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Gridiron Football Injuries

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Abstract

Objective: To review the available football epidemiology literature to identify risk factors, facilitate injury prevention and uncover deficiencies that may be addressed by future research. **Data Sources:** A literature search of Sports Discus (1940–2003), Eric (1967–2003), EMBASE (1988–2003), MEDLINE (1966–2003), CINAHL (1984–2003), and Web of Science (1993–2003) identified the published articles on American football in athletes of high school age and younger. **Main Results:** Injury rate increases with the level of play (grade in school), player age, and player experience. The lower extremity (knee and ankle joints) is most frequently injured. Football injuries are much more common in games than in practice, and occur to players who are being tackled, tackling or blocking. Most injuries are mild, including contusion, strain and sprain. Rule changes with the prohibition of initial contact with the helmet or face-mask reduced catastrophic head and neck injuries. **Conclusion:** Although no sport or recreational activity is completely risk-free, football epidemiology research is critical to injury prevention. The existing medical literature provides some valuable insights, but an increased emphasis on prospective research is required to test the efficacy of preventative measures. Quality research may contribute to a reduction in football injury risk by defining the role of player conditioning and strength training, coaching of safety fundamentals, avoidance of dangerous activities, as well as proper medical supervision and care. Sports medicine personnel, coaches, and officials must strive to minimize injuries through progressive education, improved coaching techniques, effective officiating, and equipment modifications.

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Introduction

Thirty-five million children and young adults in the United States participate in sports [1]. One of every fourteen teenagers presenting to the emergency room following a traumatic event has a sports-related injury, and American football is the most common precipitating athletic activity [2]. Approximately 1.2 million injuries occur each year as a result of 1.5 million athletes participating in

organized American football [3]. The knee and ankle are most commonly injured in this collision and contact team sport, but football has also been associated with catastrophic injuries involving the brain and cervical spine [4].

The sports medicine community has attempted to document the risks and the mechanisms of injury in the game of gridiron football, especially concussion, spinal cord trauma and death [3, 5–11]. The nature of available reports range from surveys, which estimate the absolute number of injuries, to prospective cohort analyses that identify risk factors and suggest preventative measures [12–15]. The bulk of the literature concerning gridiron football injuries has focused on the high school age athlete and older [8, 11, 15–22]. Few studies have investigated the risk of participation in American football at the youth level, but injury rate and severity appears surprisingly low when compared to those competitors who have passed through puberty [14, 21, 23–27].

Problem Statement

A review of American football epidemiology research permits administrators, sports medicine professionals, coaches and players to identify risk factors and hopefully facilitate injury prevention. This information also allows parents and their children to make informed decisions about football participation [28]. The published articles on American football in athletes of high school age and younger were identified by searching Sports Discus (1940–2003), Eric (1967–2003), EMBASE (1988–2003), MEDLINE (1966–2003), CINAHL (1984–2003), and Web of Science (1993–2003).

Two major limitations to cross-investigation comparisons are the definition of what exactly is an injury and what constitutes risk. The numerator refers to the injury events and the denominator reflects the participating players at risk [29, 30]. An epidemiological survey of the literature on high school football injuries [31] revealed numerous methodological problems. Simply put, the calculated injury rate is only good at the identification of cases (numerator) and the identification of the population-at-risk (denominator). Lack of a clear definition of injury, standardized forms, strict record keeping and precise diagnosis results in detection and recall bias. The specific definition of injury is critical, since studies that record all injuries, including minor trauma, can overestimate risk. Injury detection by telephone interview or questionnaire is fraught with inaccuracy. Emergency department chart review may not identify the injured athletes who sought evaluation elsewhere or did not require treatment [32]. Data from insurance files uncovers only the claims-made injuries, which also encourages under-reporting [33]. Parents and coaches may not have the experience to correctly diagnose and report all injuries [23]. Surveys and questionnaires have poor compliance and are fraught with error.

Most published investigations of high school and youth football injuries have not considered the population-at-risk, but have merely reported the number of participants. Injury risk factors cannot be analyzed without simultaneous measurement of injury exposure [34]. The total number of participants used as the denominator fails to account for the time of exposure, which is a key component for a meaningful analysis. Defining the population-at-risk as the players on the team roster at the start of the season does not take into consideration player attrition (transfer bias) or limited playing time (low exposure). Estimation of collective player exposure by calculating the number of players, the number of games and practices, and the approximate length of each practice and games is inaccurate. This method also implies that each practice is the same and each player participates equally in each practice and game.

Football is a noncontinuous participation sport, and interruption of competition between plays makes injury risk assessment according to player-games and player-plays more pragmatic than player-hours. The actual playing time during a 40-minute youth football game (four 10-minute quarters) has been measured at approximately eight minutes [14]. Measurement of exposure to injury by recording the offensive, defensive and special teams' plays is more sensitive. This technique of injury analysis and reporting is similar to tracking the number of bicycle trips or gymnastics maneuvers and should be more accurate in calculating injury rates. Even well-designed studies often use methods of injury incidence calculation that typically do not account for more than one injury per incident or more than one injury per player.

