Surface-Related High School Football Game Injuries on Pad and No-Pad Fields

Michael C. Meyers,*† PhD, FACSM
Investigation performed at Human Performance Laboratory, Department of Human Performance and Sport Studies, Idaho State University, Pocatello, Idaho, USA

Background: Artificial turf fields are increasingly being installed with lighter weight infill systems that incorporate a pad underlayer, which is reported to reduce surface shock and decrease injuries. At this time, the effects of a pad underlayer on football trauma are unknown.

Hypothesis: Athletes would not experience differences in surface-related injuries between pad and no-pad fields.

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

Methods: Artificial turf fields were divided into 2 groups based on a pad underlayer or no-pad system, with 58 high schools participating across 3 states over the course of 7 seasons. Outcomes of interest included injury severity, head and knee trauma, injury category, primary type of injury, injury mechanism, anatomic location of trauma, tissue type injured, and elective imaging and surgical procedures. Data underwent multivariate analyses of variance (MANOVA) using general linear model procedures and were expressed as injury incidence rates per 10-game season.

Results: Of 658 varsity games, 260 games were played on fields containing pads, and 398 games were played on no-pad fields, with 795 surface-related injuries reported. MANOVA indicated significant main effects by injury severity ($F_{3,791}$ = 11.436; $P < .0001$), knee trauma ($F_{9,785}$ = 2.435; P = .045), injury category ($F_{3,791}$ = 3.073; $P < .0001$), primary type of injury ($F_{10,785}$ = 2.660; $P < .0001$), injury mechanism ($F_{13,781}$ = 2.053; $P < .001$), anatomic location ($F_{16,778}$ = 1.592; $P < .001$), type of tissue injured ($F_{4,790}$ = 4.485; $P < .0001$), and elective imaging and surgical procedures ($F_{4,790}$ = 4.248; $P < .002$). Post hoc analyses indicated significantly greater incidences ($P < .05$) of substantial and severe injury, player-to-turf trauma, patellofemoral syndrome, neck strain, lower leg strain, and elective imaging and surgical procedures when games were played on padded turf fields. No differences in concussion rate from turf impact between pad and no-pad fields were observed.

Conclusion: In contrast to conventional wisdom, the addition of a pad under an artificial turf surface increases injury rates when compared with nonpadded fields across most injury categories. At this time, findings do not support the current trend of installing lightweight padded infill systems at the high school level of play.

Keywords: artificial surface; knee; turf; trauma

Today's generation of artificial turf fields are increasingly being installed with lighter weight infill systems. Although heavier weight (>6.0 lb/ft^2) infill systems have been proven to provide greater safety,[21] the lightweight infill systems often incorporate poured or interlocking polypropylene or thermo elastomer pad systems under the fiber-infill layers, reportedly to reduce surface shock, optimize shoe-surface stability, and reduce injuries. Interestingly, pads are more expensive than are nonpadded installations but are marketed to high schools by various turf manufacturers as providing greater safety than nonpadded, heavier infill systems provide, although heavier weight infills are widely used at the National Collegiate Athletic Association and National Football League levels of competition.

At this time, the effects of pad systems on football trauma during actual game conditions over several seasons of competition are unknown. With more than 1 million athletes playing competitive football,[26] the increasing number and cost of surgeries and rehabilitation alone reaching into the millions of dollars each season,[3,19,25] and the psychological effect and setbacks in training typically experienced by athletes after a significant injury,[1,11,24] efforts to

*Address correspondence to Michael C. Meyers, PhD, FACSM, Human Performance Laboratory, Department of Human Performance and Sport Studies, Idaho State University, 921 South 8th Avenue, Stop 8105, Pocatello, ID 83209-8105, USA (email: meyersgroupinc@gmail.com).

†Human Performance Laboratory, Department of Human Performance and Sport Studies, Idaho State University, Pocatello, Idaho, USA.

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delineate the numerous factors possibly contributing to injury have become a priority to enhance player safety.[2,13,19] Given the increasing popularity of installing base pads or e-layer (poured pads) today as an alternative to heavier infill weight systems, examination of the potential influence of this practice on the incidence of injury was warranted. Therefore, the purpose of this study was to quantify the incidence, mechanisms, and severity of surface-related injuries during high school varsity football games played on pad versus no-pad fields. It was hypothesized that high school varsity football athletes would not experience any difference in surface-related injuries while competing on either base pad or no-pad fields.

METHODS

Population

A total of 58 high schools participating across 3 states (California, Pennsylvania, Texas) were evaluated for game-related football injuries that players sustained while playing on various pad and no-pad artificial turf infill systems over 7 competitive seasons between 2010 and 2016. Criteria for inclusion were based on availability of pad and no-pad artificial playing surfaces during each season, uniformity of school size and state classification, and the presence of a full-time certified athletic trainer (ATC). The criterion of a full-time ATC was selected to ensure a uniform level of professional knowledge among those evaluating and reporting injuries for the study.[4,32] To optimize skill level and uniformity of schools, the study was limited to the larger top-tier schools within their respective states, ranging from 1230 to $\geq$2220 students.

