Review Article

Synthetic Playing Surfaces and Athlete Health

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Abstract

Synthetic playing surfaces have evolved considerably since their introduction in the 1960s. Today, third-generation turf is routinely installed in professional, collegiate, and community settings. Proponents of artificial surfaces tout their versatility and durability in a variety of climates. However, the health and injury ramifications have yet to be clearly defined. Musculoskeletal injury is largely affected by the shoe–playing surface interface. However, conclusive statements cannot be made regarding the risk of certain shoe–playing surface combinations because of the variety of additional factors, such as weather conditions, shoe wear, and field wear. Historically, clinical studies have indicated that higher injury rates occur on artificial turf than on natural surfaces. This conclusion is backed by robust biomechanical data that suggest that torque and strain may be greater on artificial surfaces than on natural grass. Recent data on professional athletes suggest that elite athletes may sustain injuries at increased rates on the newer surfaces. However, these surfaces remain attractive to athletes and administrators alike because of their durability, relative ease of maintenance, and multiuse potential.

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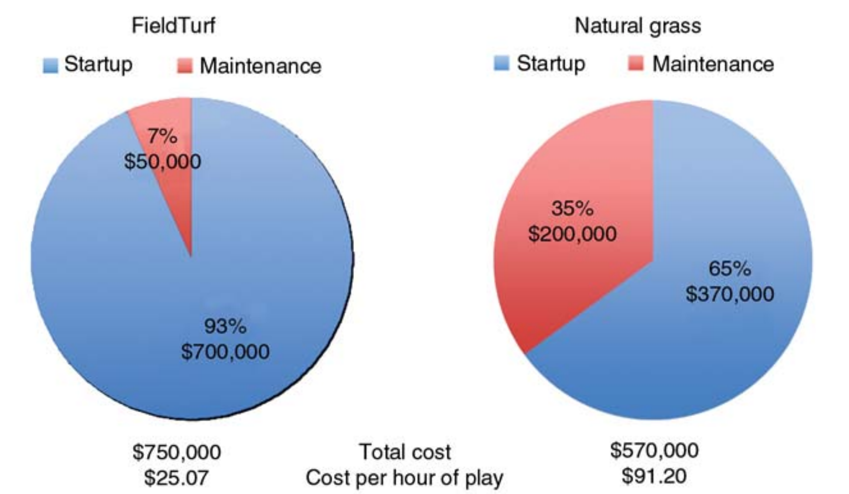
Injury rates, mechanisms of injury, and risk factors for injury in professional and high-level collegiate athletes are of considerable concern and have received much attention in the medical community.[1-5] Sports-related injuries are seen at all playing levels, however. In fact, more than 11 million adolescents participate annually in organized athletics across the 18,500 high schools in the United States.[6]

The societal effects of sports-related injury are tremendous, with nearly 2.6 million emergency department visits resulting from sports-related injuries in children and young adults (aged 5 to 24 years) annually in the United States.[7] Injured high school athletes account for almost 500,000 office visits and 30,000 hospitalizations annually. In 2007, Knowles et al[8] estimated the overall annual cost of adolescent sports-related injury in North Carolina alone to be $144.6 million. Nationwide, the financial implications are staggering, with high school athletes accounting for almost $2 billion of healthcare costs each year.[7]

Artificial surfaces were introduced in the 1960s to increase playing surface durability, provide an indoor surface that is relatively easy to maintain, and offer urban children with sport and fitness opportunities comparable to those of their rural counterparts.[2] Despite the advantages of artificial turf, significant health concerns exist, such as higher injury rates, greater potential for concussion, communicability of bac-

Figure 1



Graphic representation of installation costs for one brand of artificial playing surface and natural grass. Although installation costs of artificial turf are higher than those of natural grass, maintenance costs for natural grass are nearly four times higher than for this brand of artificial turf, resulting in a 10-year cost advantage for artificial turf when cost per hour of play is considered (natural grass, 6,250 hours; artificial turf, 29,920 hours). (Data used to create this graph were obtained from Tarkett Sports: FieldTurf: Statistical summary. http://www.fieldturf.com/en/fieldturf-difference/cost-analysis.[9])

terial and fungal illness, and potential carcinogenesis.

