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Higher Rates of Lower Extremity Injury on Synthetic Turf Compared With Natural Turf Among National Football League Athletes

Epidemiologic Confirmation of a Biomechanical Hypothesis

Christina D. Mack,*† PhD, MSPH, Elliott B. Hershman,‡ MD, Robert B. Anderson,§ MD, Michael J. Coughlin,‖¶ MD, Andrew S. McNitt,# PhD, Rachel R. Sendor,† MPH, and Richard W. Kent,** PhD
Investigation performed at IQVIA, Research Triangle Park, North Carolina, USA

Background: Biomechanical studies have shown that synthetic turf surfaces do not release cleats as readily as natural turf, and it has been hypothesized that concomitant increased loading on the foot contributes to the incidence of lower body injuries. This study evaluates this hypothesis from an epidemiologic perspective, examining whether the lower extremity injury rate in National Football League (NFL) games is greater on contemporary synthetic turfs as compared with natural surfaces.

Hypothesis: Incidence of lower body injury is higher on synthetic turf than on natural turf among elite NFL athletes playing on modern-generation surfaces.

Study Design: Cohort study; Level of evidence, 3.

Methods: Lower extremity injuries reported during 2012-2016 regular season games were included, with all 32 NFL teams reporting injuries under mandated, consistent data collection guidelines. Poisson models were used to construct crude and adjusted incidence rate ratios (IRRs) to estimate the influence of surface type on lower body injury groupings (all lower extremity, knee, ankle/foot) for any injury reported as causing a player to miss football participation as well as injuries resulting in $\geq$8 days missed. A secondary analysis was performed on noncontact/surface contact injuries.

Results: Play on synthetic turf resulted in a 16% increase in lower extremity injuries per play than that on natural turf (IRR, 1.16; 95% CI, 1.10-1.23). This association between synthetic turf and injury remained when injuries were restricted to those that resulted in $\geq$8 days missed, as well as when categorizations were narrowed to focus on distal injuries anatomically closer to the playing surface (knee, ankle/foot). The higher rate of injury on synthetic turf was notably stronger when injuries were restricted to noncontact/surface contact injuries (IRRs, 1.20-2.03; all statistically significant).

Conclusion: These results support the biomechanical mechanism hypothesized and add confidence to the conclusion that synthetic turf surfaces have a causal impact on lower extremity injury.

Keywords: stadium surface; football injury; lower extremity; synthetic turf; natural turf

Lower extremity injuries are a key concern for athletes.[9,17,37,43] Understanding the effect of field surface type on the risk of lower extremity injuries is essential, particularly with regard to synthetic turfs, which are used as playing surfaces across many levels and types of sport. The decision to install synthetic turf is driven by its multiuse capabilities, ease of upkeep, and controllability of playing conditions regardless of most weather conditions.[39] The potential for increased injury risk must be balanced against these desirable aspects of synthetic versus natural turf surfaces.[6,8,13,15,16,18]

There is a mechanistic rationale to assert a causal link between play on synthetic turf and increased risk of lower extremity injury in elite American football. Biomechanical testing of various football cleats on a variety of athletic surfaces has clearly shown differences between natural and synthetic turf in terms of the ability to create a divot, thereby releasing the cleat at loading magnitudes and rates generated during elite athletic competition.[22,23] Synthetic surfaces lack the ability to release a cleat in a potentially injurious overload situation and therefore can generate much greater shear force and torque on the foot and throughout the lower extremity.[22,23] Conversely, the ability of grass turf to facilitate release of the cleat from

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the surface at potentially injurious torsion levels serves as an inherent force-limiting mechanism.[5,12]

These biomechanical findings support the hypothesis that injury risk is greater on contemporary synthetic turfs than on natural turfs when loading from the turf through the shoe is a contributory mechanism to the injury in question. Previous assessments of the differential injury rate between synthetic and natural turfs did not explicitly explore this hypothesis, but results are generally supportive of it. Specifically, studies that focused on lower extremity injuries caused by a twisting or shearing mechanism showed greater rates of injury on synthetic versus natural turf.[6,8,15,16]