After varsity games played on natural grass were deleted (n = 171), selection bias was avoided by reporting on all remaining 658 varsity games played in the 3 selected states over the 7-year period on artificial turf, resulting in the tracking of 218 games in California (33.1%; 91 pad, 127 no pad), 169 games in Pennsylvania (25.7%; 67 pad, 102 no pad), and 271 games in Texas (41.2%; 102 pad, 169 no pad) throughout the study. Artificial turf systems were divided into 2 groups: lightweight fields integrated with a pad underlayer versus a heavyweight infill system ($\geq$9.0 lb/ft^2) installed with no pad. Information on underlayer installation was obtained through artificial turf company sales representatives. Various stadiums were used by all 58 high schools during home and away games. All teams had home facilities with an artificial turf infill system.

Procedures

For this prospective cohort study, an established comprehensive injury surveillance system was used to collect data as previously described.[12,20] Descriptive features and predictors included specific high school, athletic trainer, date of injury, personnel determining the injury, athlete weight, type of playing surface, surface quality, time period of injury, year and skill level of athlete, and game location where the injury occurred. Outcomes of interest included injury severity, head and knee trauma, injury category, primary type of injury, injury mechanism, anatomic location of trauma, type of tissue injured, and elective imaging and surgical procedures. The protocol was approved by the institutional review board at the university in which the study was based, and the study was conducted in accordance with the Declaration of Helsinki.

During the preceding summer before the football season, the ATC for each high school was provided with an overview of the study purpose and procedures, copies of the injury surveillance form, and detailed instructions for completion to avoid the potential for performance and detection biases.[30,32] Communication was maintained by the author to discuss potential concerns and to ensure accuracy of collection, comprehensiveness of information, and ease of application.

All regular season district, nondistrict, and postseason playoff games were included. Injury data were recorded after games, with adjunct support from ATC notes to avoid lapse of memory leading to inaccuracy or response distortion.[23,30] All game injuries were evaluated by the attending ATC and team physicians on-site and, subsequently, in the physician's office when further follow-up and treatment were deemed necessary. Any game trauma that occurred toward the end of the competitive schedule was monitored beyond the player's specific season to determine date of recovery and functional return to play.[21,23,29]

If minor injuries occurred, completed injury surveillance forms were emailed to the investigator within 7 working days after a game. Follow-up telephone visits were used to obtain any additional information pertaining to any changes or additions in diagnosis, treatment, or time to return to play. To avoid the potential for on-field detection bias,[32] a double-blind outcome approach was maintained throughout the study period, with underlayer or pad status unknown to the ATCs collecting the injury data, and the author limited to data compilation and analyses.

Definitions

The definition of injury was based on a combination of functional outcome, observation, and treatment.[4,23,27] A *reportable injury* was defined as any game-related football trauma reported or treated by the ATC or physician that resulted in an athlete's missing all or part of a game.[12,22,23] *Injury severity* was based on the number of days absent from game competition (time loss). As previously described, *minor* injury was defined as any trauma that required 0 to 6 days of time loss, a *substantial* injury was any trauma requiring 7 to 21 days of time loss resulting in the athlete's being unable to return to play at the same competitive level, and *severe* injury was defined as any trauma that resulted in $\geq$22 days of time loss.[20,23]

Injury category was quantified by player-to-turf impact, injuries attributed to shoe-surface interaction during player contact, injuries attributed to shoe-surface interaction without player contact, and muscle- or tendon-related overload. Regarding *stage of injury*, acute trauma was delineated from *recurring* acute injury according to criteria previously published,[20,21] with acute trauma linked to an incidence that specifically occurred during a game versus repetitive exposure resulting in symptoms and injury to the same location during the season (recurrent).

Primary type of injury was combined into the following categories: surface or epidermal (abrasion, laceration, puncture wound), contusion, concussion, inflammation (bursitis, tendinitis, fasciitis, synovitis, capsulitis, apophysitis), ligament sprain or tear, cartilage tear, muscle-tendon strain or tear, hyperextension, neural injury (burner, brachial plexus), subluxation or dislocation, and fracture (standard, epiphyseal, avulsion, stress, osteochondral). *Mechanism of injury* was defined as occurring while a player was blocked above or below the waist; tackled above or below the waist; blocking or tackling; impacting the playing surface; stepped on, fallen on, or kicked; sprinting or running with no player contact; catching or blocking a pass; or clipped or when a player sustained heat illness or overuse.