History of Artificial Turf

Artificial playing surfaces were created with the intent to increase the durability and versatility of the playing surface, thereby enabling multisport use and to provide an indoor surface that was relatively easy to maintain. Coupled with field lighting, the playing hours and income generated increased considerably at sports facilities equipped with synthetic fields. The fields were more durable than natural grass with regard to both seasonal weather conditions and frequency of use. In addition, the maintenance required for artificial surfaces was appealing, even with the higher initial investment.

The durability of artificial turf allows continual use. One manufacturer estimates that although the initial capital cost of a third-generation artificial turf field exceeds that of natural grass by $330,000, the lower maintenance costs and increased number of hours that the field can be used results in a lower cost per hour of use for third-generation artificial turf ($25.07 and $91.20, respectively)[9] (Figure 1). Similar findings have been indicated by noncommercial entities, as well.

For example, the Harvard University football stadium recently was converted from natural grass to third-generation turf to expand the utility of the space. Since then, multisport usage has increased more than 20-fold (Jon Lister, Assistant Director of Athletics, Harvard University, Cambridge, MA, personal communication, 2012). The annual maintenance costs are lower for synthetic turf, but the 10-year costs are equal to those of natural grass. The synthetic playing surface remains constant despite changing weather conditions, whereas a natural field may be reduced to bare dirt toward the end of the season in cold climates. Synthetic turf does not require weekly grooming and repainting. Annual upkeep includes light grooming, quarterly disinfection, and biannual spraying with fabric softener to reduce static. Typically, the sand and granulated rubber infill is replaced every 5 to 10 years. Furthermore, increased durability of artificial surfaces allows use of the facility for events other than sports (eg, concerts), which may increase the profitability of a venue.

In 1966, the Houston Astrodome became the first professional sports stadium in the United States in which synthetic turf was installed.[10] First-generation playing surfaces (eg, AstroTurf [Textile Management Associates]) consisted of a dense carpet that was constructed from durable nylon fibers and had no fill (ie, no substance between fibers) (Table 1). Initially, these surfaces caused high rates of skin abrasion (ie, turf burn) and generated high ball-bounce because of the absence of padding for impact absorption.[11] To address these problems, shock-absorbing pads were added beneath the playing surface, and water was added to reduce friction and, thus, severity of skin abrasion.

Second-generation playing surfaces were developed in the 1970s. Fibers were made of softer polyethylene, which were approximately twice as long as first-generation systems to accommodate sand fill (20 to 25 mm).[12] To save on costs and accommodate the fill material, the fibers also were spaced farther apart (Figure 2, B). Fill provides a softer, more uniform surface as well as a more consistent and natural ball bounce and roll. Turf shoes with multiple short dimples were introduced that interfaced well with these new artificial surfaces. However, after the ini-