Assessing how the greater force-generating capacity of synthetic turf surfaces[22,23] manifests in the relative risk of lower extremity injuries during play is complicated by several factors. First, mechanisms and tolerances of injury differ, and as a consequence, certain injuries may be less sensitive to surface type. For example, syndesmotic (ie, "high") ankle sprains involve damage to the strongest ligaments in the ankle complex.[11,35] This mechanism requires significant loading, often associated with a blow to the injured limb,[14,25,28,36,41,42] and therefore may be less sensitive to surface type. In contrast, ankle sprains that involve less substantial ligamentous structures (eg, the talofibular or calcaneofibular ligaments)[11,35] may occur more frequently without a direct blow[4,21] and thus may be more sensitive to surface type. Second, within surface type (synthetic or natural), variability in the number, shape, and length of upright fibers differs among synthetic turf fields, while grass species, percentage ground cover, moisture content, and root zone components differ among natural turf fields. These differences can affect the mechanical behavior of surfaces, and the variability can be increased by differences in the age of the field, its use patterns, and maintenance practices.[31,38] Third, it is challenging to collect sufficient data across all injuries for a full population, ensuring comparable cohorts for the 2 surface types. Fourth, the footwear worn by players at lower levels of play is usually insufficiently defined or not collected in injury databases, and the cleats may not be suited to the playing surface. The cleat pattern on a shoe has a significant effect on the loads that can be applied to the foot, particularly on synthetic surfaces.[20,23,26] Finally, field designs and maintenance practices evolve, and historical findings must be revisited as more contemporary data become available.

The National Football League (NFL) presents an opportunity to mitigate the effects of many of these complicating factors and thus better evaluate the potential association of surface type on lower extremity injury risk. Injury reporting is mandated across all 32 NFL teams within an electronic health record system in a robust and consistent manner, thereby eliminating the potential selection bias and variability inherent in similar studies. Injuries and the circumstances surrounding them (contact, impact, activity) are reported with necessary resolution to isolate injury type and mechanism in a structured manner during the course of clinical care by trained medical staff. Data are subject to quality control procedures over the course of the season, and the database is then linked to sport-related information, such as game day weather and surface conditions.[27,29] Thus, these data represent comprehensive, clinically detailed reports of injuries sustained by a well-defined population of elite athletes in well-documented conditions. Additionally, game day playing surfaces in the NFL are state-of-the-art and maintained by professional staff to a common set of formal recommended practices over the study period—including certification of mechanical hardness and infill depth within 72 hours of game time (metrics that are available within the linked injury database). All synthetic surfaces in the NFL over the study period were infilled turf, which is a mixture of crumb rubber and sand incorporated into the upright pile fibers.[30] Thus, owing to construction and quality of maintenance, NFL fields have less variability in surface conditions as compared with other settings; furthermore, this variability is, to an extent, quantifiable and measured. The NFL also has formal training procedures and professional athletic training and equipment staff who consult with players on their selection of surface-specific footwear. While there is variability among NFL players in their choice of footwear, they have unique access to high-quality shoes and informed counsel; thus, the range of cleat patterns used in the NFL is narrower and the shoe/cleat selection more informed than at other levels of play.

This study tests the hypothesis that incidence of lower body injury is higher on synthetic turf than on natural turf among elite NFL athletes playing on modern-generation surfaces.

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*Address correspondence to Christina Mack, PhD, MSPH, IQVIA, 4820 Emperor Blvd, Durham, NC 27703, USA (email: christina.mack@iqvia.com).
†IQVIA, Research Triangle Park, North Carolina, USA.
‡Department of Orthopaedic Surgery, Lenox Hill Hospital, Zucker School of Medicine at Hofstra/Northwell, Northwell Health, New York, New York, USA.
§Bellin Health Titletown Sports Medicine and Orthopedics, Green Bay, Wisconsin, USA.
‖University of California, San Francisco, San Francisco, California, USA.
¶Coughlin Foot and Ankle Clinic, Saint Alphonsus Hospital, Boise, Idaho, USA.
#Center for Sports Surface Research, Pennsylvania State University, University Park, Pennsylvania, USA.
**Center for Applied Biomechanics, University of Virginia; Biomechanics Consulting & Research (Biocore), Charlottesville, Virginia, USA.

