Synthetic Turf: History, Design, Maintenance, and Athlete Safety

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Context: Synthetic turf has become an increasingly common playing surface for athletics and has changed dramatically since its introduction more than 50 years ago. Along with changes to surface design, maintenance needs and recommendations have become more standardized and attentive both to upkeep and player-level factors. In particular, synthetic turf maintenance as it relates to athlete health and safety is an important consideration at all levels of play.

Evidence Acquisition: A literature search of MEDLINE and PubMed for publications between the years 1990 and 2018 was conducted. Keywords included s*ynthetic turf, artificial turf, field turf*, and *playing surface*. Additionally, expert opinion through systematic interviews and practical implementation were obtained on synthetic turf design and maintenance practices in the National Football League.

Study Design: Clinical review.

Level of Evidence: Level 5.

Results: Synthetic turf has changed considerably since its inception. Playing surface is a critical component of the athletic environment, playing a role both in performance and in athlete safety. There are several important structural considerations of third-generation synthetic turf systems currently used in the United States that rely heavily on strong and consistent maintenance. A common misconception is that synthetic turf is maintenance free; in fact, however, these surfaces require routine maintenance. Whether athletes experience more injuries on synthetic over natural surfaces is also of interest among various levels and types of sport.

Conclusion: Modern synthetic turf is far different than when originally introduced. It requires routine maintenance, even at the level of local athletics. It is important for sports medicine personnel to be familiar with playing surface issues as they are often treating athletes at the time of injury and should maintain a level of awareness of contemporary research and practices regarding the relationships between synthetic turf and injury.

Keywords: synthetic turf; artificial turf; field turf; playing surface

In recent years, there has been increasing focus on injury prevention in sports, particularly in American football.[38] In particular, researchers are considering how nonplayer factors such as protective equipment and the playing environment relate to athletic injury.[21] Introduced more than half a century ago, synthetic turf has recently come into the spotlight as an important factor in sport, from both a performance and a player health perspective.[53,54] Technical advancements in design and manufacturing have evolved these surfaces from a dense short-fiber (<1.25 mm) nylon carpet to a less dense and much longer (<70 mm) primarily polyethylene fiber that allows for the inclusion of granular crumb rubber and sand (infill) to occupy the space between the fibers. Some have postulated that this combination of fiber and granular material more closely mimics the properties of natural turfgrass.[30]

The rise in the popularity and use of these surfaces is demonstrated by the fact that they can be found everywhere from elementary school playgrounds to National Football League (NFL) stadiums across the United States.[1] It is estimated that by 2011, there were more than 6000 synthetic turfs installed in North America with roughly 1000 to 1500 new installations each year.[48] The aim of this review is to report on the published literature regarding the history and science of synthetic turf design, turf maintenance, and concerns for athlete health on these surfaces.

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Sports medicine personnel are often first responders to athletic injuries and should be aware of turf-related health issues.

HISTORICAL CONTEXT

It is thought that the first installation of synthetic turf at a major sporting venue occurred in Houston, Texas, at the Astrodome in 1966. ChemGrass (Monsanto), a short-fiber, dense nylon carpet, was installed over a compacted soil base in the stadium.[52] The subsequent year, a closed-cell, elastomeric foam pad was installed between the carpet backing and the soil. ChemGrass was soon referred to as AstroTurf. Throughout the 1970s and 1980s, many newly constructed multisport stadiums and several existing stadiums replaced their natural turfgrass with AstroTurf. The intrigue was based on the surface's ability to withstand a high volume of traffic while still providing a consistent playing surface. This enabled cities to construct multiuse stadiums with movable seating that could host a variety of concert and sporting events in a condensed time period without damaging the playing surface. However, by the later part of the 1980s, this first-generation synthetic turf was receiving criticism for its possible contribution to athlete injuries.[42,43,45]

Subsequently, second-generation synthetic turf, first invented in 1976 by Frederick T. Haas, was introduced. These second-generation surfaces included a shock-absorbing pad beneath a carpet that contained much longer fibers compared with the first-generation systems. The carpet pile was filled with silica sand to within several millimeters of the top of the fibers, allowing them to stand upright. While second-generation playing surfaces were not widely adopted within the United States,[20,43] they did pave the way for the modern, third-generation systems now commonly used.