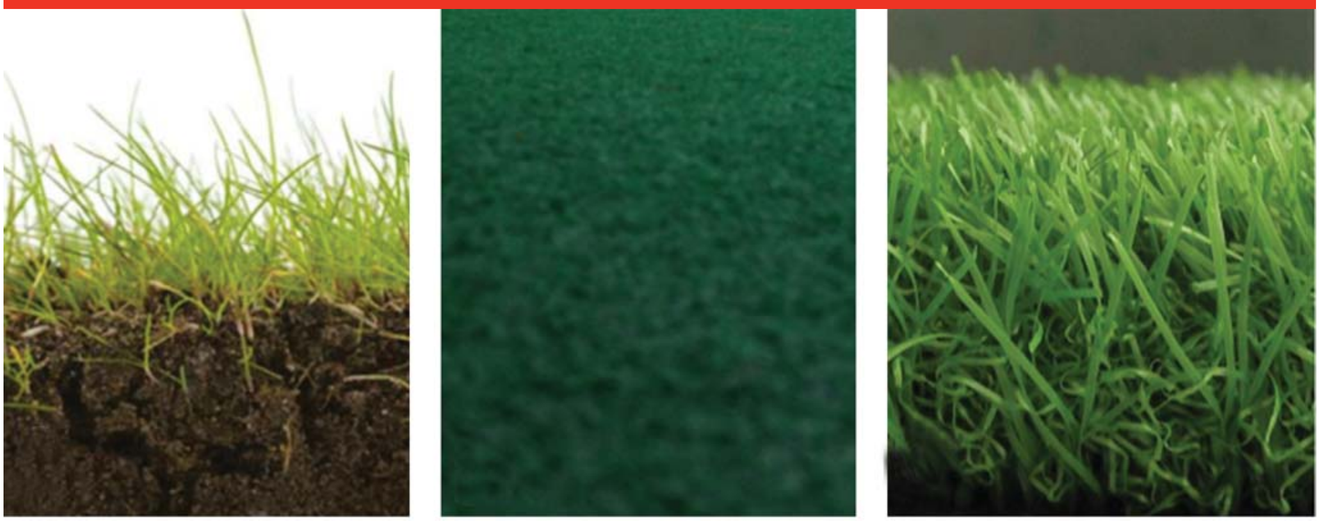
Table 1

Artificial Playing Surface Characteristics by Generation

Generation	Decade Introduced	Fiber Material	Fiber Length	Fill	Risks
First	1960s	Nylon	10–12 mm	None	Skin abrasion, ankle sprain
Second	1970s	Polyethylene	20–25 mm	Sand	ACL and MCL injury, concussion, ankle sprain, turf toe
Third	Late 1990s	Proprietary monofilaments, textured, coated	40–65 mm	Rubber, sand	Equivocal

ACL = anterior cruciate ligament, MCL = medial cruciate ligament

Figure 2



A B C

Photographs of various turf playing surfaces. **A,** Natural grass shown in cross section. **B,** Second-generation artificial turf, with a sand base and short blade length. This type has become obsolete, in favor of third-generation turf (**C**), which has longer artificial blades to better simulate grass as well as a crumbled rubber base.

tial excitement over durability and reduced maintenance expenses, players, coaches, physicians, and trainers began to notice higher injury rates, prompting further innovation in turf and turf shoes.[12]

Third-generation artificial surfaces (eg, FieldTurf) were developed in the late 1990s to more closely replicate natural grass in both consistency and fiber morphology[10] (Figure 2, C). Fiber length and density increased. The addition of newer fill consisting of a base layer of sand and rubberized particles to a level of 60% to 70% of the fiber height resulted in a product that more closely replicated dirt between blades of grass, giving the surface a more natural feel and playability (Figure 3). The percentage of sand and infill as well as the makeup of the infill vary considerably by company and field design.

Proprietary and experimental fibers, fills, and tuft densities are being investigated to develop fourth-generation surfaces consisting of varying fiber blends, spacing, length, and texture.

Shoe–playing Surface Interface

Shoe–playing surface behavior is complex and is influenced by intrinsic and extrinsic factors.[13] Intrinsic factors pertain to the athlete and include body weight, velocity, acceleration, deceleration, loading rate, angle of the foot (ie, foot-stance), and height before contact. Extrinsic factors include footwear, type of playing surface, and related environmental factors.[10,13] Extrinsic factors are of particular interest, specifically the sole and cleat/stud material, number and size of cleats, and cleat configuration.

To understand the shoe–playing surface interaction, it is important to review some physics concepts. The coefficient of friction is the linear relationship of force required to slide one surface across another. This value is a physical characteristic of the surfaces; each surface carries a unique coefficient, similar to the way in which each fingerprint is unique.[14]

Figure 3

Photograph of a third-generation artificial playing surface. Note the long artificial blade length and the black crumbled rubber base (arrow).

