf or natural grass during 3 seasons. Overall, 230 team games (49.5%) were played on FieldTurf versus 235 team games (50.5%) played on natural grass. A total of 2253 injuries were documented, with 1050 (46.6%) occurring during play on FieldTurf, and 1203 (53.4%) on natural grass. Multivariate analysis per 10 team games indicated significantly lower total injury incidence rates, $F(3, 2249) = 3.468$, $P = .016$, $n - \beta = 0.778$, on FieldTurf, 45.7 (95% confidence interval [CI], 44.2-46.3), versus natural grass, 51.2 (95% CI, 49.8-51.7). Significantly lower minor injury incidence rates, 38.0 (95% CI, 36.9-38.5) versus 39.9 (95% CI, 39.1-40.0, $P = .001$), substantial injury incidence rates, 5.0 (95% CI, 4.3-5.6) versus 7.2 (95% CI, 6.6-7.7, $P = .020$), and severe injury incidence rates, 2.7 (95% CI, 2.1-3.3) versus 4.1 (95% CI, 3.5-4.1; $P = .049$), were documented on FieldTurf versus natural grass, respectively. Multivariate analyses also indicated significantly less trauma on FieldTurf when comparing injury time loss, injury situation, grade of injury, injuries under various field conditions, and temperature. No significant differences in head, knee, or shoulder trauma were observed between playing surfaces.

Conclusion: FieldTurf is in many cases safer than natural grass. It must be reiterated, however, that the findings of this study may be generalizable to only this level of competition. Because this study is still in the early stages, investigation is ongoing.

Keywords: artificial surface; knee; head; trauma

For more than 40 years, numerous studies have attributed a greater risk and incidence of articular and concussive trauma to playing on artificial turf when compared with natural grass.[21,32,55] Over the past decade, however, a new generation of synthetic surface was developed to duplicate the playing characteristics of natural grass: FieldTurf (Montreal, Quebec, Canada) is composed of a polyethylene fiber blend stabilized with a graded silica sand and cryogenically ground rubber infill. Although FieldTurf has been recommended as a viable option to natural grass in the prevention of high school football injuries,[40] research into its long-term effects on injuries at the collegiate level, during actual game conditions over several seasons of competition, has not been published in the scientific literature.

More than 1 million athletes play competitive football.[23,43] The number of knee surgeries is rising, and their

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cost plus rehabilitation is reaching into the millions of dollars each year.[12,20,24,35,48,54] Coupled with this is the psychological trauma and setbacks in training typically experienced by athletes after a significant injury.[41] As such, efforts to address ways to minimize predisposition to injury are warranted. Therefore, the purpose of this study was to quantify the incidence, mechanisms, and severity of game-related collegiate football injuries on FieldTurf versus natural grass. It was hypothesized that collegiate athletes would not experience any difference in the incidence, mechanisms, and severity of game-related injury between FieldTurf and natural grass.

MATERIALS AND METHODS

Population

Twenty-four universities, classified Division IA (FBS) by the National Collegiate Athletic Association, were evaluated for game-related football injuries sustained on FieldTurf and natural grass during a 3-year period (2006-2008). School selection was based on the availability of both playing surfaces during the competitive season, uniformity of sport skill level, and the presence of a full-time certified athletic training (ATC) staff, thereby minimizing the potential for injury reporting bias.[11,49] The study started with 11 universities over the first year and added 13 in year 2, yielding a total of 520 seasonal games. With the exception of deleting games played on other artificial surfaces (n = 55), selection bias was avoided by reporting all remaining games and subsequent injuries on either FieldTurf or natural grass. This resulted in a total of 465 games over the 3-year period played on either FieldTurf (n = 230) or natural grass (n = 235).

Various stadiums using FieldTurf were used by all 24 schools during home and away games involving conference play in the Atlantic Coast, Big 12, Big East, Conference USA, Mountain West, Western Athletic Conference, and Pac-10. FieldTurf surfaces were considered high-quality surfaces by the ATCs. Different natural grass fields were used across the same geographical region, with similar quality and environmental influences. All teams had the opportunity to practice on either FieldTurf or natural grass.

To quantify the history and potential influence of prior injuries, all athletes underwent preparticipation physical examinations under the care of their team physicians/orthopaedic surgeons. Criteria for exclusion included (1) any known preexisting congenital or developmental factor that predisposed an athlete to potential injury and (2) the acknowledgment, complaint, or observed evidence of any medical or orthopaedic problem severe enough to compromise an athlete's performance or endanger his health as determined by self-response, medical history, and interview.[40]

Procedures

Based on paradigms suggested in prior research,[4,19,33,39,63] this research used a multifactorial approach that encompassed teams playing on both surfaces during the same period. This approach provided several advantages, including gaining a greater comparison of the nuances of each surface's influence on injury, avoiding limitations in data collection (eg, seasonal variation, subject randomization by surface), and minimizing difficulties that former studies have had in analyses and interpretation of findings.[4,47] For this prospective cohort study, a 2-sided single-page injury surveillance form was developed, based on criteria recommended and established in the literature (available as an appendix at http://www.ajs.sagepub.com/supplemental).[13,25,33,40,42,44] The form includes the following: athletic identification number; athletic trainer; date of injury; athlete weight; university; type of playing surface; surface quality; temperature at game time; year and skill level of athlete; where the injury occurred; weather and field conditions; injury category; time of injury; injury classification; injury time loss; position played at time of injury; injury situation; injury mechanism; personnel determining the injury; injury site location; principle body part; primary type of injury; grade of injury; occurrence of external bleeding; injury because of illegal action; head, eye, knee, shoulder, and thoracic/abdominal diagnosis; surgical intervention and time; and musculoskeletal, joint, or organ location of injury. The injury surveillance form was e-mailed to the head ATCs during the summer before the start of the football season. Communication was maintained to discuss potential concerns and ensure accuracy of collection, comprehensiveness of information, and ease of application.

