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A Review of Synthetic Playing Surfaces, the Shoe-Surface Interface, and Lower Extremity Injuries in Athletes

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Abstract: The evolution of synthetic playing surfaces began in the 1960s and has had an impact on field use, shoe-surface dynamics, and the incidence of sports-related injuries. Modern third-generation turfs are being installed in recreational facilities and professional stadiums worldwide. Currently, > two-thirds of National Football League teams,> 100 National Collegiate Athletic Association Division I football teams, and > 1000 high schools in the United States have installed synthetic playing surfaces. Those in favor of such playing surfaces note their unique combination of versatility and durability; they can be used in both ideal and inclement weather conditions. However, the more widespread installation and use of these surfaces have raised questions and concerns regarding the impact of artificial turf on the type and severity of sports-related injuries. There appears to be no question that the shoe-surface interface has a significant impact on such injuries. Independent variables such as weather conditions, contact versus noncontact sport, shoe design, and field wear complicate many of the results reported in the literature, thereby preventing an accurate assessment of the true risk(s) associated with certain shoe-surface combinations. Historically, studies suggest that artificial turf is associated with a higher incidence of injury. Furthermore, reliable biomechanical data suggest that both the torque and strain experienced by lower extremity joints generated by artificial surfaces may be more than those generated by natural grass fields. Recent data from the National Football League support this theory and suggest that elite athletes may sustain more injuries, even when playing on the newer artificial surfaces. By contrast, some reports based on data collected from lower-level athletes suggest that artificial turf may protect against injury. This review discusses the history of artificial surfaces, the biomechanics of the shoe-surface interface, and some common turf-related lower extremity injuries.

Keywords: artificial turf; natural grass; shoe surface; cleat; injury

Introduction

Sports-related injuries are a significant burden on the health care system, with the annual cost of treating injuries to high school athletes alone estimated to be > $2 billion.[1] Given the impact of these injuries, much effort has been devoted to studying the mechanisms underlying common sports-related injuries and how they can be prevented. One of the most important variables is the shoe-surface interface.

Synthetic playing surfaces were first introduced in the 1960s to provide children in inner cities with equal access to sports and other physical activities.[2] The overall costs and benefits of these surfaces remain a source of debate to this day. Proponents of synthetic turf suggest that it appears to provide a more consistent playing surface and its use is not weather dependent.[3] It also shows improved durability and low upkeep costs.[4]

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Despite the proposed advantages of artificial turf, concerns regarding its impact on lower extremity injury rates have led to several studies on the subject during the past 40 years.[5–11] This review discusses the evolution of artificial surfaces and describes the biomechanics of the shoe-surface interface. It further discusses some of the most common turf-related lower extremity injuries and reviews the current literature.

The History of Artificial Turf

Artificial playing surfaces were developed to improve playing surface durability and create an indoor surface that was easy to maintain. Coupled with the use of field lighting, artificial surfaces increase the number of available playing hours, resulting in an increase in the income of many sport facilities. Furthermore, the improved durability of these surfaces, with respect to seasonal weather conditions, frequency of use, and the relatively low amount of maintenance required (compared with natural grass), has made artificial turf an appealing option for sports centers despite the high initial investment costs. The initial cost of installing a third-generation artificial turf field exceeds that of natural grass by nearly $200 000; however, the fact that it is cheaper to maintain means that these costs can be recovered within the first 4 years of use. After this initial period, third-generation synthetic surfaces are more cost-effective.[4] The increased durability of artificial surfaces also means that they can be used for other nonsport events, such as concerts, which enable facilities to further increase revenue.

The first-generation playing surfaces developed in the 1960s (eg, AstroTurf®, Astro Turf, LLC) comprised a dense carpet matrix.[3] They were usually constructed from durable nylon fibers (10–12 mm in length), and no filler substance was used. This surface had several faults: it caused high levels of skin abrasion ("turf-burn") and high ball-bounce due to the absence of padding to absorb the impact. This was later corrected by adding a shock-absorbing pad beneath the playing surface. The surfaces were also sprayed with water to limit friction and reduce skin abrasion.