Similar to second-generation turf, third-generation surfaces are an infilled system wherein the space between the vertical pile fibers is filled with a granular material. Third-generation systems use an infill material consisting of either crumb rubber or a combination of crumb rubber and silica sand, as opposed to the pure sand typical of second-generation systems. The first of these third-generation systems was developed by FieldTurf and was installed in 1997 at a high school in Pennsylvania.[43] Since then, several companies have developed similar products.

COMPONENTS OF MODERN SYNTHETIC TURF SYSTEMS

Third-generation synthetic turf comprises several components (Figure 1). The first is a stable base of gravel, asphalt, or concrete. Base construction is largely determined by cost and the intended use of the surface. If only sporting events and light vehicle traffic are expected, a well-drained compacted gravel base will suffice. If the surface will need to support large cranes or other heavy vehicular traffic, porous asphalt or capillary concrete may be specified. For all installations, but particularly for outdoor venues, all components of the synthetic turf including the base should be porous to allow for surface drainage. A shock-absorbing pad, up to 25 mm in thickness, is sometimes installed over the compacted base. These pads were originally installed because first-generation systems were generally 1.25 mm or less in thickness and contained no infill. The pad increases the shock absorption of the surface.[37,51] Upon the pad, if present, sits the actual turf, which includes a backing to which the pile fibers are attached either by glue or by tufting the fibers through the backing layer. The fibers of modern systems have a pile height in the range of 40 to 70 mm and have been made of polyethylene, nylon, or polypropylene, although polyethylene fibers are most popular currently. There are 2 types of fibers: slit film or monofilament. The slit film fibers are produced in sheets, cut into strips, slit to create multiple grasslike "blades," and then twisted together and stitched or tufted into the backing. Monofilament fibers have a more symmetric cross-sectional shape compared with the slit film bladelike fibers. These thicker fibers were designed to increase resistance to wear, remain more upright, and resist matting to a greater degree compared with slit film fibers. The more upright fibers are believed to affect ball roll and are often selected when the field is used predominantly for soccer. Unlike slit film fiber, where a group of fibers is tufted through the backing, monofilament fibers are individually stitched and then glued onto the backing.

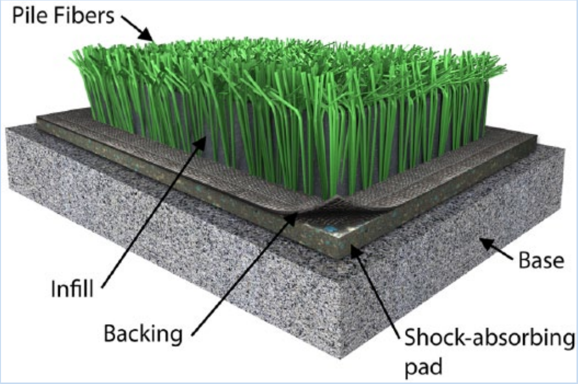

Figure 1. Components of a third-generation synthetic playing surface.

The material that takes up the space between the grasslike fibers is the infill, which typically contains either rubber or a combination of rubber and silica sand. In most current synthetic surfaces, the infill material is installed to a depth of 25 to 40 mm of the total 40 to 70 mm of fiber length. The crumb rubber typically is a product of recycled vehicle tires that are either ground or cryogenically frozen and shattered and then sized to granules between 2 and 3 mm. The benefit of rubber as a material is its high elasticity and resistance to weathering. Turf systems rely on this crumb rubber to provide cushioning to athletes during play, especially when a pad layer is not present. Other manufactured granular infill materials include elastomer, polymer, or organic substances such as coconut fiber, cork, and ground walnut shells. These alternative materials may be used more commonly in the future.