As defined by Torg et al,[15] the coefficient of release (*r*) is based on peak torque that develops at the shoe–playing surface interface. In testing different shoe types on different natural and artificial playing surfaces, Torg and colleagues[15,16] pioneered the categorization of shoe–playing surface combinations based on the value of release coefficients (*r*) as safe, probably safe, and not safe. The coefficient of restitution represents the ability of a field to absorb shock. This characteristic is of particular importance when considering concussion risk. It represents the ratio of maximum acceleration (deceleration) experienced during impact to the normal rate of acceleration due to gravity (ie, 1 G). The shock-absorbing performance of the playing surface is inversely related to the Gmax value. As the Gmax value increases, the shock-absorbing performance decreases. The United States Consumer Products Safety Commission determined that fields with a Gmax of >200 at any testing point are unsafe for athletic play.[17,18]

Rotational stiffness is the rate at which torque develops under rotation in the shoe–playing surface interface. Livesay et al[19] tested 10 shoe–playing surface combinations and found that differences in rotational stiffness were greater than peak torques in all cases. This finding led to the introduction of rotational stiffness as a new criterion with which to evaluate different shoe–playing surface combinations.

Many different shoe sole and cleat patterns are commercially available. The conventional football cleat shoe has seven 0.75-inch–long cleats (Figure 4, A). Soccer shoes have 12 or more molded cleats ranging from 0.375 to 0.5 inch in both length and cleat tip diameter. In the swivel shoe, the heel cleats are replaced with a swivel plate to prevent foot fixation; cleats remain as is in the forefoot area. The pivot disk is a 10-cm circular plate on the forefoot sole that includes a central cleat. The heel cleats are maintained. The turf shoe has a dense pattern of short (6.5-mm) elastomeric studs distributed over the entire sole (Figure 4, B). Noncleated court shoes such as basketball shoes,

Figure 4

A

B

Photographs of cleat patterns (arrows) on a conventional football cleat shoe (**A**) and a classic turf shoe (**B**). Each shoe style produces unique shoe–playing surface interaction patterns and may influence injury type and severity.

tennis shoes, and running sneakers have flat soles and no protrusions.[14,20] New-generation turf shoes have been further modified to include midsole cushioning to dissipate force during ground contact.[20,21]

Cleat shape also influences the shoe–playing surface interaction. Cleats may be edge-type (ie, located peripherally), bladed, conical, cup-shaped, tapered, triangular, or elliptical.[22] Cleats are made of elastomeric material or thermoplastic polyurethane or steel-tipped thermoplastic polyurethane.[20] Most types of shoe have higher peak torques on artificial turf than on natural grass.[14,19,20]

The effect of shoe type on the biomechanics of the shoe–playing surface interface was initially stigmatized when the conventional football shoe was deemed to be "not safe" on either natural or artificial turf due to markedly higher torque than any other shoe type.[14,15] Torg et al[15] concluded that soccer shoes with the smallest cleat length and tip diameter (ie, 0.5 inch) were safe on all playing surfaces. Livesay et al[19] and Cawley et al[13] further demonstrated that on artificial turf, turf shoes exhibited the highest torques and rotational stiffness of any shoe–playing surface combination. Heidt et al[23] showed that both conventional cleated football shoes and turf shoes exhibited significantly higher rotational torques on both natural and artificial turf compared with soccer shoes and noncleated (ie, court) shoes ($P < 0.05$). It follows that high torques generated by cleated shoes on artificial turf are related to higher total effective cleat contact surface area, which is influenced by the number of cleats as well as increased cleat length and diameter.[13-16]

Sole material affects torque and rotational stiffness. Bonstingl et al[14] found that in noncleated shoes, the outsole design and material have little effect on differences in torque generated on various surfaces. However, Villwock et al[20] found that in cleated shoes, the material of the sole had an effect on rotational stiffness. Shoes with rigid upper soles have significantly higher rotational stiffness than do shoes with relatively pliable soles ($P < 0.05$). Such a difference in material characteristics could be a factor in injury; however, to date, there are no clinical studies corroborating this finding.