Second-generation playing surfaces emerged a decade later. These were constructed from a softer polyethylene material, with longer fibers that were spaced farther apart to facilitate the use of a filler substance, usually sand. The sand filler provided a softer, more uniform surface, and a more consistent and "natural" ball-bounce and roll.[3] Around this time (the 1970s), "turf shoes" were introduced to the marketplace as an alternative to cleated sports shoes. These shoes were touted as providing a better interface with the new playing surface than the more traditional cleated and flat-bottomed shoes. Hence, people became increasingly aware of the importance of the shoe-surface interface, prompting concerns from players, coaches, physicians, trainers, and researchers about the possibility of increased injury rates (particularly injuries to the lower extremities) in athletes playing on these surfaces.[12]

Today's third-generation artificial surfaces (eg, FieldTurf, Tarkett Sports) are designed to more closely replicate natural grass with regard to shoe-surface interaction and fiber morphology. The fibers are longer than those used in second-generation surfaces, and there is more space between fibers. New fillers are used, consisting of a base layer of sand and rubberized particles, to better replicate the dirt that exists between blades of grass, providing athletes with a more comfortable and natural feel during play. However, despite these advances in turf development, the effects of artificial surfaces on the incidence of sports-related lower extremity injuries (which are likely to be multifactorial) remain controversial.[10,11,13]

Shoe-Surface Interface

Shoe-surface interface represents the interplay between intrinsic and extrinsic factors.[14] Intrinsic factors are those pertaining to the athlete's build and movement (eg, body weight, velocity, acceleration, loading rate, foot angle [foot stance], and height) before any surface contact is taken into account. Extrinsic factors include footwear, the playing surface, and environmental factors.[3,14]

Extrinsic Factors

Many different shoe designs and cleat patterns have been developed over the years. The conventional cleated football shoe has 7 cleats, each measuring 3/4 inch in length. Alternatively, the conventional soccer shoe has $\geq$ 12 short molded cleats, ranging from 3/8 to 1/2 inch in both length and tip diameter. The "swivel shoe" incorporates a swivel plate on the heel section to prevent the foot from being fixed, but has cleats on the forefoot area. The "pivot disc" shoe modification contains a 10-cm circular plate on the forefoot and a central cleat, but retains a full set of heel cleats. By contrast, the "turf shoe" has a dense pattern of short (6.5-mm) elastomeric studs, which are distributed evenly over the entire sole. Finally, conventional noncleated court shoes, such as basketball shoes, tennis shoes, and running sneakers, have flat soles.[15,16]

New-generation turf shoes have now been developed, which include midsole cushioning to further dissipate the forces generated by ground contact.[16,17] Cleat shape can influence the shoe-surface interaction. Cleats are classified as edge-type, bladed, conical, cup-shaped, tapered, triangular, or elliptical.[8] Furthermore, cleats can be made from elastomeric or thermoplastic polyurethane (TPU) materials or from steel-tipped TPU.[16]

Conventional football shoes were determined not to be safe for use on either natural or artificial turf because such shoes generate significantly higher torque in the lower extremity.[15,18] Conversely, soccer shoes with a smaller cleat length and tip diameter were determined to be safe for use on all playing surfaces.[15]

Bonstingl et al[15] showed that the swivel shoe generated considerably lower torque in the toe stance position than any other shoe type, regardless of the playing surface. This suggests that turf shoes generate a lower peak torque than other shoe types (on all surfaces) due to the limited capacity of the short cleats to penetrate the infill layer in the artificial turf or the soil in a natural surface. However, these results are not in agreement with those reported by Livesay et al[19] and Cawley et al,[14] who showed that turf shoes generated higher torques and showed greater rotational stiffness than any other shoe when used on an artificial surface. Heidt et al[20] reported that both conventional cleated football shoes and turf shoes generate significantly higher rotational torques than either soccer shoes or noncleated shoes when used on both natural surface and artificial turf. Based on these studies, one may conclude that the high torques that develop when cleated shoes are used on artificial turf are related to the greater total effective area involved in cleat-surface contact, which is proportional to cleat number, length, and size.[14,15,18,21]