Carpet sections with grasslike fibers are generally manufactured in 15-foot (4.572-m) widths. During installation, these sections are either stitched or glued together. This creates seams in the playing surface, which have been a concern. Historically, first-generation fields were thin, and small discrepancies in surface grade where the seams joined together created a concern for tripping or entrapment and therefore possible injury. Playing surface planarity due to seams in third-generation turf is less of a concern because the infill is continuous over the top of the backing seams. However, the method used to join seams and, particularly, the method used to install logos, numbers, or other permanent field markings, termed *inlays*, can result in variation of the planarity of the carpet backing and thus result in varying infill thickness across the surface. Inlays should be installed in a manner that maximizes the planarity of the carpet backing, allowing a consistent infill thickness. This is best accomplished by removing the backing of the existing carpet before installation of an inlay. Attaching the inlay backing over the existing carpet backing is not suggested as this necessitates a thinner layer of infill in those locations to create a planar playing surface. Seams of any kind should be checked regularly for separation and repaired according to the manufacturer's recommendations.

MAINTENANCE

One of the perceived benefits of synthetic turf over natural turfgrass is that synthetic turf is maintenance free. This is a misconception; synthetic turf requires regular maintenance, which should be specified by the manufacturer. Generally, turf warranties are contingent on the performance of this regular maintenance.

Standard Maintenance

Several routine maintenance practices should be performed. To raise matted-down fibers, brooming with a nylon bristled brush and raking with spring tooth tines is typically accomplished by pulling devices across the surface in multiple directions using a utility vehicle (Figure 2). The frequency of these operations depends, but may be required as often as weekly on surfaces receiving daily use. Besides raising matted-down fibers, brooming and raking can also loosen the top layer of infill material. Other devices using rotating tines or spikes can be used to penetrate, mix, and loosen the infill material to a greater depth. These are used less frequently, perhaps only 2 or 3 times per year.[49]

A maintenance practice of particular importance and observed to be lacking on most third-generation infill systems is the periodic replacement of lost infill. Infill can adhere to players' clothing and equipment or can be removed during maintenance procedures. Over time, the infill thickness can be reduced, possibly resulting in an increased risk of athlete injury by increased surface hardness, traction, or both. Infill depth should be maintained to manufacturer specifications and routinely monitored, with inspections and results recorded. Inexpensive infill depth gauges (also termed "fireproofing depth gauges") are available from turf supply companies, and the synthetic turf manufacturer can provide an acceptable range and target infill depth for its systems (Figure 3). A sample spreadsheet to aid in tracking and suggested test locations is available.[40]

Figure 2. Commercially available turf broom with spikes.

Figure 3. Seam damage.

To increase thickness, manufacturer-approved infill can be added using a commercial topdressing device common in turfgrass management. Small amounts should be applied followed by brooming to work the infill into the pile fiber. This process may need to be repeated to reach the required thickness. A professional vendor using specialized equipment may be required for fields that have not received regular infill replenishment for a number of years or where the pile fibers are heavily matted.

The buildup of paint can result in excessive surface hardness. Paint buildup should be monitored, and periodic removal of paint residue is suggested. The frequency of paint removal varies depending on the application methods, but removal after 4 consecutive applications can be used as a guide. Paint removal can be laborious, but new paint technologies and new removal equipment have been developed to aid in more efficient removal.

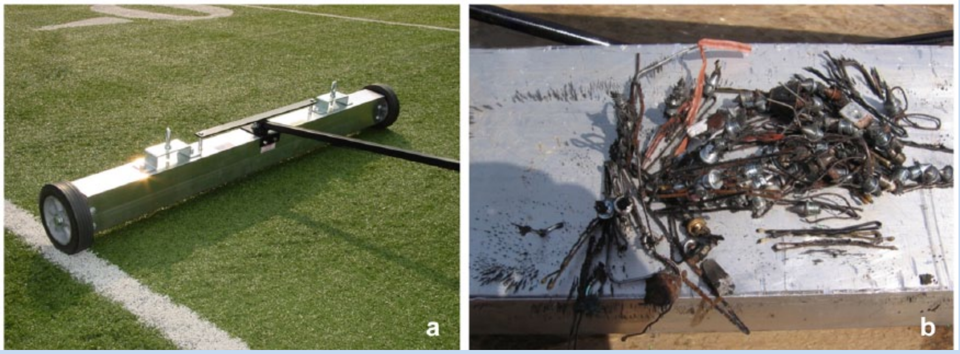

Figure 4. (A) Magnetic drag and (B) subsequent metallic debris recovered on the bottom of the drag.