Incidence of Injury

Risk of injury or 'incidence' is determined according to established principles of epidemiological research. Few studies to date have accurately addressed the risk of injury during football game participation, and comparison to other sports or free play is difficult. Participation in competitive football, especially at the youth level, can be difficult for some players and their parents because of a perceived high injury risk. The available literature both supports and refutes this perception.

A prospective study of 6–17-year-old athletes participating in six supervised sports on a military base revealed that football players sustained twice as many orthopedic injuries as any other sport [35]. However, these researchers also found that unsupervised recreational activities contributed twice as many extremity injuries as those occurring during organized sporting events. Baseline injury rate was studied in a cohort of children aged 7–13 participating in

community-organized baseball, softball, soccer and football [36]. No differences were detected over a period of two seasons when the injury risk was expressed as injuries per 100 athlete-exposures. Football participation was associated with a higher risk of serious injury (fracture, dislocation, concussion). High school athletes who played football were not at higher risk for injury when compared to students participating in other activities [18]. Junior league organized football was safer than free play based on an analysis of 70 teams [24]. Data collected on athletes in the fourth with grades [14] revealed that the risk of injury in youth football did not appear greater than other recreational or competitive sports. Godshall [37] observed approximately 2,300 Junior League football players over a 17-year period and identified only 2 major injuries. His risk-benefit analysis concluded that the leadership, discipline, self-sacrifice, and sportsmanship learned outweighed the prospect of injury.

On the other hand, surveillance of injuries to high school athletes by athletic trainers revealed that football had the highest injury rate (8.1 per 1,000 athlete-exposures) and volleyball had the lowest (1.7 per 1,000 athlete-exposures) [38]. Another one-year study of 1,283 high school athletes identified 280 injuries with football responsible for 61% [39]. Football was also responsible for the highest percentage (81 injuries/100 participants) of injuries among high school athletes in the Seattle metropolitan area [22], and high school football players were 6 times more likely to have knee surgery compared to the general population [16].

High School

The data on injury rates affecting high school football players are summarized in table 1. Review of table 1 identifies one retrospective study [8] and six prospective [15, 16, 18, 19, 38, 39] studies. Surveys and insurance or emergency record reviews were not included. The study duration ranged from one to nine seasons, although most studies followed the athletes for two to four seasons. Definition of injury varied, but typically included time-lost from participation as one of the criteria. Exposure was measured in only three of the studies by estimating the collective player participation in practices and games. Cross-study comparisons are not reliable if the definition of injury and/or measurement of exposure are inconsistent. Injury rates in the Powell and Barber-Foss [38] and Turbeville [15] studies indicate a range of 13.1–26.4 injuries per 1,000 game exposures and 1.3–5.3 injuries per 1,000 practice exposures. These discrepancies may reflect differences in study design rather than a true difference in injury incidence.

Thompson [31] identified 32 total injuries in 36 players during a single high school football season, but many trivial injuries were likely included.

Table 1. High school football injuries

	Study design	Study duration	Number of injuries/ players	Definition of injury	Measurement of exposure	Data collection method	Injury rate
Moretz [18]	Prospective cohort	Two seasons	241/903	Time lost (altered or lost practice or game)	None (estimated total time at risk)	Player telephone interview	? 0.51 injuries/ player/game hour
Olson [39]	Prospective cohort	Nine seasons	478/1200	Time lost (≥ 2 practices, ≥ 1 game)	None	Injury report form	?
Culpepper [8]	Retrospective cohort	Four seasons	1877/?	Treatment sought	None	Clinic record review	?
Prager [19]	Prospective cohort	Four seasons	251/598	Time lost	None	Player or athletic trainer report	?
DeLee [16]	Prospective cohort	One season	2,228/4,399	Any time lost, physician treatment, head injuries	Estimated collective exposure	Athletic trainer report	0.506 injuries/ athlete/year
Powell [38]	Prospective cohort	Three seasons	10,557/?	Time lost (unable to participate in current practice or game), fractures, dental, brain injuries	Collective exposure	Athletic trainer report	26.4 injuries per 1,000 game exposures, 5.3 injuries per 1,000 practice exposures
Turbeville [15]	Prospective cohort Age 12–18	Two seasons	132/717	Time lost (missing a practice/game or alteration of or loss consciousness)	Estimated collective exposure (total number of players $\times$ total number of practices and games)	Coach or athletic trainer report	13.1 injuries per 1,000 game exposures, 1.3 injuries per 1,000 practice exposures

Turbeville et al. [15] studied injury frequency and risk factors in high school football players. The football coach or an athletic trainer generated an injury report and telephone follow-up confirmed the injury type, location and treatment. Collective exposure was estimated by multiplying the total number of players by the total number of practices and games. Overall risk in this cohort measured 13.1 injuries per 1,000 game exposures and 1.3 injuries per 1,000 practice exposures. Since the actual amount of playing time was not recorded for each player, first-string players were analyzed to indirectly control for playing time. Multivariate analysis revealed that a positive injury history and increasing player experience were the only significant injury predictor variables. The authors concluded that the best predictor of injury was playing experience, not physical characteristics. Injury risk increased 40–60% for every year increase in experience; but experienced players may simply be at higher risk because they participate in more plays during each game.