Cleat pattern and shape have a marked impact on torque at the shoe–playing surface interface. Shoes with more cleats on the heel than the forefoot have lower torques than do shoes with more cleats on the forefoot than the heel.[24] Edge cleats were found to have significantly higher torques than other designs (ie, soccer-type flat cleats, conical cleats, pivot disk) ($P < 0.05$) and were significantly associated with higher anterior cruciate ligament (ACL) injury rates (0.017% [edge] versus 0.005% [all other designs combined]).[25] Queen et al[21] compared the effect of different cleat shapes on foot loading. Compared with bladed and elliptical cleats, small cleats in turf shoes had the lowest plantar pressures on the foot, specifically, beneath the metatarsal heads; use of small cleats in these shoes could potentially minimize the incidence of metatarsal stress fracture. Due to the large size of and constant changes in the athletic shoe market, long-term data and well-designed prospective studies are scarce.

Health and Injury Concerns Related to Artificial Turf

Many researchers have attempted to evaluate the impact of artificial playing surfaces on injury. It is important to note that much of the early literature reflects a shoe–playing surface interface that is no longer routinely used. For example, Scranton et al[12] reported on the incidence of noncontact ACL injuries in the National Football League (NFL) among athletes who wore turf shoes on first- and second-generation turf. Today, however, players perform on third-generation turf, often wearing cleated shoes. Historically, concussion and neurotrauma also were reported to be more frequent[26] and more severe[27,28] on artificial surfaces than on natural grass.

DeLee and Farney[29] reported that 2,228 football-related injuries, including 137 severe injuries requiring hospitalization, were sustained during the 1989 season at a total of 100 high schools in Texas. The severe injury incidence rate was 0.031 injury per athlete per year and 0.003 injury per hour of exposure per student athlete. The knee was the most commonly injured joint, followed by the ankle.

Some studies evaluating modern third-generation synthetic playing surfaces demonstrate a lesser association with sport-related injury (Table 2). In a prospective study of eight high school football teams in Texas over a 5-year period, Meyers and Barnhill[30] reported that fewer severe injuries were sustained on FieldTurf than on natural grass and that athletes injured on the artificial surfaces recovered more quickly. Although the overall injury rates between the two surfaces were similar, injury type differed markedly. There was a higher incidence of noncontact injuries, skin lesions, and muscle-related trauma on the artificial surface. In contrast, natural grass was associated with increased incidences of severe injuries, including 1- to 2-day time-loss injuries, >22-day time-loss injuries, head and neurologic trauma, and ligament injuries.

In a study of collegiate football players, however, Meyers[31] reported that FieldTurf may be safer than natural grass. Information was collected from 465 collegiate games over three seasons, with a nearly equal distribution between FieldTurf and natural grass. Of the 2,253 reported injuries, 46.6% occurred on FieldTurf and 53.4% occurred on natural playing surfaces. Injuries were classified as minor, substantial, or severe. Statistical analysis suggested decreased injury rates in all severity categories on FieldTurf. This finding was contradicted by subsequent research on professional football players. Hershman et al[32] gathered data from the NFL Injury Surveillance System on game-related injuries from 2000 through 2009 and found an overall 22% higher rate of knee and ankle injuries per team-game on FieldTurf than natural grass (Table 2). The rate of ACL injury was 67% higher on FieldTurf than on natural grass ($P < 0.001$), and the rate of ankle eversion injury was 31% higher on FieldTurf ($P < 0.001$). No statistical difference was noted for inversion ankle injuries or MCL injury.