Anatomic location of trauma was condensed to 29 anatomic sites. Type of tissue injured was analyzed by bone, joint, muscle, neural, and other. *Head injury by turf impact* included simple and complex concussions; hematoma; postconcussion and second-impact syndromes; neurologic sequelae (eg, stingers or burners, transient quadriplegia), vascular or dental injury; or associated fractures, sprains, and strains.[18,20,23] Neural trauma was restricted to any injury involving only concussion, associated syndromes, and neurologic sequelae. Because of increasing concerns of rising medical costs[3,25] and the potential for long-term articular changes,[17,33] elective imaging and surgical procedures (computed tomography, magnetic resonance imaging, radiography, in-season and postseason surgeries) were documented. Finally, based on injury concerns from the wear-and-tear and the aging of artificial surfaces,[21,22] data on turf age (new and 1-3, 4-7, and ≥8 years) were gathered for surface comparison, an area of limited documentation in the literature.

Statistical Analysis

Data were grouped by underlayer status (pad, no pad), and tabular-frequency distributions were computed using IBM SPSS Statistics (Version 26.0; IBM Corp) software, with 95% CIs determined as described elsewhere.[35] Because most high schools played approximately 10 varsity games each season, the injury incidence rate (IIR) was calculated using injuries per 10 team games [(number of injuries ÷ number of team games) × 10] as previously reported.[15,20,21]

Data were then subjected to multivariate analyses of variance (MANOVAs) and Wilks λ criteria using general linear model procedures. Data screening indicated no violations of multivariate normality, linearity, outliers, homogeneity of variance, multicollinearity, or singularity.[35] When significant main effects were observed, univariate post hoc procedures were performed within each dependent variable based on the total percentage of injuries reported on pad and no-pad fields. An experiment-wise type I error rate of .05 was established a priori, and least squared means (LSM) procedures were required because of the uneven number of observations on which to compare differences among variables. Statistical power analyses

TABLE 1
Surface-Related High School Football Injuries on Pad and No-Pad Fields by Severity of Trauma[a]

	Pad	No Pad	Total/Mean
Games evaluated			
n (%)	260 (39.5)	398 (60.5)	658 (100.0)
All injuries			
n (%)	492 (61.9)	303 (38.1)	795 (100.0)
IIR (95% CI)	18.9 (18.4-19.2)[b]	7.6 (7.2-8.0)[b]	12.1
Minor injury[b]			
n (%)	247 (50.2)	181 (59.7)	428 (53.8)
IIR (95% CI)	9.5 (9.2-9.7)[b]	4.5 (4.1-5.0)[b]	6.5
Substantial injury			
n (%)	175 (35.6)	62 (20.5)	237 (29.8)
IIR (95% CI)	6.7 (6.1-7.3)[b]	1.6 (1.2-1.9)[b]	3.6
Severe injury			
n (%)	70 (14.2)	60 (19.8)	130 (16.4)
IIR (95% CI)	2.7 (2.2-3.3)[b]	1.5 (1.2-1.9)[b]	2.0

[a]Wilks λ severity of injury ($F_{3,791}$ = 11.436; $P < .0001$). IIR, injury incidence rate [(number of injuries ÷ number of team games) × 10]; minor injury, 0-6 days of injury time loss; substantial injury, 7-21 days of injury time loss; severe injury, ≥22 days of injury time loss.
[b]$P < .05$.

(1 – β; n size calculations) were performed at the *P* value selected to establish significance in this study (<.05). Although the number of games played on fields containing a pad were less than those for no-pad fields, the number of documented injuries provided adequate statistical power for analyses (1 – β = 0.703-1.000).

RESULTS

Total Injury Frequency and Severity

Of 658 varsity games documented, 260 games were played on fields containing pads, and 398 were played on no-pad fields, with 1453 total injuries reported. Of these, 795 injuries were surface-related (player-to-turf impact, shoe surface during contact, shoe surface during no contact, lower extremity muscle-tendon overload). Analyzing these surface-related injuries, MANOVA indicated a significant main effect between pad and no-pad playing surfaces by injury severity ($F_{3,791}$ = 11.436; $P < .0001$). Post hoc analyses indicated significantly greater ($P < .05$) total, minor, substantial, and severe injury when athletes were competing on artificial turf fields with pads compared with no-pad systems (Table 1).

Although all injuries were acute, the incidence of recurrent cases over 7 seasons ranged from 8.3% to 9.6%. The incidence of injury attributed to foul play or illegal action was 1.3% of total trauma reported. Although multiple states were included with a disparate number of games, no significant IIR-by-state differences were found across pad fields (California, 18.8; 95% CI, 18.0-19.3; Pennsylvania, 19.4; 95% CI, 18.6-19.8; Texas, 18.7; 95% CI, 17.9-19.2) and no-pad fields (California, 7.7; 95% CI, 6.9-8.4;

TABLE 2
Surface-Related High School Football Injuries on Pad and No-Pad Fields by Head and Knee Trauma[a]