The respective ATCs for each university were approached because of their daily interaction with the athletes and coaches during and after sport trauma and because of their expertise in injury recognition.[11,40] During the summer before the football season, all ATCs were provided with an overview of the purpose, procedures, benefits, time demands, and importance of the study. They were also provided with copies of the injury surveillance form and detailed instructions for completion to avoid the potential for performance and detection biases.[47,49] After full explanation, all ATCs appeared enthusiastic and agreed to participate in the data collection. The protocol was approved by the institutional review board at the university in which the study was based, and it was conducted in accordance with the guidelines for use of human participants as stipulated by the American College of Sports Medicine.[2]

All regular season conference and nonconference games and postseason bowl games were included. Injury data were recorded after game completion, with support from ATC notes to avoid lapse of memory leading to inaccuracy or response distortion.[40,47] All game-related injuries were evaluated by the attending head athletic trainer and team physicians on-site and, subsequently, in the physician's office when further follow-up and treatment were deemed necessary. Any sport trauma that occurred toward the end of the competitive schedule was monitored beyond the player's specific season to determine date of recovery and functional return to play.[22,40]

Completed injury surveillance forms were faxed to us within 5 working days after a game and were entered into the database before the next game. A follow-up telephone visit was used to obtain any additional information

pertaining to any changes or additions in diagnosis, treatment, or time to return to play. To avoid the potential for on-the-field detection bias,[49] a single-blind outcome approach was maintained throughout the study period, with total data collection, compilation, and analyses limited to the data coordinator.

Definitions

Although any definition of injury and level of trauma lacks universal agreement and has its shortcomings,[11,24,44,47] this study attempted to define injury based on a combination of functional outcome, observation, and treatment.[11,22,40,44,60] A *reportable injury* was thus defined as any game-related football trauma that resulted in (1) an athlete missing all or part of a game, (2) time away from competition, (3) any injury reported or treated by the athletic trainer or physician, and (4) all cranial/cervical trauma reported.[24,40] Although some authors have recommended omitting minor injuries,[44,47] others have expressed a need to quantify and track these typically overlooked minor traumas to avoid underreporting of injury and to monitor those that may turn into chronic or overuse problems.[14,25,42,66] Prior studies have also revealed that 42% to 60% of competitive trauma results in minimal time loss and medical cost.[24,40,63] Therefore, a definition that included functional outcome, observation, and treatment on all injuries might more clearly quantify the unique nuances or trauma observed with each playing surface and so reduce the individual and player bias that allegedly influences injury reporting based solely on time loss.[40,47]

Injury time loss was based on the number of days absent from practice or game competition and was divided into 0, 1-2, 3-6, 7-9, 10-21, and 22 days or more of recovery time. Not surprisingly, a review of the literature revealed high subjectivity in the determination of what constitutes moderate or severe injury. Whereas any injury resulting in time loss of approximately 7 to 28 days has been considered moderate trauma and a time loss of $\geq$21 days has been defined as severe,[16,26,27,63] others have defined severe injury as $\geq$28 days before return to play[15] or any injury resulting in $\geq$7 days of time loss.[25,33,46,53] Furthermore, what constitutes a moderate injury in one athlete (eg, elbow injury in an offensive lineman) may be considered severe when diagnosed in another (eg, the throwing arm of a quarterback).[5,53] Therefore, as previously described, any trauma that required 0 to 6 days of time loss was defined as a *minor injury*; an injury that required 7 to 21 days of time loss, resulting in the athlete's being unable to return to play at the same competitive level, was a *substantial injury*; and trauma that required 22 or more days of time loss was a *severe injury*.[40] The delineation and subsequent analysis of minor, substantial, and severe injury served to minimize potential time loss bias.[11,40,60]

Injury category was quantified by player-to-player collision, player-to-turf collision, injuries attributed to shoe-surface interaction during player contact, injuries attributed to shoe-surface interaction without player contact, and muscle-tendon overload. Time of injury by pregame and game quarter of play was documented to delineate the influence of fatigue over time from the potential surface influence on injury occurrence.[40,63,66]

Acute trauma was delineated from recurrent and overuse injury according to criteria previously published,[36,39,40,62] with acute trauma linked to an incidence that occurred during a competitive game versus repetitive exposure resulting in symptoms and injury to the same location during the season (recurrent). An *overuse injury* was defined as repetitive exposure resulting in trauma and sequelae with no definitive onset.[39,66]

To enhance optimal cell size and interpretation, the 23 player positions were condensed and analyzed by offense, defense, and special teams, as well as by power and skill positions (quarterback, backfield, offensive line, tight end, receiver, defensive line, linebacker, secondary).[8] *Mechanism of injury* was defined as that occurring while a player was blocked above or below the waist, tackled above or below the waist, blocking, tackling, impacting with the playing surface, stepped on, fallen on or kicked, sprinting or running with no player contact, catching/blocking a pass, clipped, experiencing heat illness, or injured from overuse. *Injury situation* was defined as trauma occurring during a specific play or event, such as warm-up, rushing, passing, pass catching, pass protection, pass rush, pass defense, kickoff return, point after touchdown, field goal, kickoff, punting, punt return, or fumble recovery.