Although the sole material used for noncleated shoes has a minimal effect on torque generation,[15] Villwock et al[16] reported that the sole material used for cleated shoes has a significant effect on rotational stiffness. Shoes with rigid upper soles have a significantly higher rotational stiffness than shoes with pliable soles. The cleat material also makes a difference. Polypropylene cleats generate lower torques than polyurethane or rubber-like cleats and soles.[22]

In addition to the cleat and sole materials, the pattern and shape of the cleats has a significant impact on the amount of torque developed at the shoe-surface interface. Shoes with more cleats on the heel than on the forefoot generate lower torques than shoes with more cleats on the forefoot than the heel.[22]

Shoes with cleats located on the periphery of the sole generate significantly higher levels of torque than other designs, including soccer-type flat cleats, conical cleats, and pivot disc cleat; they are also associated with a significantly higher number of anterior cruciate ligament (ACL) injuries.[23]

Queen et al[17] found that the small cleats used in turf shoes resulted in less pressure on the plantar aspect of the foot, specifically the area beneath the metatarsal heads. They hypothesized that this could potentially minimize the occurrence of metatarsal stress fractures. Unfortunately, the sheer number of cleat patterns, materials, and sizes available in the marketplace prevents robust longitudinal studies from being performed, making it difficult to derive any firm, evidence-based conclusions.

The Impact of Artificial Turf on the Incidence of Lower Extremity Injuries

It is clear that playing surfaces and sports shoe characteristics have changed dramatically over the past several decades. It is important to keep this in mind when analyzing and interpreting the literature, as much of the early literature reflects a shoe-surface interface that is no longer relevant. In 1974, Adkison et al[5] reported higher rates of musculoskeletal injury in athletes playing on AstroTurf® than in those playing on natural grass (0.63 vs 0.51 injuries/game) over the course of 2 high school football seasons. These results were confirmed in other early studies.[2,24–26]

The modern third-generation (eg, FieldTurf) synthetic playing surfaces (Table 1) are less associated with sports-related injuries. In a prospective study, Meyers and Barnhill[11] analyzed data on football-related injuries sustained by high school athletes from 8 high school football teams in Texas over a 5-year time period and examined the relationships between the playing surface and the rate, cause, and severity of the injuries. They found that injuries sustained on FieldTurf were less severe and were followed by a more rapid recovery than those sustained on natural grass. Injuries sustained on FieldTurf tended to be noncontact injuries, such as skin lesions and muscle-related trauma. Injuries sustained on natural grass were more severe, including head and neurological trauma, as well as ligament injuries.

In a similar prospective study, Meyers[10] collected data on game-related football injuries sustained by collegiate athletes playing on both FieldTurf and natural grass. They found that of the 2253 reported injuries, 46.6% occurred on FieldTurf and 53.4% occurred on a natural playing surface. They classified the injuries as minor, substantial, or severe.

Table 1. Third-Generation Synthetic Turf and Related Injuries

Study	Sport	Level	Methods	Results
Meyers and Barnhill[11]	Football	High school	8 high schools over 5 seasons	• 1.5 vs 1.4 game-related injuries per game on FieldTurf vs natural grass, respectively (no statistical comparison was performed)
Meyers[10]	Football	College	24 universities over 3 seasons and 930 team games (50.5% on grass; 49.5% on FieldTurf)	• Lower rate of injury on FieldTurf compared with natural grass (45.7% vs 51.2%, respectively; statistically significant)
Hershman et al[13]	Football	NFL	NFL seasons 2000–2009 5360 team games (75% on grass; 25% on FieldTurf)	Knee sprains: 22% higher on FieldTurf • ACL sprains: 67% higher on FieldTurf ($P < 0.001$) • MCL sprains: no statistical difference Ankle sprains: 22% higher on FieldTurf • Eversion ankle injuries: 31% higher on FieldTurf ($P < 0.001$)[10] • Inversion ankle injuries: no statistical difference

Abbreviations: ACL, anterior cruciate ligament; MCL, medial collateral ligament; NFL, National Football League.