	Pad (n = 260)			No Pad (n = 398)		
	No.	IIR	95% CI	No.	IIR	95% CI
Head injury by turf impact						
Simple concussion	1	0.0	0.0-0.2	4	0.1	0.0-0.3
Complex concussion	8	0.3	0.2-0.6	1	0.0	0.0-0.1
Concussion injuries—total	9	0.3	0.2-0.6	5	0.1	0.1-0.3
Knee injury						
Medial collateral ligament	32	1.2	0.9-1.7	29	0.7	0.5-1.0
Lateral collateral ligament	3	0.1	0.0-0.3	4	0.1	0.0-0.3
ACL	12	0.5	0.3-0.8	12	0.3	0.2-0.5
ACL and associated tissue	17	0.7	0.4-1.0	16	0.4	0.2-0.6
PCL and associated tissue	3	0.1	0.0-0.3	0	0.0	0.0-0.0
Arcuate-popliteal complex	1	0.0	0.0-0.2	4	0.1	0.0-0.3
Lateral meniscus	0	0.0	0.0-0.0	3	0.1	0.0-0.2
Medial meniscus	4	0.2	0.1-0.4	4	0.1	0.0-0.3
Patellar tendon/patellofemoral syndrome	23	0.9	0.6-1.3[b]	12	0.3	0.2-0.5[b]
ACL injuries combined	29	1.1	0.8-1.6	28	0.7	0.5-1.0

[a]Wilks λ knee injury ($F_{9,785}$ = 2.435; P = .045); head injury ($F_{2,792}$ = 1.934; P = .072). ACL, anterior cruciate ligament; IIR, injury incidence rate [(number of injuries ÷ number of team games) × 10]; PCL, posterior cruciate ligament.
[b]$P < .05$.

Pennsylvania, 8.3; 95% CI, 7.5-8.9; Texas, 7.1; 95% CI, 6.4-7.7).

As expected, upperclassmen received the majority of trauma on both playing surfaces. On padded fields, 288 injuries occurred to seniors (58.5%; injury incidence rate [IIR], 11.0; 95% CI, 10.7-11.5); 147, to juniors (29.9%; IIR, 5.7; 95% CI, 5.0-6.2); and 42, to sophomores (8.6%; IIR, 1.6; 95% CI, 1.2-2.1). On no-pad fields, 197 injuries were reported among seniors (65.0%; IIR, 5.0; 95% CI, 4.7-5.4); 88, among juniors (29.0%; IIR, 2.2; 95% CI, 1.8-2.6); 42, among sophomores (8.6%; IIR, 1.1; 95% CI, 0.8-1.4); and 15, among freshman (3.0%; IIR, 0.4; 94% CI, 0.2-0.6). No injuries were documented among freshman on surfaces with pads.

Head and Knee Trauma

With the continued focus on reducing the frequency of concussions and lower extremity trauma on turf, these areas were specifically identified for analyses. After 7 seasons of play, no significant main effect was observed between pad and no-pad playing surfaces by head severity attributed to turf impact ($F_{2,792}$ = 1.934; P = .072) (Table 2). However, there was a borderline significant main effect by specific knee trauma ($F_{9,785}$ = 2.435; P = .045), with a significantly greater ($P < .05$) incidence of patellar tendon or patellofemoral syndrome cases documented on lightweight fields with pads compared with no-pad fields.

Injury Category

MANOVA indicated a significant main effect by injury category ($F_{3,791}$ = 3.073; $P < .0001$). Post hoc analyses indicated significantly higher ($P < .05$) player-to-turf trauma, a significantly greater incidence of injuries resulting from shoe-surface interaction during physical contact, and a greater incidence of muscle-tendon overload injuries when athletes competed on lightweight artificial turf fields with pads compared with nonpadded, heavyweight infill systems (Table 3).

Primary Type of Injury

As shown in Table 3, a significant main effect by primary type of injury ($F_{10,785}$ = 2.660; $P < .0001$) was noted between pad and no-pad fields. Post hoc analyses indicated significantly higher ($P < .05$) incidences of inflammatory response primarily related to patellar tendon or patellofemoral syndrome (Table 2) as well as greater incidences of both upper extremity (from ground impact) and lower extremity ligament sprains and muscle strains or tears when competing on fields with pads versus no-pad systems. A significantly higher ($P < .05$) incidence of contusions from turf impact also occurred on fields with pad underlayers when compared with no-pad infill systems.

Injury Mechanism

MANOVA indicated a significant main effect by injury mechanism ($F_{13,781}$ = 2.053; $P < .001$), with significantly greater ($P < .05$) incidence of injury from impact with playing surfaces containing a pad underlayer as opposed to nonpadded fields (Table 4). Significantly higher ($P < .05$) incidences of trauma attributed to blocking or tackling below the waist, being stepped on or fallen on during play, and sustaining noncontact injuries during lower extremity rotation and foot plant were also documented on the pad-augmented surfaces versus nonpadded fields.