Youth

Injury rate data for youth football are summarized in table 2 [14, 21, 23, 26]. Surveys and insurance or emergency record reviews were not included. Only four prospective cohort studies were identified. Study duration ranged from one to two seasons and all used a time-loss definition of injury. In the two studies that measured exposure to injury, game injury rates were very similar. Stuart et al. [14] reported 8.5 and Turbeville et al. [23] 8.8 injuries per 1,000 player games respectively. Goldberg [26] gathered injury data by telephone interview and questionnaire on football players aged 9 to 14. The prevalence of injury type and location are somewhat helpful, but no additional conclusions are possible without measurement of exposure time.

The prospective cohort observational analysis by Stuart et al. [14] during a single season showed that youth football injuries are uncommon, occurring once every 8.75 seasons per player. Strengths of this study include a clear definition of injury, standardized forms, strict record keeping and an orthopedic sports medicine physician on site to provide an accurate diagnosis. A coach from each team completed the game participation and exposure form and recorded the total number of offensive and defensive plays, kickoffs and punts for each team. These epidemiological principles foster injury identification with minimal detection and recall bias, along with simultaneous measurement of injury exposure. Overall risk in this cohort was 8.5 injuries per 1,000 player-games and 0.2 injuries per 1,000 player-plays.

Turbeville et al. [23] also reported on injury frequency and risk factors in middle school football players using the same study design as their high school project. First-string players were again studied to indirectly control for playing time. Overall risk in this cohort was 8.8 injuries per 1,000 game exposures, and

Table 2. Youth football injuries

	Study design	Study duration	Number of injuries/players	Definition of injury	Measurement of exposure	Data collection method	Injury rate
Goldberg [26]	Prospective cohort Age 9–14	One season	67/436	Time lost (greater than or equal to one day)	None	Questionnaire completed by league personnel	?
Linder [21]	Prospective cohort Age 11–15	Two seasons	55/340	Time lost (removal from or missing subsequent practice or game)	None	Coach report	?
Stuart [14]	Prospective cohort Age 9–13	One season	55/915	Time lost (remainder of the game), attention of a physician, all concussion, dental, eye and nerve injuries	Individual player game participation, number of plays/game for each team	Physician examination	8.5 injuries per 1,000 player-games, 0.2 injuries per 1,000 player-plays
Turbeville [23]	Prospective cohort Age 10–15	Two seasons	64/646	Time lost (missing practice or game/head injury with impaired consciousness)	Estimated collective exposure (total number of players $\times$ total number of practices and games)	Coach or athletic trainer report	8.8 injuries per 1,000 game exposures, 1.0 injuries per 1,000 practice exposures

1.0 injury per 1,000 practice exposures. The incidence of game injury in the youth players is somewhat less than Turbeville et al. [15] reported in high school athletes (13.1 injuries per 1,000 game exposures) using a similar study design.

Player Position

Injuries occur to players who are being tackled, tackling or blocking. Therefore, running backs, lineman and linebackers have the highest injury rate [28]. Injuries causing a time loss of 48 hours were more prevalent for high school offensive players (n = 153) compared to defensive players (n = 98). Excluding specialty teams, high school tackles and linebackers sustained the most injuries based on a percentage of total injuries. No exposure data for players or positions was recorded [19]. Youth football running backs and lineman were at highest risk for injuries, especially to the knee [14, 23].

Injury Characteristics

Injury Onset

The overwhelming majority of injuries in both high school and youth football are sudden or acute. Little information is available on the incidence and mechanism of overuse injuries in these young athletes.

Injury Location

Injury location expressed as a percentage of total injuries is summarized for high school football studies in table 3 [8, 15, 16, 18, 38, 39] and for youth football studies in table 4 [14, 23, 24, 26]. A review of table 3 indicated that the lower extremity is the most frequently injured body region (31–59%) followed by the upper extremity (21–34%). The knee (15–37%) and ankle (11–27%) joints are most susceptible to football trauma. Upper extremity injuries typically involve the shoulder (8–15%), and wrist and hand (7–11%). Table 4 shows a similar distribution for youth players with the majority involving the lower extremity (36–51%) followed by the upper extremity (25–41%). The knee (17–22%) and ankle (10–17%) are again most susceptible for the lower extremity, the wrist and hand (14–30%) for the upper extremity. The ankle physes (distal tibial and fibular growth plates) are especially vulnerable for a fracture in skeletally immature athletes [14].