To optimize analyses, primary type of injury was combined into the following categories: surface/epidermal (abrasion, laceration, puncture wound), contusion, concussion, inflammation (bursitis, tendinitis, fasciitis, synovitis, capsulitis, apophysitis), ligament sprain, ligament tear, muscle strain/spasm, muscle tear, cartilage tear, tendon strain, hyperextension, neural (burner, brachial plexus), subluxation/dislocation, and fracture (standard, epiphysial, avulsion, stress, osteochondral). Injuries were also defined according to grade (1, 2, or 3). Anatomical location of injury was combined from 40 physical areas and analyzed by type of trauma (cranial/cervical, upper extremity, thoracic, and lower extremity) and further analyzed by type of tissue injured (bone, joint, muscle, neural, other). Cranial/cervical trauma included grade 1 to 3 concussion, hematoma, postconcussion and second-impact syndromes, neurological sequelae (eg, stingers/burners, transient quadriplegia), vascular or dental injury, or associated fractures, sprains, and strains.[40] Neural trauma was restricted to any injury involving only concussion, associated syndromes, and neurological sequelae. Because of growing concerns addressing excessive head, knee, and shoulder trauma in football,[11,20,40,47] these areas were identified for further analyses (see Appendix 1, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

Although studies have associated a greater rate of injury during competition under both dry and normal surface conditions,[3,52] there has been limited information on factors such as weather and the effect of playing under surface conditions that influence injury frequency.[1,3,20,31,40,61] Therefore, environmental factors, such as field conditions and temperature, were obtained before game time by each team's respective ATC and/or through the local airport climatic data center to ascertain the potential influence on

injury from changes in weather and surface conditions throughout the season.[45]

Statistical Analyses

Because of variations in the frequency of injury within several categories potentiating inadequate cell size, statistical power, and limitations on analysis, some data were combined during the 3-year period based on prior recommendations in the literature.[33,40,44] This step resulted in the following categories: injury category, time of injury, injury classification, injury time loss, position played at time of injury, injury mechanism, injury situation, injury site location, primary type of injury, grade of injury, anatomical location of injury, type of tissue injured, head diagnosis, knee diagnosis, shoulder diagnosis, specific lower extremity joint and muscle trauma, and environmental factors. Tabular-frequency distributions were computed for data in each category using SPSS 15.0. For ease of interpretation, the percentages of total injuries within each category that occurred on the playing surface were calculated, and 95% confidence intervals (95% CIs) were determined as described elsewhere.[51]

Because most universities schedule a similar number of games each season, exposure to injury was defined in terms of team games, as previously recommended.[40,63] Based on this definition, and to approximate a standard season, injury incidence rate (IIR) was expressed using (1) injuries per 10 team games = (number of injuries/number of team games) $\times$ 10 and (2) injuries per team game = number of injuries/number of team games.

To achieve a more thorough understanding beyond traditional frequency analyses and to eliminate the possibility of irrelevant sources of error,[37,39] following the season, data were numerically recoded, grouped by playing surface (FieldTurf, natural grass), and subjected to multivariate analyses of variance and Wilks lambda criteria using general linear model procedures.[37] Data screening indicated no violations of multivariate normality, linearity, outliers, homogeneity of variance, multicollinearity, or singularity.[59] When significant main effects were observed, univariate post hoc procedures were performed within each dependent variable based on the total percentage of injuries reported on each playing surface. An experiment-wise type I error rate of .05 was established a priori, and least squared means procedures were required because of the uneven number of observations on which to compare differences between variables. Statistical power analyses ($n - \beta$; n-size calculations) were performed at the P value selected to establish significance in this study.

RESULTS

Injury Incidence

A total of 465 collegiate games were evaluated for game-related football injuries sustained on FieldTurf and natural grass during 3 seasons (Table 1). Overall, 230 team games were played on FieldTurf (49.5%) versus 235 team games played on natural grass (50.5%). A total of 2253 injuries were documented, with 1050 (46.6%) occurring during play on FieldTurf as compared to 1203 (53.4%) on natural grass.

When IIRs were compared between types of playing surface, there was a significant main effect, $F(3, 2249) = 3.468$, $P = .016$, $n - \beta = .778$, between surfaces by injury level. Total injuries per 10 team games, 45.7 (95% CI, 44.2-46.3) versus 51.2 (95% CI, 49.8-51.7), and injuries per team game, 4.6 (95% CI, 4.4-4.6) versus 5.1 (95% CI, 5.0-5.2), were documented on FieldTurf versus natural grass, respectively. When minor trauma (injuries requiring 0 to 6 days of rehabilitation) was compared, a significantly lower incidence of minor injuries ($P = .0001$) per 10 team games, 38.0 (83.3%; 95% CI, 36.9-38.5) versus 39.9 (78.0%; 95% CI, 39.1-40.0), and injuries per team game, 3.8 (95% CI, 3.7-3.9) versus 4.0 (95% CI, 3.9-4.0), was documented on FieldTurf versus natural grass, respectively. When substantial trauma (injuries requiring 7 to 21 days of injury rehabilitation) was compared between type of playing surface, a significant lower incidence of substantial injuries ($P = .020$) per 10 team games, 5.0 (95% CI, 4.3-5.6) versus 7.2 (95% CI, 6.6-7.7), and injuries per team game, 0.50 (95% CI, 0.43-0.56) versus 0.72 (95% CI, 0.66-0.77), was documented on FieldTurf versus natural grass, respectively. When severe trauma (injuries requiring 22 or more days of injury rehabilitation) was compared between type of playing surface, a significantly lower incidence of severe injuries ($P = .049$) per 10 team games, 2.7 (95% CI; 2.1-3.3) versus 4.1 (95% CI, 3.5-4.7), and injuries per team game, 0.27 (95% CI, 0.21-0.33) versus 0.41 (95% CI, 0.35-0.47), was documented on FieldTurf versus natural grass, respectively.