TABLE 3
Surface-Related High School Football Injuries on Pad and No-Pad Fields by Injury Category and Primary Type of Injury[a]

	Pad (n = 260)			No Pad (n = 398)		
	No.	IIR	95% CI	No.	IIR	95% CI
Injury category						
Player-to-turf impact	169	6.5	5.9-7.1[b]	79	2.0	1.6-2.4[b]
Shoe surface–contact	245	9.4	9.1-9.6[b]	165	4.1	3.7-4.6[b]
Shoe surface–noncontact	39	1.5	1.1-2.0	33	0.8	0.6-1.1
Muscle-tendon overload	39	1.5	1.1-2.0[b]	26	0.7	0.5-0.9[b]
Primary type of injury						
Surface/epidermal	7	0.3	0.1-0.5	2	0.1	0.0-0.2
Contusion	97	3.7	3.2-4.3[b]	17	0.4	0.3-0.7[b]
Concussion	9	0.3	0.2-0.6	5	0.1	0.1-0.3
Inflammation	20	0.8	0.5-1.2[b]	5	0.1	0.1-0.3[b]
Ligament sprain	168	6.5	5.9-7.0[b]	165	4.1	3.7-4.6[b]
Ligament tear	27	1.0	0.7-1.5	33	0.8	0.6-1.1
Cartilage tear	4	0.2	0.1-0.4	6	0.2	0.1-0.3
Muscle-tendon strain/tear	114	4.4	3.8-5.0[b]	36	0.9	0.7-1.2[b]
Hyperextension	8	0.3	0.2-0.6	5	0.1	0.1-0.3
Subluxation/dislocation	12	0.5	0.3-0.8	9	0.2	0.1-0.4
Fracture	26	1.0	0.7-1.4	20	0.5	0.3-0.8

[a]Wilks λ injury category ($F_{3,791}$ = 3.073; $P < .0001$); primary type of injury ($F_{10,785}$ = 2.660; $P < .0001$). IIR, injury incidence rate [(number of injuries ÷ number of team games) × 10].
[b]$P < .05$.

TABLE 4
Surface-Related High School Football Injuries on Pad and No-Pad Fields by Injury Mechanism, Type of Tissue Injured, and Elective Imaging and Surgical Procedures[a]

	Pad (n = 260)			No Pad (n = 398)		
	No.	IIR	95% CI	No.	IIR	95% CI
Injury mechanism						
Blocked above waist	8	0.3	0.2-0.6	3	0.1	0.0-0.2
Blocked below waist	75	2.9	2.4-3.5[b]	39	1.0	0.7-1.3[b]
Blocking	49	1.9	1.5-2.4	46	1.2	0.9-1.5
Tackled above waist	4	0.2	0.1-0.4	6	0.2	0.1-0.3
Tackled below waist	48	1.8	1.4-2.4[b]	36	0.9	0.7-1.2[b]
Tackling	23	0.9	0.6-1.3	19	0.5	0.3-0.7
Impact with playing surface	170	6.5	5.9-7.1[b]	74	1.9	1.5-2.3[b]
Stepped on, fallen on, kicked	54	2.1	1.6-2.6[b]	28	0.7	0.5-1.0[b]
No contact–rotation/plant	38	1.5	1.1-1.9[b]	28	0.7	0.5-1.0[b]
Sprinting/running	10	0.4	0.2-0.7	9	0.2	0.1-0.4
Catching/blocking pass	6	0.2	0.1-0.5	2	0.1	0.0-0.2
Clipped	4	0.2	0.1-0.4	5	0.1	0.1-0.3
Heat illness	1	0.0	0.0-0.2	4	0.1	0.0-0.3
Overuse	2	0.1	0.0-0.3	4	0.1	0.0-0.3
Type of tissue injured						
Bone	26	1.0	0.7-1.4	20	0.5	0.3-0.8
Joint	245	9.4	9.1-9.6[b]	223	5.6	5.1-6.1[b]
Muscle	205	7.9	7.3-8.3[b]	51	1.3	1.0-1.6[b]
Neural	10	0.4	0.2-0.7	6	0.2	0.1-0.3
Other	6	0.2	0.1-0.5	3	0.1	0.0-0.2
Elective imaging and surgery						
CT	9	0.3	0.2-0.6	2	0.1	0.0-0.2
MRI	56	2.2	1.7-2.7[b]	49	1.2	0.9-1.6[b]
Radiography	113	4.3	3.8-5.0[b]	56	1.4	1.1-1.8[b]
Surgery, in- or postseason	51	2.0	1.5-2.5[b]	40	1.0	0.7-1.3[b]
Total procedures	229	8.8	8.4-9.1[b]	147	3.7	3.2-4.2[b]

[a]Wilks λ injury mechanism ($F_{13,781}$ = 2.053; $P < .001$); type of tissue injured ($F_{4,790}$ = 4.485; $P < .0001$); elective imaging and surgical procedures ($F_{4,790}$ = 4.248; $P < .002$). CT, computed tomography; IIR, injury incidence rate [(number of injuries ÷ number of team games) × 10]; MRI, magnetic resonance imaging;
[b]$P < .05$.