Although cervical spine injuries are uncommon in most studies, a preseason examination of 104 high school football players revealed a history of neck injury in 17, positive physical examination findings in 2 players, and radiographic abnormalities in 8 [40]. Seventy-four high school players were studied over two seasons in an attempt to identify all injuries to the cervical

Table 3. High school injury location

Percentage of total injuries	Olson [39] n = 478	Moretz [18] n = 241	Culpepper [8] n = 1,877	DeLee [16] n = 2,228	Powell [38] n = 10,557	Turbeville [15] n = 132	Range
Head			8	5		7	
Neck	[10	[6		1	[13	2	[6–15
Face				4	2	6	
Back	2	5	5	8		4	2–8
Trunk	5		3	1	9	1	1–9
Upper extremity	26	21	34	23	26	22	21–34
Shoulder	9	7	13	11		9	7–11
Upper arm	1		1		12	2	1–2
Lower arm	1	<1	2				1–2
Elbow	2	3	3	4			2–4
Wrist			3		[14	3	8–15
Hand	[13	[10	12	8		5	1–3
Pelvis/groin			<1			3	2–17
Hip		[12	2	7	17		31–50
Lower extremity	58	58	46	48	31	59	4–10
Upper leg	4	4	5			10	4–10
Lower leg	4		4	8			4–8
Knee	37	22	22	20	15	20	15–37
Ankle			11	18		27	11–27
Foot	[12	[22	4	2	[16	2	2–4
Other	1	10	<1				

spine. Eight neck injuries were documented, including six muscle strains, one ‘stinger’, and one transient neurapraxia.

Situation

The risk of injury appears to be greater in competition than in practice, both at the high school and youth levels. High school football injuries are much more common in games than in practice [15, 16, 18, 40]. Moretz et al. [18] found the risk of injury for Oklahoma high school football players to be 18 times higher in a game than in practice. The risk of injury in youth football is also higher in games, but injury incidence appears less than high school reports [14, 23]. Inconsistency in exposure measurement techniques and different expressions of injury rate make comparison of the available research difficult. Turbeville et al. [15, 23] reported a 10-fold increased risk of game injury (13.1 injuries per 1,000 game exposures) than in practice (1.3 injuries per 1,000 practice exposures)

Table 4. Youth injury location

Percentage of total injuries	Roser [24] n = 48	Goldberg [26] n = 67	Stuart [14] n = 55	Turbeville [23] n = 64	Range
Head	8	10	7	2	2–10
Face					
Neck					
Back	[5	3	9	[9	3–9
Trunk	6	5	5	6	5–6
Upper extremity		32	25	41	25–41
Shoulder	2	5	7		5–7
Upper arm					
Elbow	1	6	4	[11	4–6
Lower arm			[9	17	14–30
Wrist	7	[21	5	13	5–13
Hand	9		2	3	2–3
Pelvis/groin					
Hip		3			3
Lower extremity		47	51	36	36–51
Upper leg			5	[2	[2–10
Lower leg			5		
Knee	8	22	20	17	17–22
Ankle		10	15	17	10–17
Foot		15	4		4–15
Other			2		

in high school players and almost 9-fold increased risk of game injury (8.8 injuries per 1,000 game exposures) than in practice (1.0 injury per 1,000 practice exposures) in youth players.

Chronometry

The risk of injury was 510 per 1,000 player-game-hours of exposure compared to 150 per 1,000 player-practice-hours during the preseason and 28 per 1,000 player-practice-hours during the season [18]. These rates suggest that injuries are 5.4 times more likely in preseason practice and 18.2 times more likely in games than in inseason practice.

Injury Severity

Most youth football injuries are mild, and the most common type is a contusion. Severity of injury is typically based on time loss until return to participation.

Table 5. High school injury type

Percentage of total injuries	Moretz [18]	Olson [39]	Culpepper [8]	DeLee [16]	Powell [38]	Turbeville [15]
Sprain	40	21	32	45	32	[54
Strain	22		12		21	
Contusion	18	14	25	21		17
Fracture	[13	24	11	7	8	11
Dislocation		8	2	3		5
Concussion		9	1	5		6
Laceration			<1	16		1
Dental				2		
Other	7	37	16		39	6

Table 6. Youth injury type

Percentage of total injuries	Roser [24]	Goldberg [26]	Linder [21]	Stuart [14]	Turbeville [23]
Sprain	[35	34	[45	9	[55
Strain		12		20	
Contusion	17	22	33	60	17
Fracture	35	15	18	7	27
Dislocation	1	4			
Concussion	4	6		2	
Laceration	[7		4		2
Abrasion		2			
Dental					
Other		2		2	

An example of severity grading includes: mild (no limitations expected and either no time loss or players expected back at football within 3 days); moderate (athletes returned within 4–14 days); and severe (long-term sequelae expected and athletes expected to be out of football longer than 14 days).