Debris, while not unique to synthetic surfaces, is also a concern that requires attention. Surface debris such as garbage and leaves can be removed with a blower, sweeper, or vacuum. Commercially available towable magnets are used to remove metal debris such as parts of helmets, jewelry, paper clips, and construction materials (Figure 4).

Other contaminants, including items such as chewing gum, tobacco, sunflower seeds, oil, and other organic contaminants, can be removed mechanically or chemically at the recommendation of the turf manufacturer. Body fluids should be diluted and flushed from the surface with water. Antibacterial solutions are available for disinfection of the surfaces, but laundry detergent and ultraviolet light can be comparably effective.[31] Less common biological concerns, such as weeds, algae, or mold, can be treated with chemicals as needed.

PROTECTING MULTIUSE SYNTHETIC SURFACES

One of the most important benefits of modern synthetic surfaces is the increased usability of the facilities. This is particularly important in stadium settings, where the venue hosts events such as concerts, trade shows, or nonturf sports such as basketball or hockey. To maintain a playable surface, it is important that the synthetic turf is protected during these events. This protection was traditionally accomplished using plywood-type flooring overlaid on the synthetic turf. However, a variety of engineered polypropylene and metal systems are now available, some of which will support the weight of large cranes and other heavy construction traffic. The goal of these systems is to distribute loads across the surface to prevent infill and gravel base movement.[27] Without proper protection, vehicles may cause damage to the carpet and shock pad or create depressions in the base grade that require costly repairs.

ATHLETE HEALTH AND SAFETY

Playing surfaces take on an important role in player health and safety, as evidenced by the common incidence of noncontact injury across many sports, which often involve some degree of interface between an athlete and the playing surface.[4,10,25,28] For these reasons, type and proper upkeep of surfaces as related to injury risk is an important focus, particularly for American football where the overall risk of injury is higher than many other sports[17] and athletes have a high exposure to contact with playing surface as well as other athletes.

ATHLETE-TURF INTERACTION

Dating back to the 1990s, research has shown reason for concern over injury rates on synthetic turf.[41,42,45] Researchers have attempted to evaluate the impact that synthetic turf may have on injury occurrence; however, the available literature lacks a comprehensive epidemiological assessment of differential injury risks or rates on modern synthetic versus natural turf. Many of the studies published to date report on playing surfaces that are no longer routinely used and are not subject to consistent maintenance practices.

There is a mechanistic rationale to assert a causal link between play on a synthetic surface and increased risk of lower extremity injury, specifically within sports that involve heavy loading of the surface, such as soccer and American football. Biomechanical testing with a variety of cleats has shown that synthetic playing surfaces inherently lack the ability to “divot” or otherwise damage under potentially injurious forces and torsion levels, whereas natural turfgrass surfaces are able to do so. Divoting, defined as the complete shearing or removal of the turf/root system from the remainder of the root zone, is an implicit cleat-release mechanism of natural turfgrass. Because synthetic surfaces lack this ability to release a cleat in a potentially injurious overload situation, they have the capacity to generate greater shear force and torque on the foot and hence throughout the lower extremity.[23] This supports 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. The epidemiological assessments that have been published examining a differential injury rate between synthetic and natural turfs are generally supportive of this hypothesis: Studies that focus on lower extremity injuries caused by a twisting or shearing mechanism typically show greater rates of injury on synthetic versus natural turf.[9,16,18] Mack et al (unpublished data) examined this among NFL players and found a greater rate of lower extremity injuries on synthetic turf game-day fields than on natural turfgrass game-day fields. In the aggregate, the lower extremity injury rate was 16% greater on synthetic surfaces, though specific subcategories of lower extremity injuries exhibited up to twice the rate on synthetic turf. Lower extremity injuries as noncontact/surface contact exhibited greater differential injury rate ratios (ranging from 1.2 to 2.0), particularly among more distal regions of the lower extremity. These findings are consistent with previous NFL studies[16] as well as with the majority of studies among collegiate football players.[9,13,18,19] Current research has attempted to inform the design of football cleat patterns that can replicate the release of natural turfgrass on synthetic turf at loads and rates relevant to elite-level football to bring the differential injury rate closer to zero.[21]