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METHODS

Study Time Frame and Data Source

NFL injury data are collected prospectively from club medical staff for all 32 teams through a mandated process governed by the NFL's collective bargaining agreement with the NFL Players Association. Data on injury type, return to participation, player position and onset details (eg, contact/noncontact), player activity when the injury occurred, and other factors relating to playing conditions are recorded for all injuries requiring treatment or missed playing time.[27,29] Injuries from 2014 to 2016 were reported through a centrally hosted electronic health record system; before this, data were collected through a proprietary Injury Surveillance System with similar interface and data entry processes. Rigorous procedures around quality and completeness of reporting are in place, including regular training and reporter guidance, monthly data quality reports to clubs during the season, prospective data queries to collect missing information, and comparison with media reports and game video for high-profile injuries.

Injury data were combined with 2 other sources of data: (1) the NFL Game Statistics and Information System (GSIS), provided by NFL Football Operations and containing the number of plays per game, game day weather, and playing surface type; and (2) measurements of field surface hardness for 2012 to 2016, provided by the NFL Taskforce for Game Day Surfaces Recommended Practices.

Injuries

All incident cases of lower extremity sports-related injuries occurring in all regular season NFL games from 2012 to 2016 that resulted in time loss from football-related activities were included in the primary analysis, as a broad group as well as within anatomic subcategories of knee and ankle/foot. Within each injury category, 2 levels of outcomes were examined:

Any time loss: injuries that resulted in (1) removal from the remainder of the game or practice and/or (2) missed participation from a subsequent NFL practice or game.

≥8 days: a subset of "any time loss" injuries in which a player missed ≥8 days of participation, representing a missed week of football activity and in many cases approximating at least 1 missed NFL game.

Injuries that occurred during practices or during games outside the regular season were excluded from the analysis to minimize heterogeneity in the surfaces and player population considered.

A secondary analysis restricted to noncontact and surface contact injuries was performed within each of the aforementioned groups, as injuries occurring without a direct blow to the limb are more likely to be related to shoe-surface interaction—and hence to surface type—than are player-to-player contact injuries. This "noncontact/surface contact" category, which is presented as a secondary analysis, includes injuries reported by the team's athletic trainer as resulting from sprinting, running, jumping, cut/change of directions, and other noncontact activity, as well as injuries reported due to playing surface contact (eg, injuries resulting from a cleat stuck in the playing surface or a direct impact to the playing surface). Injuries were excluded if they were reported as resulting from contact with another player or object (eg, contact with sideline obstruction or goal post) or an unknown contact type. Because evaluation and reporting of injury mechanism have a subjective component, sensitivity analyses were performed to assess (1) the influence of reports of unknown or unspecific mechanisms and (2) the association on injuries specifically reported as being due to player contact.

Field Type

Field type was classified as either natural or synthetic for every NFL field based on whether it has a root zone designed to support turf growth or not, regardless of natural turf species, synthetic turf manufacturer, or particular design (Appendix Table A1, available in the online version of this article). Hybrid fields, which incorporate a small percentage of synthetic fibers into a natural turf system, were classified as natural. Although there is mechanical variability among natural turf species and among synthetic turf designs, testing showed that this intratype variability is small as compared with the intertype variability between natural turfs and synthetic turfs en bloc.[22] Furthermore, aggregation of all NFL fields into either of those 2 categories is functionally justified, as it comports with analysis of the hypothesized biomechanical mechanism—specifically, natural turf divoting in a way that mitigates injury risk as compared with synthetic surfaces. All NFL turfs classified as "natural" are able to divot or otherwise sustain damage during play, and all of the turfs deemed "synthetic" are not.