Injury Types

Type of injury is summarized for high school players in table 5 [8, 15, 16, 18, 38, 39] and youth players in table 6 [14, 21, 23, 24, 26]. Most studies agree that minor injuries such as contusions, strains and sprains account for the bulk of all injuries. Turbeville et al. [15] showed that sprains and strains were most

common in high school players, followed by contusions, and fractures. Injury type is very similar in high school and youth players, but the diagnostic terminology is not uniform. Sprains (9–45%) and strains (12–22%) combined account for approximately half of all injuries at both levels. Contusions represent between 14 and 60% and concussions only 1–9% of all injuries. Fractures occur in 7–24% of injuries to high school players and 7–35% of injuries to youth players. These fractures typically involve the growth plates of the wrist and ankle.

Catastrophic Injury

The likelihood of serious or catastrophic injury to youth football players is relatively small, but the risk increases for high school players. Mueller [41] defined catastrophic injury as any severe injury incurred during participation in a school-sponsored sport. These injuries are categorized as fatal, nonfatal (permanent or severe functional disability) or serious (no permanent functional disability, but severe injury). Sports injuries were further classified as direct or indirect. Direct injuries result from participation in the skills of the sport. Indirect injuries are caused by systemic failure as a result of exertion while participating in a sport activity or by complication secondary to a nonfatal injury.

Fatalities

The Annual Survey of Football Injury Research conducted by Mueller [42] registered 684 total football fatalities at all levels of play from 1945 through 1994. Most of the head injury fatalities ($n = 345$, 74.2%) and cervical spine fatalities ($n = 76$, 65.5%) occurred to high school players during games. The total number of fatalities climbed to 712 through 1999 [41]. Head injuries were responsible for 491 (69%), cervical spine injuries for 116 (16.3%), and other injuries for 105 (14.7%).

Football head-related fatalities were most prevalent in junior and senior high school (75%) largely due to the number of participants. The volume of high school players was estimated at 1.5 million as compared to 75,000 college players. Fatal head injuries usually occurred while tackling or being tackled during a game. Subdural hematoma was the most common diagnosis (75%). The declining rate of football head-related fatalities is likely due to the 1976 rule change prohibiting initial contact with the head or face together with improved coaching of blocking and tackling techniques.

Cantu and Mueller [43] identified catastrophic American football head and spine injuries to high school, college, sandlot and professional players by analyzing epidemiological and medical data from 1977–1998. Catastrophic injuries were defined as death, brain or spinal cord injury, and cranial or spinal

fracture. During this 11-year period, 118 football players died, 200 received a permanent spinal cord injury, and 66 suffered a permanent cerebral injury. Although the data were not broken down by age or level, 164 of the 200 cervical cord injuries were sustained by high school players and all 66 cerebral injuries occurred at the high school or college level.

Concussion

Despite the available data, most parents are uninformed about the risks of severe brain injury from their children playing high school football [44]. Athletic trainers recorded injury and exposure data for varsity athletes in 10 different sports at 235 high schools in a 1-year study [45]. Mild traumatic brain injury was diagnosed in 1,219 participants during the 3-year study period. Football accounted for 63.4 percent of the head injuries. Six cases of subdural hematoma and intracranial injury were identified in football players. Head injury rates were 11 times higher for games than for practice [46].

The incidence of concussion, common signs and symptoms as well as return-to-play criteria were analyzed from a survey of high school and collegiate football team athletic trainers [47]. Players who sustained a concussion were 3 times more likely to sustain a second concussion in the same season compared with uninjured players. Only 9% of concussed athletes lost consciousness, 86% developed a headache, and 31% returned to play on the same day. These observations are important, though based on a survey with a 62% response rate. Players, coaches and health care providers should be aware of the increased risk of a second concussion, and symptomatic athletes should never be allowed to return to play.

Concussion appears to be relatively uncommon in youth football players [14, 24, 26]. Stuart et al. [14] recorded only one concussion when over 900 youth players aged 9–13 years were carefully followed during a single season. Turbeville et al. [23] identified only one mild head injury during a two-season study of middle school athletes.

Injury Risk Factors

Risk factors for injury can be intrinsic (personal), which represent characteristics of the specific player, or extrinsic (environment, equipment), from features out of the athlete's control (table 7). Determination of a true cause and effect relationship is very difficult because of numerous confounding variables. Increasing age and level of play appear to be associated with increase in injury incidence, but the relationship of body weight to injury risk remains unclear.

Table 7. Injury risk factors

Intrinsic	Extrinsic
Age	Conditioning
Grade in school	Field conditions
Tanner stage	Helmet type
Weight	Shoulder pad type
Body fat	Shoe type
Ligamentous laxity	Knee braces
Playing experience	
Psychosocial factors	
Dangerous activities	

Intrinsic Factors

Physical

Goldberg et al. [26] could not identify a correlation between injury risk and age in youth football players. However, Stuart et al. [14] found that the risk of injury to youth football players increased with level of play (grade in school) and player age. The risk of injury for an eighth grade player was 4 times greater than the risk of injury for a fourth grade player. Potential contributing factors included increased size, strength, speed, and aggressiveness.