TABLE 5
Surface-Related High School Football Injuries on Pad and No-Pad Fields by Anatomic Location of Trauma and Turf Age[a]

	Pad (n = 260)			No Pad (n = 398)		
	No.	IIR	95% CI	No.	IIR	95% CI
Anatomic location						
Head	13	0.5	0.3-0.8	5	0.1	0.1-0.3
Neck	20	0.8	0.5-1.2[b]	0	0.0	0.0-0.0[b]
Shoulder girdle	40	1.5	1.2-2.0[b]	23	0.6	0.4-0.9[b]
Upper arm/elbow/forearm	29	1.1	0.8-1.6[b]	7	0.2	0.1-0.4[b]
Hand/wrist/finger/thumb	19	0.7	0.5-1.1	20	0.5	0.3-0.8
Upper and lower back/spine	14	0.5	0.3-0.9	4	0.1	0.0-0.3
Chest/ribs/abdomen	8	0.3	0.2-0.6	2	0.1	0.0-0.2
Pelvis/hips/buttocks	13	0.5	0.3-0.8	6	0.2	0.1-0.3
Groin	2	0.1	0.0-0.3	1	0.0	0.0-0.1
Upper leg	33	1.3	0.9-1.7[b]	13	0.3	0.2-0.6[b]
Knee/patella	95	3.7	3.1-4.3[b]	84	2.1	1.7-2.5[b]
Lower leg	91	3.5	2.9-4.1[b]	27	0.7	0.5-1.0[b]
Ankle	89	3.4	2.9-4.0	97	2.4	2.0-2.9
Heel/Achilles tendon	2	0.1	0.0-0.3	3	0.1	0.0-0.2
Foot	18	0.7	0.4-1.1[b]	6	0.2	0.1-0.3[b]
Toe	6	0.2	0.1-0.5	5	0.1	0.1-0.3
Lower extremity combined	349	13.4	12.8-14.0[b]	241	6.1	5.6-6.5[b]
Turf age						
New	66	2.5	2.0-3.1[b]	36	0.9	0.7-1.2[b]
1-3 y	233	9.0	8.5-9.3[b]	127	3.2	2.8-3.7[b]
4-7 y	131	5.0	4.4-5.6[b]	125	3.1	2.7-3.6[b]
≥8 y	62	2.4	1.9-2.9[b]	15	0.4	0.2-0.6[b]

[a]Wilks λ anatomic location of trauma ($F_{16,778}$ = 1.592; $P < .001$); turf age ($F_{3,791}$ = 13.701; $P < .0001$). IIR, injury incidence rate [(number of injuries ÷ number of team games) × 10].
[b]$P < .05$.

Type of Tissue Injured

A significant main effect by type of tissue injured was found ($F_{4,790}$ = 4.485; $P < .0001$). Univariate analyses indicated a significantly greater incidence ($P < .05$) of joint and muscle trauma experienced by athletes while playing on fields containing a pad underlayer compared with nonpadded fields (Table 4).

Elective Imaging and Surgical Procedures

A significant main effect by elective imaging and surgical procedures ($F_{4,790}$ = 4.248; $P < .002$) was observed, with post hoc analyses indicating a significantly greater ($P < .05$) number of lower extremity elective magnetic resonance imagings and radiographs requested after athletes competed on lightweight artificial turf fields integrated with pads compared with fields installed with only heavyweight infill systems with no pad underlayer (Table 4). The significantly greater ($P < .05$) incidences of surgical procedures and total procedures combined after competition on the pad-supplemented turf fields compared with nonpadded fields were a concern.

Anatomic Location of Trauma

MANOVA indicated a significant main effect by anatomic location of trauma ($F_{16,778}$ = 1.592; $P < .001$). Post hoc analyses indicated significantly greater ($P < .05$) incidences of neck, shoulder girdle, and upper extremity trauma from surface impact as well as upper leg, knee or patella, lower leg, foot, and lower extremity trauma combined when athletes competed on lightweight artificial turf fields with pads compared with nonpadded systems with substantial infill weight (Table 5).

Turf Age

As existing artificial surfaces continue to age, there has been conjecture as to the influence of age of the playing surface on injury.[21,22] In this study, a significant main effect by turf age at time of injury was found ($F_{3,791}$ = 13.701; $P < .0001$). Post hoc analyses indicated significantly greater ($P < .05$) incidences of trauma across fields that were new as well as 1-3, 4-7, and ≥8 years from time of installment when athletes competed on lightweight artificial turf fields with pads compared with no-pad systems with substantial infill weight (Table 5).

DISCUSSION

Previous studies have compared injuries that athletes sustain while competing on artificial and natural grass surfaces. The current research, however, specifically focused on surface-related trauma during seasonal high school varsity football competition, comparing artificial turf fields installed with a pad underlayer versus fields installed without a pad. Although some similarities in injury characteristics existed, games played on fields with a pad underlayer resulted in significantly greater rates of injury.