Table 2

American Football–related Lower Extremity Injuries on Third-generation Synthetic Turf

Study	Level of Play	Results and Conclusions
Meyers and Barnhill[30,a]	High school	Equivalent number of injuries per game: 1.5 on FieldTurf (Textile Management Associates) and 1.4 on natural grass. No statistical comparison was performed.
Meyers[31,a,b]	College	FieldTurf may be protective: 45.7% of injuries occurred on FieldTurf and 51.2% occurred on natural grass ($P = 0.016$).
Hershman et el[32]	Professional	Knee sprain: 22% higher incidence on FieldTurf than on natural grass. ACL sprain: 67% higher incidence on FieldTurf ($P < 0.001$); MCL sprain: no statistical difference. Ankle sprain: 22% higher incidence on FieldTurf. Eversion ankle injury: 31% higher incidence on FieldTurf ($P < 0.001$); inversion ankle injury: no statistical difference.

ACL = anterior cruciate ligament, MCL = medial collateral ligament
[a] One or more authors declared a potential conflict of interest
[b] Percentages given are from a multivariate analysis.

Foot and Ankle Injuries

Foot and ankle injuries are common among athletes, accounting for 25% of all injuries seen.[33] Game-related ankle injuries in National Collegiate Athletic Association (NCAA) men's football, men's and women's lacrosse, and men's and women's soccer account for 15.6%,[34] 17%,[35,36] and 18.3%,[37,38] respectively, of all injuries in each sport. In contrast, foot injuries in these athletes represent a much smaller percentage, averaging 1.9%.[34-36,38,39]

Turf Toe

Bowers and Martin[40] coined the term turf toe to describe metatarsophalangeal (MTP) joint hyperextension injury with predisposing factors that included "playing surface hardness and shoe flexibility." Turf toe is a plantar MTP capsuloligamentous injury that results in pain, disability, and instability. Injury patterns include strain, tear, dislocation, subchondral impaction of the metatarsal head, and sesamoid fracture. Turf toe and sesamoid fracture have similar presentations,[41,42] and accurate diagnosis is critical to proper management. Patients typically describe an acute injury and present with pain and swelling about the great toe MTP joint. Rodeo et al[4] suggested artificial turf as a risk factor for turf toe, reporting in 1990 that 83% of professional football players sustained the injury on artificial turf ($P < 0.05$). The foot is most vulnerable to this injury when the great toe is dorsiflexed, the foot is plantarflexed, and an axial load is applied, forcing the great toe into hyperextension.[41,43] Recently, flexible shoe wear has been implicated as a risk factor; however, additional research is needed to elucidate the pathomechanics of turf toe in relation to modern synthetic surfaces.[43]

Ankle Ligamentous Injury

In an analysis of NCAA Injury Surveillance System data gathered over 16 years, Hootman et al[44] found ankle ligament sprain to be the most common injury type, accounting for 15% of all injuries. Williams et al[45] found an increased risk of sustaining an ankle injury on third-generation artificial turf compared with natural grass in 8 of the 14 cohorts evaluated in a systematic review. Ekstrand et al[46] evaluated 290 elite European soccer players who performed on third-generation turf compared with 202 players from the Swedish Premier League who performed on a natural grass surface. They found no evidence of increased injury rates on artificial turf. They did find a higher incidence of ankle sprains on artificial turf, but because of the small number of these injuries incurred by study participants, the authors cautioned against drawing conclusions and recommended further investigation.

High ankle sprain typically is caused by an eversion rotation-type mechanism that results in tibiofibular syndesmotic injury. Although this injury pattern is relatively uncommon, it often results in prolonged disability.[47-49] The high-friction shoe–playing surface interface, which allows minimal slippage of a planted foot, has been implicated in this injury mechanism. A recent report of NFL surveillance data indicated that the rate of game-related high ankle sprain was 31% higher on FieldTurf than on natural grass.[32]

Knee Injuries

Darrow et al[50] assessed data on sports-related injuries from 2005 through 2007 at 100 US high schools. Severe injury was defined as any injury that resulted in lost participation lasting >3 weeks. Knee injuries were the most common type, accounting for 29% of severe injuries.