Linder et al. [21] examined the relationship between sexual maturity (Tanner stage) and the incidence of injury in junior high school football players. The coach recorded an injury if a player was removed from a practice or a game. An overall injury rate of 16% was reported over two seasons. No serious or permanently disabling injuries occurred. Ten fractures, including five physal injuries were diagnosed. Injuries were more prevalent in the older players who were also more physically mature (Tanner stages 3, 4, 5). The authors admit that no direct conclusions can be drawn since individual exposure data were not collected.

Turbeville et al. [15] found that injured players were older, bigger, stronger, more experienced, and more likely to have sustained an injury in the previous season. The increased injury risk to the more experienced than uninjured players may actually reflect increased playing time, aggressiveness, or pubescence.

The North Carolina Study investigated junior and senior high school football injuries and also measured grip strength, physiologic maturation, ponderal index (weight relative to height), age, height, weight and body fat (subscapular skinfold) in 466 athletes. [48] Junior high players were less likely to be injured even though both levels had a wide variation in sexual maturation. The injured junior high players were lighter and less mature than noninjured teammates. In the author's opinion, 17% of all injuries were preventable, resulting from poor equipment, hazardous conditions or improper technique.

Tanner's method of assessing sexual maturity was used in 340 male football players between the ages of 11 and 15 [21]. Each team's coach recorded injuries over two seasons if a player was removed from a practice or game and/or missed a subsequent practice or game. Tanner stages 5, 4, and 3 combined were associated with more injuries than Tanner stages 2 and 1 combined. Higher injury prevalence was evident with increasing age in these adolescent athletes. Player age was not controlled when testing for maturity as a risk factor. No exposure data were recorded, and the authors admit that the more mature athletes may have received more playing time. This study suggests that increasing sexual maturity may be a risk factor for adolescent football injuries.

Stuart et al. [14] compared the risk of injury for players above and below the mean body weight according to each grade level. A trend was evident that heavier players (individual body weight > mean body weight) sustained more injuries than lighter players (individual body weight < mean body weight). However, discriminate function analyses with weight predicting injury revealed no significant relationship between body weight and injury.

A prospective cohort analysis of 216 high school football players was designed to determine adiposity is associated with increased risk of injury. Athletic trainers recorded injuries as well as practice and game exposure time. Skinfold measurements revealed body fat range of 9.3–40.2%. Eighty-six injuries occurred during 15,207 hours of total playing time for an injury rate of 0.026 injuries/player/1,000 hours. The trend was for players with more body fat, greater body weight, and greater body mass index to sustain lower extremity injuries. Body mass index greater than 26 kg/m² was consistently (except >34 kg/m²) associated with risk of lower extremity injury ($p < 0.05$) [49].

Preseason height, weight, and triceps/subscapular skinfold were measured in 98 high school football players. During the season, certified athletic trainers recorded all injuries that required one of these players to miss at least one practice or game. Twenty-seven players (28%) had the sum of skinfolds ≥ 95 th percentile for age, but the overall prevalence was not significantly elevated when compared to player's ≤ 95 th percentile. Although this study did not show an increased injury risk for obese football players, the high incidence of obesity in this athletic population was alarming [50].

No correlation was found between generalized ligamentous laxity and risk of knee or ankle ligament injury in 402 high school football players followed during a single season [51]. An abnormal preseason history or physical exam did not predict an increased risk of neck injury in these high school athletes [52].

Psychosocial

An investigation to test the relationship of anger/aggression, attention and stressful life events to injury and to determine whether the relationship of

stressful events to injury is mediated by anger or by impaired vigilant or focused attention [53]. High school football players completed preseason measures of anger, vigilant attention or focused attention, and stressful life events and were then followed through one season to identify injuries. Logistic regression indicated that high anger directed outward ($p < 0.05$) and low focused attention ($p < 0.01$) increased injury risk, while stressful life events and vigilant attention interacted. Injury risk was elevated when recent stress was present ($p < 0.05$) and increased as vigilance decreased, suggesting that stressful life events elevate injury risk by reducing vigilance.

Using the Life Event Scale for Adolescents, Coddington and Troxell [54] postulated that a player's mental or emotional state might increase the risk of injury. They based this opinion on the fact that high school players, who experienced more family instability, parental illness, separations, divorces and deaths were more likely to sustain a significant injury. Their review of coaches' records identified only 23 injuries. This small sample size and other possible confounding variables do not allow for a definite association between the player's emotions and risk factor of injury.