While these studies, among others, have begun to sort out differences in some athlete populations, a full understanding of the difference in injury risk is complicated by the size and power of the studies as well as differences among sexes, sport, level of competition, weather, footwear, and variations in the playing surfaces themselves, including maintenance.[26,34-36,46,47,53,54]

NONMUSCULOSKELETAL INJURIES AND OTHER HEALTH CONCERNS

In addition to the lower extremity injury concerns discussed,[21] head injuries, infectious diseases, heat, and the potential for carcinogenic effects of the playing surface material have all been studied to some extent with regard to synthetic turf surfaces.

Head Injuries

Head injuries in athletes are a serious concern. The majority of concussions in American football result from collisions between players, but nearly 20% of concussions are caused by the athlete impacting the playing surface.[7,14,15,33]

For a given effective head mass during a vertical impact to a surface, the head will experience greater peak acceleration when striking a harder surface than a softer one. Studies have hypothesized that a harder surface is correlated with increased head injury risk,[39] but the risk of a head injury from a blow to a surface also depends on many other factors, including the magnitude of the force, the fit and material characteristics of the helmet, and the direction of force application relative to the player's body.

Surface Temperature

The temperature of synthetic turf playing surfaces is an important factor to consider. In 1971, Buskirk et al[6] found that surface temperatures on AstroTurf were as much as 50°C higher than natural turfgrass.[6] Third-generation infill systems have been reported to have surface temperatures as high as 93°C.[42] This is possible because the infill material has been shown to have very low heat flux, and most of the energy from the sun goes into heating the exposed pile fibers, which have a low specific heat. Thus, the surface temperature is driven by the total amount of solar radiation.[4]

Different methods have been tested for cooling these surfaces.[24] Varying colors of crumb rubber and pile fibers resulted in only a marginal reduction of surface temperature compared with the traditional black infill and green fiber.[8] The application of water through irrigation has been shown to effectively reduce the surface temperature of infill systems but only for a short time.[32] During exposure to solar radiation, the surface temperature of synthetic turf remains a concern for professional athletics as well as to high school fields and even elementary playgrounds, where supervising adults may not be aware of this aspect of synthetic turf.

Carcinogenic Risk

The health effects of the material in third-generation synthetic turf components have been the subject of much debate. In several states, advocacy groups have proposed a moratorium on these materials until they can be proven safe for players. The main concern is carcinogenic risk related to the exposure to harmful chemicals present in the rubber infill.[5,55] This was based on a laboratory study conducted at the Connecticut Agricultural Experiment Station in 2007 that raised concerns about exposure to potentially hazardous compounds in third-generation synthetic turf systems.[29] Four concerning chemicals (benzothiazole, butylated hydroxyanisole, *n*-hexadecane, and 4-[*t*-octyl] phenol) were found at elevated levels in the laboratory. A subsequent study by the Connecticut Academy of Science and Engineering[55] concluded "risks are well within typical risk levels in the community from ambient pollution sources and are below target risks associated with many air toxics regulatory programs." The committee went on to conclude that "Based upon these findings, the use of outdoor and indoor artificial turf fields is not associated with elevated health risks. However, it would be prudent for building operators to provide adequate ventilation to prevent a buildup of rubber-related VOCs and SVOCs at indoor fields."

To the authors' knowledge, there have been no documented reports of cancer related to the use of synthetic turf surfaces, although given the long induction period between exposure and many cancers, a causal relationship on a case by case basis would be difficult to detect. Birkholz et al[3] demonstrated that crumb rubber poses minimal risk. Zhang et al[56] analyzed samples of infill rubber for the bioavailability of polycyclic aromatic hydrocarbons (PAHs) and several metals. They showed that the rubber infill, especially on newly installed fields, contained levels of PAHs that were above health-based soil standards; however, the level of PAHs was noted to decrease as the fields aged. PAHs in this study had zero or near-zero bioavailability. Lead (metal) was detected in the samples and was shown to have some bioavailability.