Overall, the incidences of minor, substantial, and severe injuries were significantly lower on FieldTurf.

However, not all studies reach the same conclusions. Data obtained from the National Football League (NFL) Injury Surveillance System (ISS) (which investigates game-related injuries) between 2002 and 2008 shows that the injury rate per team game was 27% higher on FieldTurf than on natural grass.[13,27] This was most evident for ACL injuries and eversion ankle injuries, which occurred more frequently (88% and 48%, respectively) on FieldTurf than on natural playing surfaces. The authors found no significant differences in the rates of inversion ankle sprains or medial collateral ligament (MCL) sprains occurring on synthetic surfaces or natural grass.

There is an interesting correlation between the incidence of surface-related injuries and playing at the elite level. One may infer that the more elite players (typically represented by NFL players) generate higher peak torques and strain because they carry more mass and generate more power than high school and college players. Further investigation is required.

Lower Extremity Turf-Related Injuries

Foot and Ankle Injuries

Nearly 25% of all injuries sustained by athletes are related to the foot and ankle.[28] Game-related ankle injuries account for 15.6%[29] of the injuries sustained by male National Collegiate Athletic Association (NCAA) football players, 16.95%[30,31] of the injuries sustained by male and female lacrosse players, and 19.1%[32,33] of the injuries sustained by male and female soccer players (according to the NCAA ISS). By contrast, foot injuries represent a much smaller percentage, averaging 1.86% across these sports.[29–31,33,34]

Turf Toe

Hyperextension injury of the metatarsophalangeal (MP) joint of the great toe is often referred to as "turf toe"[6] and is relatively common in football players.[35] The toe is most vulnerable to this injury when in dorsiflexion at the same time as the foot is in plantarflexion; any axial load then applied (eg, an offensive lineman falling onto the back of another player's heel) will force the great toe into hyperextension. Flexible shoes and hard playing surfaces are thought to be risk factors.[6]

Turf toe causes pain, disability, and varying degrees of instability. Patients typically describe an acute injury and present with pain and swelling of the metatarsophalangeal joint of the great toe. Plain radiographs can aid in diagnosis of sesamoid fracture or diastasis of a bipartite sesamoid.[35] Magnetic resonance imaging may be useful to confirm/rule out injury to the plantar capsuloligamentous structures.

Turf toe injuries are classified into 1 of 3 grades,[36] which help to determine the appropriate management strategy. Grade I injuries involve localized swelling and ecchymosis, representing attenuation of the soft tissue–supporting structures. Patients are treated symptomatically and can return to play when able. Patients with grade II injuries present with a pain-limited range of motion, with moderate swelling of the great toe due to a partial tear of the plantar capsuloligamentous structures. These patients are treated with short-term (2–4 weeks) immobilization in a walking boot or a hard-sole shoe. Grade III injuries are the most severe. Complete disruption of the soft tissue structures leads to large-scale swelling and ecchymosis, weakness of metatarsophalangeal flexion, and gross instability. These patients are treated with long-term immobilization (10–16 weeks) in a walking boot or hard-sole shoe, and may be considered for surgical intervention. Full recovery after surgical repair may take up to 1 year.[37]

Ankle Ligament Injuries

The classic ankle sprain results from an inversion or "rolling" motion of the foot relative to the tibia and causes injury to the lateral stabilizing ligaments. Hootman et al[38] evaluated the NCAA ISS data and found that ankle ligament sprains were the most common injury, accounting for 14.9% of all injuries.

Ekstrand et al[39] evaluated 290 elite European soccer players who played on third-generation turf and compared their injuries with those sustained by 202 players from the Swedish Premier League who played on natural grass. They found no relationship between the playing surface and the incidence of injury. They did, however, report a higher incidence of ankle sprains in players competing on artificial turf, but cautioned against drawing any conclusions; rather, they suggested that further investigations were needed given the small number of ankle injuries sustained by the study participants. Williams et al[40] reported a significantly increased risk of ankle injury in rugby, soccer, and American football players playing on third-generation artificial turf compared with natural grass.