Dangerous Activities

'Spearing' involves flexing the neck and initiating contact with the top of the helmet. This dangerous manoeuvre has been associated with cervical spine fracture/dislocation and spinal cord injury. As a result, physicians, administrators and coaches preached avoidance of using the head as the primary point of contact in tackling and blocking. In January 1996, the National Alliance Football Rules Committee changed the rules to make 'butt-blocking' or 'face-tackling' a personal foul (15-yard penalty). Coaches need to teach proper blocking and tackling techniques, which do not involve using the facemask or top of the helmet as the primary point of contact [55].

Despite these concerns, a survey of Louisiana high school football players identified an alarming rate of players who admitted to tackling with the top of their helmet. Eighty-three percent of those players stated that their coach taught these dangerous techniques [56].

A survey of Minnesota high school football coaches raised some concerns about players using illegal techniques such as butt blocking and face tackling [57].

Heck [58] reviewed 9 game films from a high school football season to establish the cumulative incidence per season of ball carrier spearing and concurrent defensive spearing by tacklers. During a single season, 167 incidents of ball carrier spearing (1 per 5.2 plays) and 72 incidents of concurrent defensive spearing (1 per 2.3 ball carrier spears) were identified. Despite the frequency of these rule violations, the game officials did not call any spearing penalties. The authors encourage officials to acknowledge these rule infractions and ask

coaches to teach correct ball carrying, blocking and tackling techniques. Lack of rules enforcement is a modifiable risk factor for injury.

Extrinsic Factors

Training Methods or Conditions

Cahill et al. [59] compared the circumstances, number and severity of knee injuries during a 4-year period when football players participated in a preseason-conditioning program to the previous 4 years where no such program existed. The 5–6 week total body conditioning program included cardiovascular exercise, heat acclimatization, weight training, flexibility drills and agility exercises. The knee injury rate per 1,000 athletes was 68 for the no conditioning group and approximately 40 for the closely-supervised conditioning group. The operative rate per 1,000 players was 15.2 for the no conditioning group, 5.7 for the closely-supervised conditioning group and 2.3 for the less-supervised conditioning group. Early season knee injuries were reduced by 67% in the conditioning groups as compared to the no conditioning group. The authors concluded that preseason conditioning significantly reduces the early season knee injuries, the total number of knee injuries and the injury severity.

Environment

Wisconsin high school football teams were studied to determine the association of injury to field conditions [60]. ‘Good’ conditions were associated with the highest frequency of injury (3.3 injuries/game). ‘Wet’ and ‘slippery’ conditions were associated with the lowest rate (1.8 injuries/game). ‘Hard’ and ‘muddy’ conditions were associated with intermediate injury risk (2.3 and 2.1 injuries/game respectively). The authors postulated that wet and slippery conditions caused a reduction in player velocity and rotational stability of the shoe with the ground.

Adkison et al. [61] reported on 349 time-loss injuries from 424 high school football games played on natural grass and 236 games played on synthetic turf. Data analyses showed the injury rate for AstroTurf (0.63 injuries per game) as compared to grass (0.51 injuries per game) and Tartan Turf (0.28 injuries per game). A prospective study of 26 high school football teams during 148 games played on grass and 80 games played on artificial turf revealed higher injury rate and severity on the synthetic surface [62]. The artificial turf studied was a single stadium where 12 of the schools played a majority of their games. The higher injury rates for the synthetic surface were predominantly sustained when the turf was dry, implicating increased traction as a potential risk factor.

The risk of knee and ankle injuries was reduced by 30% with resurfaced fields and regular cleats, and by 46% with resurfaced fields and soccer shoes when compared to schools with no changes.

Equipment

Mueller and Blyth [63] reported on football injuries in 43 North Carolina high schools. Investigators visited each school during the preseason to evaluate the protective equipment of each player for make, fit and condition. The investigators then returned to the schools each week to interview each injured player. The North Carolina High School Football Injury Study suggested that specific brand name football helmets and shoulder pads were associated with higher injury 'rates', and a properly maintained playing surface combined with soccer-style shoes reduced knee and ankle injuries. The data provided are actually the prevalence of injury according to specific equipment brand. However, the author's conclusions are difficult to substantiate, since no exposure data were provided.

The relationship of football shoe design and injury rate encouraged regulations on the size and configuration of cleats. The conventional shoe, with seven $\frac{3}{4} \times \frac{3}{8}$ inch cleats, was associated with a higher incidence and severity of injury when compared to the soccer-style shoe with fourteen $\frac{3}{8} \times \frac{1}{2}$ inch cleats [64]. Four different football shoe cleat types were prospectively evaluated in high school football players to determine torsional resistance and the relationship with anterior cruciate ligament tears [65]. The edge design with longer, irregular cleats placed at the peripheral margin of the sole produced significantly higher torsional resistance and was associated with a significantly higher anterior cruciate ligament injury rate when compared to the flat, screw-in, and pivot disc designs.

Deppen and Landfried [66] compared high school football players at schools with mandatory or voluntary prophylactic knee brace use by tracking injuries, practice and game exposure. They found no differences in knee injury risk with and without bracing.