Subanalyses excluding 3 potentially heterogeneous synthetic fields were performed to assess the effect of these surfaces on the results: Seattle's and New England's stadiums, which both use monofilament rather than slit film fibers, and Dallas's stadium, which has lower infill depth than that of other synthetic surfaces in the study (mean, 22.0 mm vs 40.5 mm).

Statistical Analysis

Incidence rates were calculated using injuries per play to quantify the specific amount of exposure to active play during each game, thereby accounting for differences in the pace of each game, which may change over time or be related to surface type or NFL team. Poisson models were constructed to estimate crude and adjusted incidence rate ratios (IRRs); review of injury distribution confirmed that the data were well suited to Poisson analysis, with approximately equal mean and variance for each outcome of interest.

Statistical adjustment was used to account for the effect of game day surface hardness and wet versus dry field conditions—2 systematically measured variables that may be related to injury risk and surface type.[40] Surface impact

TABLE 1
Incident Lower Extremity Injuries by Contact and Surface Type: 2012-2016 Regular Season Games

	Turf, n (%)			
Injury Outcome	Synthetic	Natural	Total	Noncontact / Surface Contact, n (%)
Games	555 (43.4)	725 (56.6)	1280	
Plays	93,019 (43.5)	120,916 (56.5)	213,935	
Lower extremity				
Any time loss[a]	2268 (47.2)	2533 (52.8)	4801	1560 (32.5)
≥8 d[b]	886 (46.0)	1041 (54.0)	1927	691 (35.9)
Knee, ankle, foot				
Any time loss	1492 (47.6)	1645 (52.4)	3137	745 (23.7)
≥8 d	601 (47.6)	661 (52.4)	1262	295 (23.4)
Knee				
Any time loss	742 (47.9)	808 (52.1)	1550	403 (26.0)
≥8 d	297 (47.3)	331 (52.7)	628	167 (26.6)
Ankle, foot				
Any time loss	750 (47.3)	837 (52.7)	1587	342 (21.6)
≥8 d	304 (47.9)	330 (52.1)	634	128 (20.2)

[a]Any time loss: injuries that resulted in any amount of missed participation time in a National Football League practice or game.
[b]≥8 days: injuries that required a player to miss ≥8 days of participation in football activities, approximating at least 1 missed National Football League game.

hardness is measured by NFL groundskeepers with a Clegg Impact Soil Tester equipped with a 2.25-kg missile and a drop height of 457 mm and is reported in terms of a Gmax value.[2,3] The testers used in the NFL have been specially calibrated to an accuracy of 1% over the range of 0 to 150 Gmax. Independent inspectors randomly test several game day fields weekly to confirm the team-reported measures. NFL reporting requirements include testing in 10 locations, as specified by ASTM F1936,[1] within 72 hours preceding the commencement of every game and after any pregame event that imposes significant traffic or surface loads (eg, a concert or other sporting event). The average hardness score (Gmax) across these 10 field locations was calculated for each game and adjusted within deciles.

This study was approved by the Mt. Sinai Institutional Review Board (study 76-0001[0003] NFL).

RESULTS

Over the 5 seasons of data collection, 1280 NFL games were played: 555 (93,019 distinct plays) on synthetic surfaces and 725 (120,916 distinct plays) on natural surfaces (Appendix Table A1). The rate of distinct plays per game, regardless of injury incidence, was 167.6 on synthetic and 166.8 on natural. A total of 4801 lower extremity injuries occurred (Table 1), affecting 2032 NFL players. Over the course of the study, there were 2268 injuries on synthetic turf and 2533 on natural turf, with injury rates per game of 4.1 and 3.5, respectively.