The majority of trauma comprised acute injuries on both FieldTurf (88.7%; IIR = 40.5; 95% CI, 39.5-40.8) and natural grass (88.0%; IIR = 45.1; 95% CI, 43.6-45.7). Only 119 of 1050 injuries reported on FieldTurf (11.3%; IIR = 5.2; 95% CI, 4.5-5.8) and 144 of 1203 reported on natural grass (12.0%; IIR = 6.1; 95% CI, 5.5-6.7) were classified as recurrent trauma or complications from prior injury. As expected, upperclassmen received the majority of trauma on both playing surfaces. On FieldTurf, 330 injuries occurred to seniors (31.4%; IIR = 14.3; 95% CI, 13.5-15.0), 371 to juniors (35.3%; IIR = 16.1; 95% CI, 15.3-16.7), 240 to sophomores (22.9%; IIR = 10.4; 95% CI, 10.0-10.8), and 109 to freshmen (10.4%; IIR = 4.7; 95% CI, 4.1-5.4). On natural grass, 417 injuries were reported among seniors (34.7%; IIR = 17.7; 95% CI, 17.0-18.2), 378 among juniors (31.4%; IIR = 16.1; 95% CI, 15.2-16.7), 309 among sophomores (25.7%; IIR = 13.1; 95% CI, 12.4-13.8), and 99 among freshmen (8.2%; IIR = 4.2; 95% CI, 3.6-4.9).

Head, Knee, and Shoulder Trauma

As shown in Appendix 1, there was no significant main effect, $F(5, 2247) = 0.871$, $P = .500$, $n - \beta = .316$, between surfaces by head injury when combined by all sources of

TABLE 1
Incidence of Game-Related Collegiate Football Injuries Between FieldTurf and Natural Grass[a]

Variable	FieldTurf	IIR	95% CI	Natural Grass	IIR	95% CI	Total or Mean
Team games evaluated							
n	230			235			465
%	49.5			50.5			100.0
All injuries							
n	1050	45.7	44.2-46.3	1203	51.2	49.8-51.7	2253[b]
%	46.6			53.4			100.0
Per 10 games	45.7			51.2			48.5
Per game	4.57			5.12			4.85
Minor injuries							
n	875	38.0	36.9-38.5	938	39.9	39.1-40.0	1813[c]
%	83.3			78.0			80.5
Per 10 games	38.0			39.9			39.0
Per game	3.80			3.99			3.90
Substantial injuries							
n	114	5.0	4.3-5.6	169	7.2	6.6-7.7	283[d]
%	10.9			14.0			12.6
Per 10 games	5.0			7.2			6.1
Per game	0.50			0.72			0.61
Severe injuries							
n	61	2.7	2.1-3.3	96	4.1	3.5-4.7	157[e]
%	5.8			8.0			7.0
Per 10 games	2.7			4.1			3.4
Per game	0.27			0.41			0.34

[a]IIR, injury incidence rate; CI, confidence interval. Injuries per 10 team games = (number of injuries/number of team games) × 10. Injuries per team game = number of injuries/number of team games. Minor injury, 0 to 6 days of injury time loss; substantial injury, 7 to 21 days; severe injury, 22 or more days.
[b]$P = .016$.
[c]$P = .001$.
[d]$P = .020$.
[e]$P = .049$.

trauma, as well as no significant main effect, $F(10, 2242) = 0.461$, $P = .916$, n – β = .246, between surfaces by knee injury. A similar nonsignificant main effect, $F(7, 2245) = 1.543$, $P = .148$, n – β = .653, between surfaces by shoulder injury was also observed.

Injury Category

As shown in Appendix 2 (available at http://ajs.sagepub.com/supplemental/), multivariate analysis indicated no significant playing surface effect by injury category, $F(5, 2247) = 0.494$, $P = .781$, n – β = .187. Confidence intervals, however, indicated a lower incidence of injuries attributed to player-to-player collision ($P = .784$) on FieldTurf (54.3%; IIR = 24.8; 95% CI, 23.7-25.4) versus natural grass (54.9%; IIR = 28.0; 95% CI, 27.1-28.5), as well as a lower incidence of injuries attributed to shoe-surface interaction during contact ($P = .520$) on FieldTurf (21.8%; IIR = 10.0; 95% CI, 9.8-10.0) versus natural grass (22.9%; IIR = 11.7; 95% CI, 11.1-12.3).

Time of Injury

No significant main effect between playing surface was observed across time of injury, $F(5, 2247) = 0.833$, $P = .526$, n – β = .303. Confidence intervals (Appendix 2), however, indicated a lower incidence of injuries occurring during the second quarter of play ($P = .186$) on FieldTurf (28.3%; IIR = 12.9; 95% CI, 12.2-13.5) versus natural grass (30.8%; IIR = 15.8; 95% CI, 14.9-16.4), as well as a lower incidence of injuries occurring during the third quarter ($P = .609$) on FieldTurf (28.9%; IIR = 13.2; 95% CI, 12.4-13.8) versus natural grass (29.8%; IIR = 15.3; 95% CI, 14.4-15.9). Incidence rates for both FieldTurf and natural grass surfaces revealed that a limited number of injuries occurred during the pregame, increased from the first to second quarter, but declined from the third to the fourth quarter of play.