A "high ankle sprain" is an eversion injury of the ankle mortise resulting in disruption of the tibiofibular syndesmosis. High ankle sprains injuries tend to be associated with artificial playing surfaces. Although these injuries are relatively uncommon, they result in prolonged disability.[41–43] A high ankle sprain usually occurs when an athlete is struck on the outside of the leg while the foot is firmly planted. Signs include swelling, ecchymosis, tenderness on palpation of the syndesmosis, and a positive squeeze test.[41] Radiographs can help to classify the injury and guide the management strategy. National Football League ISS data from 2010 suggest that this type of ankle injury has a 48% higher incidence on FieldTurf compared with natural grass.[27]

Knee Injuries

Darrow et al[44] examined the incidence of sports-related injuries in 100 high schools in the United States from 2005 to 2007. "Severe injury" was defined as any injury that resulted in preventing an athlete from participating in sport for 3 weeks. They found that knee injuries were the most common, accounting for 29% of severe injuries. In the NFL, an average of 6 game-related knee ligament injures occur per team per season.[12] Powell and Schootman[12] reported that between 1980 and 1989, NFL players sustained knee sprains more frequently on synthetic surfaces than on natural grass. Hershman et al[27] also found a difference in the incidence of knee injuries sustained on artificial and natural playing surfaces, reporting an 88% increase in game-related ACL injuries in NFL players competing on FieldTurf. Drakos et al[9] used a cadaver model to measure the degree of ACL strain imparted by a simulated "cut" (simultaneous axial loading and internal rotation of the femur) under different shoe-surface conditions. Significantly less stress ($P < 0.5$) was measured in the anteromedial bundle of the ACL when the subject was wearing cleats on a natural grass surface. They concluded that this shoe-surface interface may result in fewer noncontact ACL injuries due to the reduced stress placed on the ACL. By contrast, a literature review conducted by Williams et al[40] found no consistent association between the playing surface (third-generation turf vs natural grass) and the incidence of knee injuries. Meyers and Barnhill[11] reported a higher incidence of knee sprain/MCL injuries in high school football players playing on FieldTurf than in those playing on natural grass. However, they also reported a trend toward higher rates of ACL injury on natural grass than on synthetic surfaces, although the result was not statistically significant.[11]

Conclusion

Both synthetic playing surfaces and the shoes that athletes wear when competing on these surfaces have changed considerably over the past several decades, with a trend toward increasing installation of third-generation surfaces worldwide.[45] How this trend affects the health and safety of the athletes who play on these surfaces is still not clear. Biomechanical studies indicate that the shoe-surface interface has a significant impact on the incidence and type of sport-related injury,[9,19] suggesting that the amount of torque and subsequent strain generated when playing on artificial surfaces is greater than that generated when playing on natural grass.[9,16] Older studies of early-generation synthetic turf suggested that artificial surfaces were associated with higher injury rates.[2,5,24–26]

The clinical literature presents a more conflicted picture because many confounding variables, such as weather conditions, the mechanism of injury, the type of shoe worn by the athlete, and field wear, prevent definitive conclusions from being drawn. Furthermore, recent studies of third-generation turf suggest a possible correlation between the incidence of injury and the level of play (elite vs amateur). Meyers and Barnhill[11] report that less severe injuries are sustained by high school athletes playing on FieldTurf than those playing on natural grass, with a more rapid return to play after injury. In a separate study that evaluated college athletes, the authors reported that, overall, third-generation synthetic playing surfaces were associated with lower injury rates. By contrast, Hershman et al[27] reported that NFL players sustained significantly higher rates of ACL and eversion ankle injuries when playing on FieldTurf. However, these data are contradicted by studies conducted on lower-level athletes.[10,11]

Artificial surfaces have many financial benefits and result in increased field use. Therefore, these surfaces will continue to be installed globally. The optimal shoe-surface playing conditions remain unclear and may be both level and sport specific.

Conflict of Interest Statement

Samuel A. Taylor, MD, Peter D. Fabricant, MD, M. Michael Khair, MD, Amgad M. Haleem, MD, and Mark C. Drakos, MD, disclose no conflicts of interest.

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