Play on synthetic turf resulted in a 16% increase in injuries as compared with play on natural turf (IRR, 1.16; 95% CI, 1.10-1.23) across all lower extremity injuries resulting in any missed football participation. If the injury rate observed on natural surfaces is applied to the games played on artificial turf during the study period, 319 fewer lower extremity injuries would be expected. This association between synthetic surfaces and increased lower extremity injury held when analytics focused more narrowly on injuries that resulted in players missing ≥8 days of football activity, as well as for injury categories examining the knee and ankle/foot separately. The association was particularly notable when restricted to noncontact/surface contact injuries, with IRRs (95% CIs) of 1.27 (1.15-1.41) across all lower extremity injuries, 1.46 (1.20-1.77) for knee injuries, and 1.68 (1.36-2.08) for ankle/foot injuries. Results were consistent for injuries with ≥8 days missed, increasing to an IRR as high as 2.03 (1.42-2.89) for ankle/foot injuries. The differential injury rate between synthetic and natural surfaces became more pronounced for groupings of noncontact/surface contact injuries located more distally (ie, closer to the playing surface) (Figure 1).

Over the 5-year period, the average surface impact hardness per game was similar between synthetic and natural turfs, with mean and median (range) Gmax scores of 81 and 82 (48-105) on natural turf and 74 and 75 (52-95) on synthetic. Adjustment for this variable and field moisture (wet vs dry field) did not meaningfully alter crude results (Table 2).

Additional analyses assessing potential misclassification of noncontact and surface contact injuries and examining the effect of the synthetic fields in Dallas, New England, and Seattle did not meaningfully change the results (Appendix Table A2). Analyses restricted to injuries attributed to player contact, as reported by athletic trainers, did not show a higher injury rate on synthetic versus natural surfaces (IRR [95% CI] for lower extremity: any time loss, 1.06 [0.97-1.14]; ≥8 days, 1.01 [0.90-1.15]).

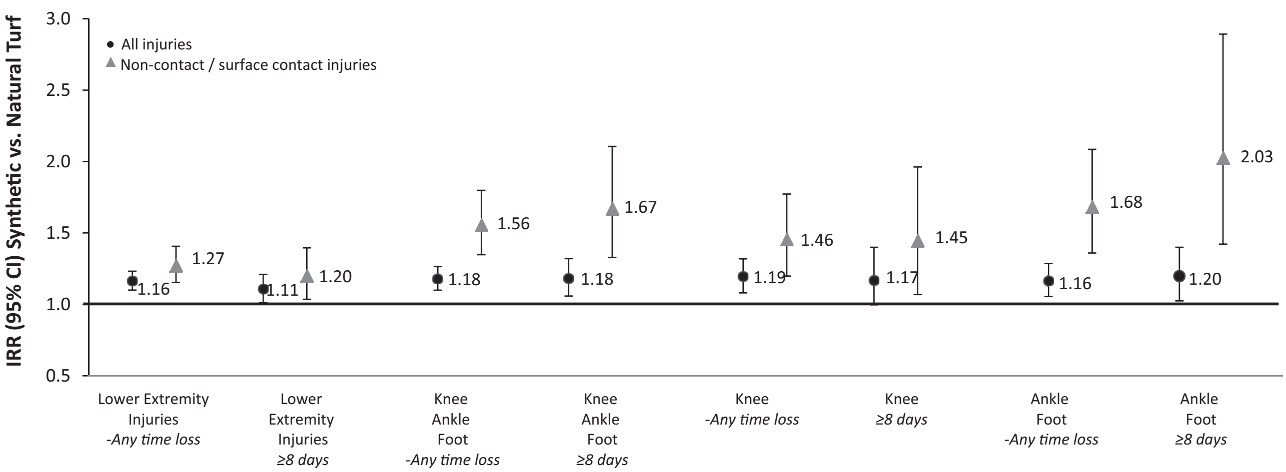

Figure 1. Unadjusted lower extremity incidence rate ratios (IRRs) comparing injuries on synthetic vs natural turf: 2012-2016 regular season games. Any time loss: injuries that resulted in any amount of missed participation time in a National Football League practice or game. ≥8 days: injuries that required a player to miss ≥8 days of participation in football activities, approximating at least 1 missed National Football League game.