Suggestions for Injury Prevention

Youth and high school football injury risk may be reduced by player conditioning and strength training, the use of high quality, well-fit equipment, coaching of safety fundamentals, avoidance of dangerous activities, enforcement of existing rules, as well as proper medical supervision and care.

The 1976 rule change prohibiting initial contact with the head or face (spearing, face tackling and butt blocking) together with improved coaching of blocking and tackling techniques appears to have reduced the incidence of head and neck injuries. This rule change has also played a very important role in the decline of football fatalities. Head and cervical spine trauma resulting in football-related fatalities are depicted by decade from 1945 through 1994 in figure 1. The

Fig. 1. High school football fatalities [45].

incidence of high school football fatalities over time is depicted in figure 2. Mueller [41, 42] recommended additional measures to reduce head and neck fatalities:

- mandatory medical examinations for all football athletes
- education of players, parents and coaches
- coaching of proper blocking and tackling techniques
- strengthening of the neck muscles
- strict enforcement of rules
- physician or athletic trainer coverage
- preparedness for all emergencies
- immediate medical attention for any player with signs of head trauma

Injury prevention or ‘acceptable risk’ can be achieved by minimizing extrinsic risk factors and counterbalancing intrinsic risk factors. Intrinsic factors include the developmental mindset along with biologic characteristics of the individual. Extrinsic factors include predictors of injury related to the activity or environment. In reality, the literature contains a paucity of actual preventative trials.

A cohort interventional analysis by Bixler and Jones [67] attempted to determine whether a warm-up and stretching session at half-time affected injury risk in the 3rd quarter of the game. The authors found a significant decrease in 3rd quarter sprains and strains, but no difference in total injuries. Preassignment of participating teams may have introduced bias since increased susceptibility by an individual team or a particular game may have skewed the results.

Neck circumference and range of motion were studied in 40 high school football players [68]. No correlation was found between the athlete's neck size and range of motion. The authors speculate that proper fitting equipment, neck conditioning exercises and changes in the rules might reduce the risk of injury to the cervical spine region in football players. Although impingement of the helmet and facemask against the shoulder pads may restrict motion and tensile forces, the most dangerous mechanism of injury is an axial load to the partially flexed cervical spine.

Observations of high school football players over a 12-year period by Cahill and Griffith [6] suggested that a preseason conditioning program, consisting of cardiovascular stress, heat acclimatization, weight training, flexibility drills and agility exercises, reduced the number and severity of knee injuries. A follow-up study showed that a decrease in supervision of the quality of the preseason program did not affect the apparent benefits [59]. No exposure data were collected, and no other potential confounding variables were examined.

Despite the lack of true epidemiological research, the experiences of numerous authors provides some important recommendations that may prevent injuries or improve the care of the athlete:

- provide emergency medical services (physicians, athletic trainers, paramedics or emergency medical technicians) during games [69]
- match players by Tanner stage and development [70]
- encourage appropriate training and conditioning [70]
- properly fit equipment and footwear [70]
- educate coaches and parents [70]
- maintain playing fields [17]
- use of soccer-style shoes [17]
- allow only noncontact and controlled activities in practice [17, 63]
- increase vigilance over technique during injury-prone preseason practices [17]
- delay return to full contact until complete recovery of injured players [63]
- teach fundamental blocking and tackling skills [39]
- strengthen the neck muscles [39]
- ensure qualified coaches to render emergency care prior to physician evaluation or emergency transport [39]
- forbid use of the head for initial contact [39]

In Garrick's opinion, no new items of equipment would significantly reduce football injuries [71].

According to the FIMS/WHO Ad Hoc Committee on Sports and Children, sport governing bodies should: monitor the level of intensity and categories of competition in their sports, prepare and maintain ongoing statistics of illness

and injury, certify the credentials of coaches and determine standards for protective equipment, playing fields, and duration of competition.

Suggestions for Further Research

To make informed decisions about football injury prevention, risk must be reliably identified in relation to multiple variables. Comparison of injury incidence and risk factors requires well-designed injury epidemiology studies. Ideally, protocols involve the prospective analysis of a defined cohort by an experienced research team. Each study needs a standardized, strict definition of injury and medical terminology, diagnosis by a sports medicine professional, accurate measurement of player exposure, and data analysis based on injury per player play. Longer study duration may determine residual injury effects and cost. High quality epidemiology study design will allow assessment of numerous variables such as player size, rules, protective equipment and playing surface.

Football head-related fatalities, concussion, neck and spinal cord injuries have been reduced by rule changes and improved coaching of blocking and tackling techniques. An increased emphasis on research to test the efficacy of these and other preventative measures is needed.

Youth football leagues are typically organized by age or grade level with some position restrictions according to body weight. A better understanding of the association between injury risk and player age, physical maturity and body weight may promote prevention through validated matching strategies.

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