Injury Time Loss

Findings indicated a significant playing surface effect by injury time loss, $F(5, 2247) = 2.480$, $P = .030$, n – β = .783, with subsequent post hoc analysis (Appendix 2) revealing a significantly lower incidence of injuries resulting in 7- to 9-day time loss ($P = .017$) on FieldTurf (6.3%; IIR = 2.9; 95% CI, 2.3-3.5) versus natural grass (9.0%; IIR = 4.6; 95% CI, 4.0-5.2). A significantly lower incidence of injuries resulting in 22 days or more of time loss ($P = .044$) was also reported on FieldTurf (5.8%; IIR = 2.7;

95% CI, 2.1-3.3) versus natural grass (8.0%; IIR = 4.1; 95% CI, 3.5-4.7).

Position Played at Time of Injury

Although confidence intervals indicated lower incidences of offensive, defensive, and backfield injuries on FieldTurf, from a multivariate standpoint, no significant playing surface effect was observed between surfaces by overall player position (offense, defense, special teams), $F(2, 2250) = 0.300$, $P = .741$, $n - \beta = .098$, or by skill position, $F(9, 2243) = 0.538$, $P = .848$, $n - \beta = .271$.

Injury Mechanism and Situation

Although no significant main effect, $F(12, 2240) = 1.091$, $P = .363$, $n - \beta = .646$, between surfaces by injury mechanism was observed, there was a significant main effect, $F(14, 2238) = 2.170$, $P = .007$, $n - \beta = .971$, between surfaces by injury situation. As shown in Appendix 3 (available at http://ajs.sagepub.com/supplemental/), post hoc analyses indicated a significantly lower incidence of injuries occurring during rushing plays ($P = .040$) on FieldTurf (34.8%; IIR = 15.9; 95% CI, 15.0-16.5) versus natural grass (34.6%; IIR = 17.7; 95% CI, 16.9-18.2), as well as a significantly lower incidence of pass defense injuries ($P = .023$) on FieldTurf (14.2%; IIR = 6.5; 95% CI, 5.8-7.1) versus natural grass (17.7%; IIR = 9.1; 95% CI, 8.6-9.4). Further analyses revealed significantly lower incidence of trauma reported during punting ($P = .020$) on FieldTurf (1.0%; IIR = 0.5; 95% CI, 0.3-0.8) versus natural grass (2.3%; IIR = 1.2; 95% CI, 0.8-1.7), as well as a significantly lower number of injuries reported following pile-on ($P = .011$) on FieldTurf (0.3%; IIR = 0.1; 95% CI, 0.0-0.4) when compared to natural grass (1.2%; IIR = 0.6; 95% CI, 0.4-1.0).

Primary Type of Injury

As shown in Appendix 4 (available at http://ajs.sagepub.com/supplemental/), a significant main effect, $F(14, 2238) = 1.771$, $P = .042$, $n - \beta = .907$, by primary type of injury was noted between the 2 surfaces, with subsequent post hoc analysis revealing a significantly lower incidence of ligament tears ($P = .024$) reported on FieldTurf (2.7%; IIR = 1.2; 95% CI, 0.9-1.7) versus natural grass (4.6%; IIR = 2.3; 95% CI, 1.9-2.9). A significantly lower incidence of muscle tears ($P = .002$) was also reported on FieldTurf (0.3%; IIR = 0.1; 95% CI, 0.0-0.4) when compared to natural grass (1.7%; IIR = 0.9; 95% CI, 0.6-1.3).

Grade and Anatomical Location of Injury

There was a significant main effect, $F(2, 2250) = 12.337$, $P = .0001$, $n - \beta = .996$, between surfaces by injury grade (Appendix 4). A significantly lower incidence of second-degree injuries ($P = .0001$) was reported on FieldTurf (13.8%; IIR = 6.3; 95% CI, 5.7-6.9) versus natural grass (19.5%; IIR = 10.0; 95% CI, 9.8-10.0), as well as a significantly lower incidence of third-degree injuries ($P = .007$) on FieldTurf (8.9%; IIR = 4.0; 95% CI, 3.4-4.7) versus natural grass (12.4%; IIR = 6.3; 95% CI, 5.7-6.9)

In regard to location of injury, there was no significant main effect, $F(3, 2249) = 1.675$, $P = .170$, $n - \beta = .442$, between surfaces. Confidence intervals, however, indicated a lower incidence of upper extremity injuries ($P = .045$) reported on FieldTurf (30.4%; IIR = 13.9; 95% CI, 13.1-14.5) versus natural grass (34.2%; IIR = 17.5; 95% CI, 16.7-18.0).