TABLE 2
Adjusted Lower Extremity IRRs
Comparing Injuries on Synthetic vs Natural Turf:
2012-2016 Regular Season Games[a]

	All Injuries		Noncontact / Surface Contact Injuries	
Injury Outcome	IRR	95% CI	IRR	95% CI
Lower extremity				
Any time loss[b]	1.15	1.09-1.23	1.31	1.18-1.47
≥8 d[c]	1.08	0.98-1.20	1.18	1.00-1.39
Knee ankle foot				
Any time loss	1.18	1.09-1.28	1.67	1.43-1.95
≥8 d	1.19	1.05-1.35	1.72	1.33-2.22
Knee				
Any time loss	1.20	1.07-1.34	1.55	1.25-1.91
≥8 d	1.16	0.97-1.39	1.14	0.80-1.62
Ankle foot				
Any time loss	1.17	1.05-1.31	1.83	1.45-2.31
≥8 d	1.21	1.02-1.45	2.19	1.48-3.23

[a]IRR, incidence rate ratio.
[b]Any time loss: injuries that resulted in any amount of missed participation time in a National Football League practice or game.
[c]≥8 days: injuries that required a player to miss ≥8 days of participation in football activities, approximating at least 1 missed National Football League game.

DISCUSSION

Among NFL athletes playing in 2012-2016 regular season games, higher rates of lower extremity injury occurred on synthetic turf than on natural turf. These results are consistent with 2000-2009 NFL findings[15] and with the majority of studies among collegiate football players.[6,8,13,16,18] Two football-related studies did not observe a difference between surface types among lower extremity injuries with publicly reported NFL data,[7,24] and 3 National Collegiate Athletic Association studies conducted with football and soccer players[32-34] reported lower rates of injury on 1 brand of synthetic turf (FieldTurf) as compared with natural turf. The latter studies aggregated injuries across the body without targeting the lower extremity injury groupings related to the biomechanical hypothesis here.

The associations found in this study and the marked increase in the rate ratio when injuries were restricted to noncontact/surface contact injuries support the biomechanical hypothesis discussed in the introduction. Furthermore, the ratios generally increased as more distal noncontact/surface contact injuries were considered. When athletic training staff labeled contact with another player as the mechanism, there was no observed difference in injury rate between surface types (Appendix Table A2). These findings add confidence to the conclusion that the field surface has a causal effect on lower extremity injury.

There are multiple technical and clinical indications of these findings. Synthetic turf should continue to evolve toward designs that maintain the desirable traits that facilitate maintenance and allow increased usage as compared with natural surfaces. While these designs must generate ground-reaction forces that players expect and that will allow performance during play, synthetic turf must also advance toward allowing the cleat to release more readily at potentially injurious loading levels. As divoting or other damage to the synthetic surface is unlikely to be a viable mechanism of load limiting, additional research on the functional mechanics of cleat release, shoe-turf interactions, lower extremity injury biomechanics, and natural turf divoting would facilitate this design evolution. A second indication is the continued refinement of cleat patterns and a comprehensive, collaborative consideration of cleat-turf interaction by producers of football shoes and synthetic turfs. Jastifer et al[19] recently summarized the literature motivating the concept of the football shoe as an important piece of safety equipment. As such, it is imperative that its design consider the nature of the surface on which it is to be used and the specific mechanics of its cleat pattern's interaction with synthetic surfaces. Until shoe and synthetic turf designs evolve to the point that the lower limb injury rate approaches that on natural turf, players and trainers may consider additional lower limb protection when on synthetic turf. Future research should consider such countermeasures in addition to enhanced shoe and surface designs.

The results of this study are subject to some important limitations with regard to their generalizability. First, the epidemiologic data and the biomechanical data are specific to playing conditions in the NFL, which may differ from athletes and conditions in other sports and at other levels of American football. There are also differences between the maintenance practices of NFL teams and those of municipalities or other groups responsible for the upkeep of athletic surfaces. Regular topdressing of infill surfaces with crumb rubber has become standard practice in the NFL to maintain infill depth within manufacturer-specified ranges. As infill is removed or displaced during the use of a synthetic field, longer lengths of fiber are exposed, which can increase the shear force and torque capacity of the synthetic surface by engagement with a cleat and possibly increase the risk of certain injuries.