Head and Neck Injuries

Findings do not support the premise that substituting an underlayer pad for less infill weight to reduce surface hardness leads to a decrease in head trauma after ground impact. With the expense of today's pad underlayers, adding upward of $80,000 to the cost of a field, the nonsignificant influence on concussion rate is an important caveat to take away from this study. Regardless of the small incidence of head-to-surface impacts in this study (16.3% of total concussions), the results clearly indicate that the high-quality fields that contained heavy infill weight reduced the potential for head-to-surface trauma without the use of a pad underlayer.[21]

Even more disconcerting is the significantly greater rate of neck trauma observed on pad-supported surfaces (Table 5). Previous studies have attributed this manifestation to decreased impact absorption and energy dissipation during surface impact, resulting in a greater rebound or whiplash effect on the softer padded infill systems.[21.23]

Knee Trauma

The significantly greater incidence of patellar tendon or patellofemoral syndrome injuries documented on the padded fields (Table 3) may reflect greater cleat contact time and more surface deformation with concomitantly lower impact energy absorption and dissipation by substituting less infill for a greater reliance on a pad underlayer.[23] Although numerous dynamics may contribute to patellofemoral trauma, the more pliable surface may accentuate predisposition to lower extremity fatigue and subsequent musculotendinous trauma.[2.16] Unstable surfaces or an improper innersole have been repeatedly associated with excessive rear foot eversion or overpronation in the literature.[31,34,36] This condition typically results in changes in knee valgus angles as well as asynchronous gait coordination from altered knee and hip mechanics, subsequently leading to patellofemoral stress and various other pathologies over time.[5,6] Obtaining lower extremity kinematic data during actual play, however, was beyond the scope of this study, limiting further supposition. Future research in this area is warranted to identify factors that affect safe play on these lightweight surfaces among adolescent athletes during competition.

Another concern was the anterior cruciate ligament and associated tissue trauma on both surfaces, which comprised 31.8% of all knee injuries and 7.2% of all injuries reported in this study. This is consistent with the continuing increase in severe trauma observed in other high school studies across both artificial and natural grass surfaces,[20,21,23] eventually resulting in increased health-related issues at a later age.[9,17] A priority should be placed on addressing this continuing pattern observed across all field surfaces during adolescent football activity.

Injury Category

Given the challenges in maintaining consistency of artificial turf surfaces with multipurpose fields continually in use at the high school level combined with the increasing size, strength, and speed of these athletes,[10,23] it is possible that the significantly higher injury rates on padded fields during player-to-turf impacts and muscle-tendon overload cases, as well as injuries attributed to shoe-surface interaction during player contact, may reflect less margin of error due to less infill than that observed with nonpadded fields. The more compliant, padded surfaces, commercially geared toward reducing severity of head impacts, ultimately did not influence concussion rates or degree of head trauma but, as mentioned, contributed significantly to greater rates of neck strains and tendinopathies around the knee compared with the firmer heavyweight infill systems. These observations are consistent with previous findings across various infill weight fields.[21]

Primary Type of Injury

The significantly higher incidence of ligament sprains, muscle and tendon strains, and joint inflammation documented on fields with a pad underlayer may be related to the greater shoe-surface contact time usually associated with a less consistent, softer surface,[20,23,27] which is supported by earlier summations noting an inverse relationship between the incidence of musculotendon and ligament trauma and surface integrity.[16] Results may also be a function of varying shoe-surface peak torque and a lack of consistent rotational stiffness on padded fields compared with firmer, no-pad infill systems.[7] Further investigation in which the biomechanics of the shoe-surface interaction are studied beyond the laboratory setting is recommended to more closely replicate the environmental variability, player contact, and anatomic and neuromuscular complexities during actual sports performance.[10,14]

Injury Mechanism

Previous authors have surmised that artificial surfaces enhance the speed of the game[20,23] but at the cost of a greater potential for trauma because of greater rates of acceleration, in-shoe loading patterns, and torque during pivoting, change of direction, direct contact with an opposing player, deceleration, or mishaps.[7,21] The significantly higher incidence of injuries documented on pad-integrated fields in this study, however, did not support the efficacy of using a pad underlayer and less infill weight when analyzing injuries during surface impact, noncontact injuries during leg plant and rotation, and injuries while being blocked or tackled below the waist. Rather, the findings support the use of heavyweight infill systems without a pad underlayer for high school competitive play.