Type of Tissue Injured

There was no significant main effect, $F(5, 2247) = 0.559$, $P = .732$, $n - \beta = .208$, between surfaces by tissue type. Confidence intervals, however, indicated a lower incidence of joint injuries ($P = .969$) reported on FieldTurf (46.2%; IIR = 21.1; 95% CI, 20.3-21.6) versus natural grass (46.1%; IIR = 23.6; 95% CI, 22.6-24.2), as well as a lower incidence of muscle injuries ($P = .997$) reported on FieldTurf (36.7%; IIR = 16.7; 95% CI, 15.9-17.3) versus natural grass (36.7%; IIR = 18.8; 95% CI, 18.1-19.1). When lower extremity joint trauma was analyzed, this study found a significant playing surface effect, $F(7, 224 = 2.310$; $P = .024$, $n - \beta = .852$, involving a significantly higher incidence ($P = .001$) of distal tibiofibular ligament sprains on natural grass (12.9%; IIR = 1.8; 95% CI, 1.4-2.4) when compared to FieldTurf (4.7%; IIR = 0.6; 95% CI, 0.4-1.0).

Environmental Factors

The attempt to quantify environmental conditions at time of injury revealed that the majority of injuries occurred during dry weather (see Appendix 5, available at http://ajs.sagepub.com/supplemental/). In regard to field conditions, there was a significant main effect, $F(2, 2249) = 5.450$, $P = .001$, $n - \beta = .939$, between surfaces, with a significantly lower incidence of injuries during no precipitation–dry field conditions ($P = .003$) reported on FieldTurf (86.3%; IIR = 39.4; 95% CI, 38.4-39.6) versus natural grass (81.0%; IIR = 41.4; 95% CI, 40.3-42.0), as well as a significantly lower incidence of injuries during no precipitation–wet field conditions ($P = .0001$) reported on FieldTurf (3.9%; IIR = 1.8; 95% CI, 1.3-2.3) versus natural grass (8.5%; IIR = 4.3; 95% CI, 3.7-5.0).

When analyzing data by cold days (eg, $\leq 69°F$) as compared to hot days (eg, $\geq 70°F$) as suggested by others,[40,45] there was a significant main effect, $F(1, 2251) = 82.360$, $P = .0001$, $n - \beta = 1.000$, between surfaces by environment temperature. A significantly higher incidence of injuries during cold days ($P = .0001$) was reported on FieldTurf (54.3%; IIR = 24.8; 95% CI, 23.7-25.4) versus natural grass (35.4%; IIR = 18.1; 95% CI, 17.4-18.6). On hot days, a significantly lower incidence of injuries ($P = .0001$) was also reported on FieldTurf (45.7%; IIR = 20.9; 95% CI, 20.2-21.3) versus natural grass (64.6%; IIR = 33.1; 95% CI, 31.9-33.7).

DISCUSSION

The purpose of this prospective cohort study was to quantify the incidence, mechanisms, and severity of game-related collegiate football injuries on FieldTurf versus natural grass. It was hypothesized that collegiate athletes would not experience any difference in the incidence, mechanisms, and severity of game-related injury between FieldTurf and natural grass. Although similarities did exist between FieldTurf and natural grass, unique differences in sport trauma were observed between the 2 playing surfaces.

Injury Incidence

Over the 3-season study, 2253 game-related injuries, or 31.3 injuries per university per season, were recorded among 24 universities competing on both surfaces, indicative of the athletic speed, strength, and subsequent other opportunities for trauma at the collegiate level of competition, when compared to 2.4 to 15.7 injuries per high school per season reported in prior studies.[5,9,40] The incidence of acute injury (88.3%) was similar to findings in earlier studies, ranging from 72% to 94%.[40,47] The incidence of substantial and severe trauma recorded in this study was similar to seasonal trauma reported elsewhere in football but in contrast to nonsignificant surface differences in the severity of trauma in soccer, which may be a function of the level of trauma/impact potential between the 2 sports.[9,15,16,40,56] Although the large variation in injury definition among these studies prevents an accurate comparison, both the total number and the number of minor, substantial, and severe injuries recorded in this study reflect the typical level of trauma observed at the collegiate level of play.

In addition to acute injury, repetitive or recurrent trauma is considered a major contributor to future trauma.[18,21,27,40,65] The incidence of recurrent cases over 3 seasons in this study ranged from 11.3% on FieldTurf to 12.0% on natural grass, higher than the 4.8% previously reported on FieldTurf at the high school level[40] but similar to the 13% to 17% of recurrent trauma reported in collegiate and professional high-contact field sports during a single season[17,62] and substantially lower than the 57% of prior injury recently reported in high school football on natural grass over a 3-year period.[27] Whether recurrent trauma was observed over the same surface in all studies is not known. The increased interest but paucity of studies that address recurrent trauma prevents further discussion at the collegiate level of play.

The higher incidence of injury to upperclassmen on both surfaces is solely attributed to greater playing exposure and subsequent predisposition to injury typically observed at this level of play, in which lower classmen receive less playing time.[27,40] With regard to foul play, the incidence (0.5%) of injury attributed to illegal action was negligible. This is lower than the 0.8% to 5.7% occurrence reported in prior collegiate and high school football[24,40] but in far contrast to the 25% to 62% reported among other intercollegiate and senior sports.[14,46,67] In summary, the lower rate of overall injury documented on FieldTurf may be attributed to the lower incidence of substantial and severe trauma on the artificial surface when compared to natural grass.

Head, Knee and Shoulder Injuries

There were no significant differences in head, knee, or shoulder trauma between the 2 surfaces. But when compared with that of high school football studies,[11,40] the greater incidence of first-degree and total concussions combined, as well as the greater incidence of anterior cruciate ligament–involved trauma, reiterates the level of severe trauma observed during collegiate competition on both surfaces (Appendix 1). The nonsignificant level of traumatic injury on FieldTurf is consistent with prior findings indicating similar nonsignificant playing surface effect.[16,56] These findings are in contrast to prior studies indicating a higher incidence of severe injury on artificial surfaces,[20,53] a reflection of earlier synthetic materials as opposed to the newer generation of artificial surfaces being installed today.