Air quality with rubber infill has been another concern. Dye et al[11] found that indoor facilities have detectible levels of almost 100 chemicals and particulates that could be identified and another 200 chemicals that were detected but not able to be identified. They do not, however, address the effect these chemicals may have on human health or whether these chemicals are similarly detected on outdoor fields with open air.[11] To assess the body's ability to absorb these chemicals, van Rooij and Jongeneelen[50] performed a study in football players where urine was analyzed from 7 players over a 3-day period for PAH metabolites. They noted that the urine samples for PAH metabolites were minimal and within the ranges of PAHs taken up from environmental sources or diet.

While the majority of studies conclude that there is little to no elevated health risk associated with rubber infill, it will be difficult to prove without a doubt. Because of this, it is likely that studies will continue on these synthetic fields to further assess athlete safety.[12]

Skin Infections

Media outlets have raised concern about the development of skin infections in players exposed to synthetic turf.[17,44] The concern can be broken down into 2 considerations. The first is the synthetic turf surface's slightly greater propensity compared with grass to abrade and thus create a break in the skin.[36] The second is the ability of the surface to host microorganisms. Two studies have focused on separate outbreaks of methicillin-resistant *Staphylococcus aureus* (MRSA) and examined the role of third-generation synthetic turf on infections. Kazakova et al[22] reviewed a community-acquired MRSA outbreak among 5 members of the St Louis Rams football team. They noted that all the infections occurred at areas of turf abrasion. They also noted that MRSA was found in 42% of the players and staff on the team.[22] Begier et al[2] reported on an MRSA outbreak that occurred within a college football team. Both of these reports included teams that had third-generation synthetic turf on their home field, and while both concluded that turf abrasion sites could facilitate infection due to the break in skin, neither study implicated the source of the infection as the playing surface itself. Both studies raised concern for poor sanitary conditions in the associated facilities (locker rooms, etc) as well as skin-to-skin contact between players as the likely source of the infection.

McNitt and Petrunak[31] found no *S. aureus* bacteria in a survey of 20 fields of third-generation synthetic turf. Of note, there was generally less total microbe load on synthetic turf compared with natural turfgrass. This study also tested for the presence of *S. aureus* in the associated training facilities and did find *S. aureus* on towels, blocking pads, and weight equipment.

The cause of a lack of viable *S. aureus* on the playing surface was further studied by McNitt and Petrunak.[31] They assessed the ability of the bacteria to survive on synthetic turf and the effectiveness of several antimicrobial treatments. On outdoor surfaces where the bacteria were exposed to ultraviolet light from the sun and to high surface temperatures, the population of bacteria fell quickly, regardless of whether a control agent was applied. Indoors, the bacteria survived for multiple days, but the number of surviving bacteria decreased significantly with time. Antimicrobial treatments and laundry detergent decreased the survival rate of the bacteria present on indoor surfaces.

Third-generation infill systems with polyethylene pile fiber have been shown to be considerably less abrasive than first-generation nylon systems, although both are more abrasive than well-maintained natural turfgrass.[34,42] The likelihood of being exposed to infectious bacteria on synthetic surfaces appears to be minimal, but the abrasiveness of synthetic turf may increase the likelihood of a break in the skin's defense mechanism compared with natural turfgrass.

CONCLUSION

Modern synthetic turf is far different than when originally introduced and in large part has improved in both structure, quality of components, and ability to be consistently maintained. It is important for sports medicine personnel to be familiar with playing surface issues as they are often treating athletes at the time of injury on these surfaces and may also be important advocates for improved synthetic turf maintenance practices. These surfaces require routine and targeted maintenance at all levels of play. There remains a concern for player safety on these surfaces. In particular, understanding shoe-surface interaction, methods for facilitating release of the foot, and the role of surface hardness in various injuries are an important focus.

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