It is also understood that many factors influence lower extremity injury rates. This study minimized many of these potential confounders simply by restricting its focus to the NFL: field variability is minimized by standardized practices and the quality of every NFL surface on game day; shoe variability is minimized by informed selection and by professional equipment managers and trainers; and population variability is minimized by limiting the analysis to elite athletes who play in the NFL. Regardless, variability in player size, speed, play style, and other factors exists and cannot be completely accounted for. Likewise, there may be systematic differences in the nature of game play on synthetic and natural surfaces, although the number and distribution of plays did not differ across surface types among the games analyzed here. Furthermore, the ability of players to move more quickly on synthetic surfaces is either nonexistent or biomechanically trivial in terms of kinetic energy and differential injury risk.[10,12] There is, however, indication in the literature that soccer players may modify their behavior to avoid sliding tackles and the resulting contact with a synthetic surface.[5] While no similar observations have been reported in American football, the possibility of bias in our data attributed to systematic behavioral differences by surface type cannot be completely excluded. Finally, these findings from a closed NFL population may not apply directly to other levels of football or other sports in general.

Data collection across 5 years is subject to changes over time as well as variation in injury reporting. Specifically, in injury surveillance, correct ascertainment of return-to-play information may be unreported because of a player's movement within or out of the league. As such, analyses restricting injuries to those involving $\geq$8 days missed are subject to missing data. As a metric of injury effect or severity, return to play is limited in that other factors beyond clinical implications of an injury affect a player's return, including team schedules and player skill. Wet versus dry surface information is reported by NFL personnel on game day and may be subject to error in some cases, particularly when weather changes and variable surface drying occur over the course of the game. Limitations of Gmax include variation in measurement practices by stadium personnel or across years and changes in surface condition between the time of the measurement and game time, as measurements can be taken as early as 3 days before game day.

Classifying injury mechanism within any reporting system is difficult, as sideline observation is both subjective and prone to error in any setting when clinical care is also being administered. We recognize the limitations of sideline and even video assessment of mechanism. Thus, the primary analysis of this article focused on injuries regardless of contact mechanism, with contact-type restrictions as a secondary analysis. While contact injuries may be affected by surface type in some cases, results of the noncontact restriction strengthen the association and explain findings for specific injuries, further bolstering the biomechanical hypothesis of this study.

These results merit a global and extended look at these data, with attention to differences between synthetic surfaces in terms of their manufacturers and their changes in upkeep and weather. More biomechanical research is warranted focusing on the shoe cleat–surface interaction. Additional studies are underway examining variability among artificial surfaces and how factors such as age of field, infill depth and composition, and fiber density may affect injury. The study is strong in that it limits confounding variables; that said, there is more work to be done to understand these relationships, particularly on fields without gold standard upkeep, such as NFL practice fields.

CONCLUSION

Play on synthetic turf resulted in 16% more injuries per play than that on natural turf (IRR, 1.16; 95% CI, 1.10-1.23) across all lower extremity injuries causing a player to miss any football participation—an association that became more pronounced as analytics focused on injuries located more distally (ie, nominally closer to the playing surface). The association was particularly notable when noncontact/surface contact injuries were examined, increasing to 2.03 (1.42-2.89) for ankle and foot injuries resulting in $\geq$8 days missed from football participation. The significance and nature of these associations add confidence to the conclusion that the field surface has a causal effect on injury that is related to a lack of release between a player's shoe and a synthetic turf surface, which implies that the selection of footwear is critical from an injury mitigation standpoint, especially on synthetic surfaces. While strictly generalizable to NFL American football athletes, these results can inform priorities among shoe and surface manufacturers, as well as decision makers in the athletic equipment and stadium industries.

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