Tissue Type and Anatomic Location

As previously mentioned, the significantly higher incidences of joint and muscle injury reported on the pad-augmented fields were surprising but, as earlier noted, may indicate an inverse relationship between a playing surface's energy absorbency or compliance and the degree of fatigue and tissue trauma.[2,14] The coefficient of restitution or degree of rebound was not established in this study; however, when compared with the nonpadded fields that primarily rely more on heavier infill weight, findings on lighter weight, pad-supplemented infill systems may reflect lower energy absorption at ground impact. The energy of impact is subsequently transferred back to the lower extremity region, increasing the potential for trauma.[2,16] This was substantiated by the pad-related increase in lower extremity trauma found in this study, especially involving the significantly higher incidence of femoropatellar and combined lower extremity joint injuries reported on padded fields. Lending support to this theory was the prevalence of significant muscle trauma to the lower leg and combined lower extremity musculature when athletes play on padded infill surfaces.

Elective Imaging and Surgical Procedures

With increasing health care costs and equivocal injury findings, it is surprising that the tracking of elective imaging and surgical procedures has not been largely addressed in previous injury risk studies.[22] The pronounced increases in upper and lower extremity trauma observed on pad-augmented fields that required subsequent imaging and surgical intervention over 7 seasons reiterates the negative effect that lightweight infill pad systems have on game-related surface trauma during high school competition,[20,21,23] potentially leading to future health-related quality of life issues.[1,33] The findings strongly suggest the need to further investigate the effect of modifications of playing surfaces on adolescent safety as well as to include subsequent medical procedures in future studies to substantiate efficacy of outcomes. This would lead to pertinent insight into actual safety improvements and move the sports medicine discussion beyond supposition and simple documentation of the incidence and severity of trauma across various sport surfaces.

Age of Playing Surface

As previously mentioned, speculation exists as to the influence of surface age on injury,[21] with scant information in the literature primarily focusing on artificial turf versus natural grass.[22] The recent popularity in artificial turf systems, however, has brought to the forefront the effect of surface age on sports trauma. The significantly higher rate of injuries reported on the padded fields across all surface age categories, when compared with the nonpadded fields, is of clinical concern, reflecting decreasing long-term protection for these athletes playing on lighter infills as well as increasing medical costs. The limited research on the influence of turf age on sports injury prevents further comparison and warrants continued research at all levels and types of sports competition.

Limitations

There were potential limitations to the study that may have influenced the type and number of injuries reported. These included the inability to control the inherent random variation in injury typically observed in high-collision team sports[21]; the strength and conditioning status of the athletes and variations in the type of equipment used[2,9,29]; variations in weather and subsequent field surface temperature conditions[2,28]; differences in postural or joint integrity, musculoskeletal structure, and biomechanics of player movement[2,8,9,19]; coaching style and experience and play calling[13,29]; foul play and the quality of officiating[21,29]; actual versus average time to exposure to injury[4,11,14]; sports skill level, intensity of play, and fatigue level at time of injury[11,13]; an athlete's ephemeral response to seeking help, injury, and subsequent pain[24,30]; unreported congenital or developmental factors predisposing an athlete to additional injury[2,11,29]; or unforeseen mishap.[12,29] There is also the opportunity for an injury to go unreported despite the comprehensive nature of any reporting system.[12,21]

Key strengths of the study were the opportunity to follow a large number of US high schools during the 7-year period, which minimized fluctuations often observed in single-season injury patterns and individual team effect and enhanced the ability to identify injury differences and trends between pad and no-pad fields. In addition, the combined method of assessing functional outcome, time loss, direct observation, and treatment records as well as the daily interactions of ATCs in direct communication with athletes in this study minimized the potential for transfer bias and unreported injuries throughout the season.[14,23]

The influence of risk factors other than a pad or no-pad infill system cannot be overlooked. Because of inherent challenges of collecting data on multiple indices and on numerous teams and players over an extended period of time, the degree of influence from these risk factors remains a limitation that can only be acknowledged at this time.[13,14] However, the prospective cohort multivariate design enhanced sample size, resulted in variation of play on all surfaces, controlled for seasonal and team variation, and allowed for greater insight into both significant and subtle differences on pad and no-pad high school fields.

CONCLUSION

Although some similarities in injury characteristics existed across pad and no-pad infill systems over the 7-year period of competitive play, athletes competing in games on padded underlayer fields experienced significantly greater rates of injury. These differences were clearly evident in regard to severity of injury, knee trauma, injury category, primary type of injury, injury mechanism, type of tissue injured, elective imaging and surgical procedures requested, and age of turf surface as well as upper and lower extremity joint and muscle trauma. The hypothesis that high school varsity football athletes would not experience any difference in the incidence, causes, and severity of game-related surface injuries between pad and no-pad fields was not supported.

In contrast to conventional wisdom, the addition of a pad under an artificial turf surface increased injury rates when compared with no pad fields across most injury categories. At this time, findings do not support the current trend of installing lightweight padded infill systems at the high school level of play. This is the first longitudinal study to investigate the influence of field padding on sports trauma when integrated with an artificial turf infill system. Ensuring optimal adolescent sports safety through research-supported guidelines, rather than perception, should be considered before future field installations.

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