In a recent review, Williams et al[45] found an inconsistent association between risk of knee injury and playing surface (ie, third-generation turf, natural grass). Although the total number of injuries was small, Meyers and Barnhill[30] showed higher rates of knee sprain/MCL injuries on FieldTurf than on natural grass in high school football players. In contrast, data from the NFL in the years 1980 through 1989 indicated an average of six game-related knee ligament injures per team per season.[51] Bradley et al[52] studied knee injuries in the NFL from 1994-1998. There was an average of 2,100 injuries annually during the study period. More than 20% of all injuries were related to the knee, and 2% (209) of all injuries were ACL tears. Injury rates were higher during preseason practices and games. Powell and Schootman[51] reported higher rates of knee sprain among NFL players on a synthetic surface (ie, AstroTurf) than on natural grass in the years 1980 through 1989. Most recently, Hershman et al[32] reported that game-related ACL injury in NFL players was 67% higher on FieldTurf than on natural grass.

Biomechanical data suggest that the chance of knee injury may be affected by the shoe–playing surface interface. Drakos et al[53] used a cadaver model to assess ACL strain during a simulated cut (ie, axial load and internal rotation of the femur) with four different shoe–playing surface combinations: AstroTurf–turf shoe, third-generation turf–turf shoe, third-generation turf–cleats, and natural grass–cleats. Significantly lower strain occurred in the anteromedial bundle of the ACL in specimens tested with cleats on natural grass ($P < 0.05$). The authors postulated that the effect of the shoe–playing surface interface on ACL strain during a cutting motion may affect the rate of noncontact ACL injury. This has been corroborated by other studies that found higher peak torques and greater rotational stiffness on the newer artificial surfaces.[19,21]

Nonmusculoskeletal Injuries

The impact of artificial surfaces on athlete health often focuses on the shoe–playing surface interface and its relation to lower extremity injuries. However, there are also concerns regarding increased concussion rates, transmission of communicable diseases, and potential carcinogenicity related to the crumb rubber infill used in third-generation artificial turf.

Concussion

Concussion is a significant concern for players, families, coaches, and trainers. In their 11-year prospective study evaluating the trends regarding concussions in high school athletes, Lincoln et al[54] noted that football accounts for more than half of all concussions. Player-to-player contact is the most common mechanism (76.2%), but a sizable number of concussions are caused by contact with the playing surface (15.5%).[55] The playing surface directly affects how much energy is absorbed by the brain. In one study, peak acceleration after impact was measured on three different playing surfaces: natural grass outdoors, indoor artificial turf (ie, practice field), and turf in a domed stadium (ie, game field).[28] Peak acceleration was greatest on the stadium turf field, followed by the natural grass field, followed by the practice turf field.

In vivo observations have demonstrated that athletes who sustain concussions on artificial turf are more likely to lose consciousness than those who sustain a concussion on natural grass.[27] These preliminary data were obtained on players injured on second- and early third-generation artificial turf surfaces. Newer studies are needed to determine the effect of softer contemporary artificial surfaces on concussion risk.

Coefficient of restitution is a measure of the ability of a field to absorb shock; thus, fields with lower coefficients of restitution will absorb more shock, which theoretically can lower concussion risk. The currently accepted standard for Gmax safe levels is 200 G, as set forth by ASTM International[18] and the United States Consumer Product Safety Commission.[17]

To ensure consistent compliance and safety, impact testing should be performed regularly. Over time, synthetic surfaces become harder, and Gmax values increase at a rate determined by materials used, construction, level of play, and frequency of use. Annual testing provides a historical trend for any given field and alerts field managers to potential problems before they become critical. The effect of weather and climate on impact testing should provide impetus for more frequent testing during peak use and the preseason.

Skin Infection

Skin infections are common in various athletic activities. For example, wrestlers are exposed to fungal infections from direct contact with opponents or contaminated mats; these infections cause 17% of time-loss wrestling injuries.[37,56] When considering the impact of artificial turf on infections, it is important to take into account two factors: the ability of the surface to create surface abrasions that can become superinfected, and the hospitability of the surface to pathogens. Ekstrand and Nigg[11] reviewed surface-related injuries in soccer players and concluded that abrasions are more common on artificial turf than on natural grass.