Injury Category

Results of this study indicate no significant differences between playing surfaces across injury categories. Although prior efforts have noted a greater incidence of muscle-tendon overload injuries on FieldTurf during high school games and contributing findings as a function of faster play on a more compliant, elastic surface than that observed with natural grass,[21,40] this was not observed at this level of competition. Others have reported similar nonsignificant findings between artificial and natural grass surfaces.[15,16,56] As shown in Appendix 2, any univariate differences in player-to-player collisions and shoe-surface interaction during player contact between FieldTurf and natural grass were attributed to total injuries incurred rather than surface influence ($P = .520$-$.784$).

Time of Injury

Increasing fatigue over time and declines in available energy substrate and coordination predispose an athlete to injury.[62,65] The nonsignificant differences within and between playing surfaces in this study indicated minimal influence on injury incidence from pregame through the fourth quarter of play. As previously noted, the acute differences in the composition and quality of surfaces may have influenced the type and severity of trauma but did not affect the time of injury observed over the 3-season period. Again, univariate differences in second- and third-quarter trauma may be attributed to total injuries as opposed to actual surface differences ($P = .186$-$.609$). Findings may also be reflective of the score and subsequent play calling of coaches.[5,6,27,40]

Injury Time Loss

As similarly noted when discussing severity of injury, the polyethylene nature of FieldTurf, promoted as a nonabrasive

surface with a natural-earth feel, resulted in a significantly lower incidence of minor injuries requiring 0 to 6 days of time loss. Of primary concern is the significantly greater incidence of injuries ranging from 7 to 9 days of time loss and 22 days or more of time loss associated with competing on natural grass. In this study, increased incidence of injury resulting in extensive time loss ($\geq$22 days) is consistent with prior findings on natural grass at the high school level of competition.[40] Whether these findings with the natural grass surface are a function of decreasing turf quality with high temperatures (Appendix 5), lower surface compliance, and a higher coefficient of restitution observed following noncontact injuries on natural grass,[13,51] overuse because of multipurpose use, or simply the lack of resiliency of natural grass as the season progresses, is not clear and is beyond the control of this study.

Position Played at Time of Injury

Whether data were grouped by generalized positions (eg, offense, defense, special teams) or by specific skill positions as described by others,[18,19] multivariate analyses indicated no significant effect of playing surface on position played at the time of injury. Although prior studies have expressed concerns with the greater impact forces and incidence of injuries among special team, offensive, defensive, and offensive backfield players while competing on artificial surfaces,[21,40] this study did not support those concerns. Unfortunately, at this time, the limited frequency of injury among some positions (eg, quarterback, tight end) may have prevented further in-depth analyses and discussion of potential injury differences and position susceptibility.

Injury Mechanism and Situation

Prior authors have surmised that the more consistent artificial composition enhances the speed of the game[5,40] but allows for greater opportunity for injury owing to overextension and greater fatigue potential of muscles and a greater rate of acceleration, speed, and torque.[36,40,55] Nonetheless, there were no significant differences in injury mechanism between playing surfaces in this study (Appendix 3). In regard to the injury situation, the significantly lower incidence of injury on FieldTurf versus natural grass observed in situations involving rushing, pass defense, punting, and pile-on may be simply influenced by the quality of the playing surface or by several factors noted in the literature.[4,7,18,32,36,39,40,65] Risk factors repeatedly mentioned in the literature have included pivoting, change of direction, direct contact with an opposing player, deceleration, unfortunate mishaps (eg, moving pileup), or being jolted during an uncontrolled or compromised movement.[5,37,56] Others have identified equipment (eg, shoe/cleat design), the abrasive nature and variations in playing surfaces, and various anatomical and biomechanical influences.[4,5,7,58]

Primary Type of Injury

The significantly lower incidence of ligament and muscle tears, as well as the lower incidence of ligament sprains documented on FieldTurf, is consistent with prior findings indicating lower extremity sprains on artificial turf,[15] which may be related to the lower shoe-surface traction usually associated with a more consistent, compliant surface.[40,44] This is consistent with earlier summations noting an inverse relationship between the incidence of ligament trauma and surface compliance.[51] Although others have reported greater shoe-surface peak torque and rotational stiffness with artificial surfaces,[34,64] these studies were conducted under noncompetitive, laboratory conditions using traditional mechanical simulations lacking environmental variability, player contact, and the anatomical and neuromuscular complexities during actual sports performance, thus limiting comparison to on-the-field sports activity.[28] Further investigation into the biomechanics of the shoe-surface interaction beyond the laboratory setting will be necessary to elucidate more definitive causes.

Grade and Anatomical Location of Injury

The significantly lower incidence of second- and third-degree injuries on FieldTurf (Appendix 4) is in contrast to nonsignificant findings on similar surfaces during high school football and soccer competition,[40,56] a level of play where the degree of speed, power, and subsequent impact trauma is lower than that observed at the collegiate or professional level of sport.[5] Findings may more clearly reflect the higher impact attenuation/shock absorbency of the more compliant turf surface at this level of play.[15,40]

In regard to anatomical location, the nonsignificant differences between playing surface are in contrast to earlier studies indicating a lower concussion rate on natural grass when compared to the earlier generation of artificial surfaces.[13,20] The overall incidence of cranial/cervical trauma, as well as the incidence of both upper and lower extremity injury on both surfaces in this study, were greater than that previously reported among high school, college, and professional athletes.[9,13,20,21,29,40,47] Results may reflect the level of athletic size and prowess, when comparing the time that these studies were conducted.[5]

Type of Tissue Injured

This study did not establish the coefficient of restitution or degree of rebound; however, when compared to the polyethylene/cryogenic rubber composition of FieldTurf, lower extremity findings on natural grass seemed to reflect a less compliant surface and lower energy absorption at ground impact. The energy of impact is subsequently transferred back—in this case, to the lower extremity region—increasing the potential for trauma.[65] This may be reflected in the significantly higher incidence of distal tibiofibular ligament sprains on natural grass when compared to FieldTurf. Although others have reported a significantly greater incidence of ankle sprains, combining data derived from 8 brands of artificial turf,[15] the authors did not control for length and time of collection or variation in turf type or quality, methodological concerns that may have benefitted from further analyses.

Environmental Factors

Limited attention has been directed toward the potential influence of weather conditions on injury during competition.[21,40,45] In this study, the majority of play and injuries occurred during conditions of no precipitation, therefore minimizing the opportunity to thoroughly ascertain possible influences under various field conditions. The significantly lower incidence of injury on FieldTurf during play on wet fields may reflect the more consistent surface that the turf provides during inclement weather. The significantly lower incidence of injuries on FieldTurf when temperatures remained above 70°F is in contrast to findings previously reported on other surfaces,[40,45] although those surfaces were an earlier type of turf or natural surfaces under drier conditions when compared to today's highly managed collegiate grass surfaces. The more consistent FieldTurf surface may not have impeded normal performance (eg, speed, impact) during games under cold weather conditions, thus contributing to the significant increase but lower total number of injuries when compared to injuries occurring with higher temperatures.

Contrary to that of prior studies on the original artificial turf surfaces, the significantly greater incidence of injury during hot days on natural grass supports prior findings that indicated enhanced shoe-surface interaction potentiating articular trauma with increasing turf temperature,[45,60] as well as reports of greater frequency of knee trauma with higher temperatures.[44] In summary, these findings are of clinical concern and warrant further investigation for optimal natural grass management practices.[58]

Limitations

Several potential limitations to the study may have influenced the type and number of injuries reported. These included the inability to determine and control the inherent random variation in injury typically observed in high-collision team sports[8,37]; the strength and conditioning status of the athletes and variations in the type of equipment used[4,5,7,25,31,36,59,68]; the weather conditions and variations in field conditions[1,7,22,30,56]; the differences in postural/joint integrity, musculoskeletal structure, and biomechanics of movement[4,7,10,31,38,66]; the time of year[7,15,31]; the coaching style, experience, and play calling[5,6,21,27,36,38]; the quality of officiating and foul play[64]; the player's position and actual versus average time to exposure to injury[5,11,22,25,27,32]; the sport skill level, intensity of play, and fatigue level at time of injury[20,27,31,32,50,59,65,68]; the athlete's ephemeral response to help seeking, injury, and subsequent pain[36,38,40,41,47]; the unreported congenital/developmental factors predisposing an athlete to additional injury[5,10,31,36,56,57,65]; or, simply, any unforeseen mishap.[37,40] Also, there is always the opportunity for an injury to go unreported despite the comprehensive nature of any reporting system.[5,24,36]

Key strengths of the study included the opportunity to follow several universities during the 3-year period, which prevented seasonal injury fluctuations and individual team effects and which enhanced the ability to identify differences and trends in surface effect. In addition, the combined method of assessing functional outcome, time loss, direct observation, and treatment records, as well as the daily interactions of ATCs and players evaluated in this study, minimized the potential for transfer bias and unreported injuries throughout the season.[40,62] The daily evaluation and follow-up telephone visits also increased the opportunity to quantify and track typically overlooked minor indices that often evolve into chronic or overuse problems.[40,62]

Note that the percentage of influence from risk factors other than simply surface type cannot be overlooked. Because of the inherent challenges of collecting data on multiple indices and on numerous teams and players over an extended period, the degree of influence from these risk factors remains a limitation that can only be acknowledged at this time.[27,39,65] The prospective cohort multivariate design did enhance sample size, result in randomization of play on both surfaces, control for seasonal and team variation, and allow for greater insight into significant and subtle differences between a new generation of artificial turf and natural grass.

Finally, the lack of a universally accepted definition of sport injury will continue to be a challenge and subsequent influence on injury interpretation.[40,44] With the concomitant difficulty in subjectively determining a plethora of surface conditions and quality of natural grass,[40,58] any attempt to interpret the injury-surface interaction with any degree of accuracy will continue to pose concerns.

CONCLUSION

Although similarities did exist between FieldTurf and natural grass over the 3-year period of competitive play, there were significant differences in injury incidence, severity of injury, injury time loss, injury situation, grade of injury, injuries under various field conditions, and temperature. No significant differences in head, knee, or shoulder trauma were observed between playing surfaces. Both surfaces, from a statistical and clinical standpoint, exhibited unique injury mechanisms that need to be addressed to reduce the number of game-related collegiate football injuries. The hypothesis that collegiate athletes would not experience any difference in the incidence, mechanisms, and severity of game-related injury between FieldTurf and natural grass was not supported. FieldTurf is in many cases safer than natural grass. However, the findings of this study are generalizable to only this level of competition. Because this study is still in the early stages, investigation is ongoing.

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