Bacterial infections can manifest as impetigo, cellulitis, erysipelas, folliculitis, or abscess.[57] Usually, these pathogens require a breach in the skin caused by abrasion, laceration, or other local trauma. The two most common offending bacterial species are *Staphylococcus aureus* and group A *Streptococcus*. Methicillin-sensitive *S aureus* was found in 42% of the players and staff of one professional American football team.[58] The incidence of community-acquired methicillin-resistant *S aureus* (CA-MRSA) infection is increasing; the same study indicated that 9% of the St. Louis Rams professional football team contracted a CA-MRSA infection during the 2003 season. All the infections developed at turf-abrasion sites. Begier et al[59] investigated a CA-MRSA outbreak involving a college football team and reported a relative risk of 7.2 for turf burns (ie, abrasions caused by artificial playing surface). Waninger et al[60] evaluated artificial turf as a risk factor for CA-MRSA in the laboratory setting and determined that CA-MRSA inoculum could survive on artificial turf in high concentrations for 1 week and at lower concentrations for up to 1 month. Survival of the inoculum may be affected by precipitation, temperature variability, or other outdoor sport surface–related variables that were not controlled in this laboratory study.

Airway Irritation

No published data suggest that modern third-generation synthetic playing surfaces are a source of allergens that may potentiate allergic rhinitis or exacerbate asthma. Several extrinsic factors influence upper- and lower-airway reactive disease, including temperature, humidity, allergens, and mucosal irritants. Exposure to pollutants such as nitrogen oxides,[61] diesel exhaust particles,[62] and chlorine from pool water,[63,64] which have been linked to airway irritation in skating athletes and swimmers, respectively, has not been reported in athletes who play on turf. Although theoretically, heat retention by the field and replacement of pollen-producing natural grass could possibly be protective, no data currently exist to support that idea.

Carcinogenic Risk

Concerns about the potential carcinogenic risk associated with exposure to recycled rubber infill granulates in third-generation artificial turf, whether through inhalation, ingestion, or topical contact, have not been substantiated, and there are no documented reports of any such occurrence to date. Birkholz et al[65] found that crumb rubber used on playgrounds poses a minimal hazard to children. van Rooij and Jongeneelen[66] quantified exposure of football players to polycyclic aromatic hydrocarbons by measuring urine excretion of 1-hydroxypyrene. They found uptake of the compound to be comparable to that incurred though normal environment and/or diet. The Connecticut Department of Public Health assessed inhalation exposure to chemicals of potential concern.[67,68] Theoretical modeling, which took into account respiration rate for both adults and children, determined that the levels were at or below the minimum levels of concern for cancer risk in all cases. It was concluded that inhalation of air at synthetic turf fields is not associated with increased health risks.

Summary

Synthetic playing surfaces have changed considerably since their introduction in the 1960s. Third-generation turf has been installed in a variety of settings, including NFL stadiums, NCAA division I schools, scores of high schools, and many recreational football fields.

Despite the increased popularity of third-generation artificial turf fields, the effect of this playing surface on athlete health and injury rates has yet to be fully elucidated. Confounding variables such as weather conditions, contact versus noncontact injuries, shoe wear, and field wear make it difficult to definitively state the true risk of certain shoe–playing surface combinations. Although previous research suggested that rates of injury are higher on artificial turf than on natural grass, these results must be substantiated based on currently available artificial turf surfaces. Current data from the NFL suggest that elite athletes may sustain injuries at increased rates even on the newer surfaces;[32] however, these findings have been debated in players below the elite level.[30,31]

Artificial surfaces are attractive to administrators because of the potential for decreased costs and maintenance. However, this enthusiasm should be tempered by the potential increase in injury risk in elite athletes. Optimal shoe–playing surface playing conditions may be level- and sport-specific. The shoe–playing surface interface is a modifiable risk factor for injury, and further research is needed to improve playing conditions for athletes at all levels.

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