

Epidemiology of Concussion in the National Football League, 2015-2019

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Background: Concussion in American football, and specifically the National Football League (NFL) is a major area of interest and key focus for injury prevention. Complete and accurate characterization of when, how, and to whom these injuries occur can facilitate injury reduction efforts. Existing studies of concussion in the NFL use publicly available data, potentially limiting data quality and the inferences that can be made.

Hypothesis: Concussion incidence in the NFL decreased across the 2015-2019 seasons.

Study Design: Descriptive epidemiology study.

Level of Evidence: Level 4.

Methods: Concussion incidence, including counts, one-season risk, and rates per game and player-plays, among active NFL players from 2015 to 2019 is described by year, season, play type, and roster position.

Results: A total 1302 concussions were identified from 2015 to 2019 among 1004 players. Of these, 80% occurred in NFL games. The average annual incidence of in-season game concussions changed over the study period, from 230.7 per season (2015-2017) to 177.0 per season (2018-2019); this represented a 23% decrease in game settings ($P < 0.01$). Practice concussions fluctuated across the years of the study from 38 to 67 per season (average = 50.8/season). There were 70.6 concussions per 100 preseason games, which was slightly higher than the regular season rate per game of 61.7. Overall, there were 790 regular season game concussions across 4,657,243 player-plays and 114,428 player-games during the 5-year study. In regular season games, the majority of concussions were sustained on running and passing plays ($n = 119$ /season), and the highest average rate per play occurred on kickoffs (0.69/100 plays). Defensive secondary (cornerbacks, safeties, and generic defensive backs) and offensive line incurred the most concussions, and the highest rates of concussion were among tight ends and wide receivers.

Conclusion and Relevance: Concussions in the NFL are a key focus for player safety. Concussion reduction strategies were implemented before 2018, after which there was a sustained 2-year decrease in concussion incidence, providing a new benchmark from which to work toward further injury reduction.

Keywords: concussion; American football; National Football League; epidemiology

Over the past 30 years, perhaps no other injury in sports has captured the attention of the public, the media, and sports medicine scientists as much as mild traumatic brain injury, also known as concussion.^{12,13} Tracking concussion

incidence in American football is particularly important because of high incidence rates compared with many other sports. Incidence and prevalence of concussion in football have been reported and studied extensively at the youth,^{6,33} middle

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school,² high school,^{22,30,35-37,41} and collegiate levels.^{17,18,34,42} In professional sports, epidemiologic studies of concussion have been reported in Major League Baseball,^{7,38} the National Basketball Association,³¹ the National Hockey League,⁵ Australian Rules Football,^{9,27} and globally across soccer^{3,10} and rugby.¹¹

The first epidemiologic study of concussion among professional athletes in the National Football League (NFL) was published by the Mild Traumatic Brain Injury Committee in 2004,³² with a follow-up article appearing in 2010.⁸ Since then, several studies using publicly available data have reported concussion rates of 0.66 concussions per game, with one study reporting an increased incidence of 1.6 over the past decade.^{4,9,14-16,20,21,28,29,39,40} These publications vary in time frame and methodology, leading to variations in reported incidence. Most notably, these studies all use publicly available data, potentially limiting data quality and the inferences that can be made.

Accurately characterizing concussion incidence can be difficult because of the complexity of assessing and diagnosing concussion.²⁶ Although many concussions go un- or underreported and therefore untreated, the medical community has implemented additional protocols for detecting and diagnosing this injury across all levels and types of sport. Despite the challenges of characterizing this injury, it is important to both characterize and track the epidemiology of concussion. While much progress has been made across sports, geographic locales, and levels of play, there remains a need for additional research.

The purpose of this study was to present NFL concussion incidence from 2015 to 2019 using electronic health record (EHR) data based on reports from medical staff.

METHODS

Study Design and Study Population

This is a retrospective, observational study of concussions sustained by active NFL players during any team-related activity and reported through the NFL's EHR system from the 2015 through 2019 NFL seasons. NFL player injury data were obtained from all 32 NFL clubs from the League's EHR.¹⁴ All injuries requiring medical treatment across all 32 NFL clubs are mandated to be entered into the EHR. Data quality is rigorously reviewed, and concussion reports are audited against both internal and external sources, including media reports. Medical staff use the EHR for clinical care and are trained throughout the year to standardize reporting, including details of the injury such as setting, timing in the season, player activity, and eventual return to participation. The EHR data are linked to sport-related information from the NFL Game Statistics and Information System (GSIS), which provides complete exposure information for clubs and individual athletes at the game and play level (number of plays and type of play). Approval for this study was obtained from the Mt Sinai Institutional Review Board (#0006018123) and through the NFL-NFLPA Player Scientific and Medical Research Approval Process.²³

Concussion incidence is described overall, as well by year (defined by the NFL League year and trading period, which

begins yearly in mid-March), season (offseason, preseason, regular season, and postseason), team activity (game, practice, conditioning/other), play type, and roster position (offensive line, running back, tight end, quarterback, wide receiver, defensive secondary, defensive line, linebacker, kicker/punter/long snapper). In-depth game-related concussion analyses are limited to regular season injuries to focus on a closed, stable athlete population with a homogenous style of play. To account for the number of unique players participating in football activities each year, cumulative incidence was calculated as a one-season concussion risk both by season and as a five-season average, accompanied by 95% CIs calculated using the exact binomial distribution. Risk of repeat concussion within a single NFL season was calculated as the number of players with more than one diagnosed concussion in a season (offseason through postseason) out of the total number of players with concussion in that season. Risk of multiple concussions across seasons will be examined separately.

Incidence rate of game-related concussions was calculated as the rate per 10,000 player-plays to account for the number of plays in which each individual player participated as recorded in GSIS. As a secondary metric, and for comparability across sports where rate is estimated through athlete-exposures (AEs), the rate per 1000 player-games was also calculated. Additionally, incidence counts by year were calculated as the number of concussions per NFL season. All incidence rates, counts, incidence rate ratios (IRRs), and 95% CIs were calculated using the Poisson distribution; *P* values were based on Wald chi-square tests.

RESULTS

Concussion Incidence

From 2015 to 2019, 1302 concussions were identified among 1004 players. The majority of concussions occurred in game settings ($n = 1046$, 80.3%), with 221 (17.0%) during in-season practices, and 35 (2.7%) in offseason, conditioning, or other team activities over the 5 years of the study. Of the 221 in-season practice concussions, 175 (79.2%) occurred in preseason practices, with the majority of these ($n = 129$) occurring from player report date to the start of NFL preseason games (Training Camp).

Regular season had the highest game incidence counts ($n = 790$, 60.7%), with a rate of 61.7 per 100 games (range: 49.6-71.5). Although preseason games had fewer concussions ($n = 228$, 17.5%) than regular season games, preseason games had higher concussion rates (70.6 per 100 games; preseason game range per year: 52.3-83.1; 5-year 95% CI: 62.0-80.4) than regular season games (61.7 per 100 games; regular season game range per year: 49.6-71.5; 5-year 95% CI: 57.6-66.2; IRR [95% CI] preseason vs regular season = 1.14 [0.99-1.33]) (Table 1, Figure 1). Game concussion numbers decreased meaningfully in the last 2 years of the 5-year study period to 164 in 2018 and 190 in 2019 compared with the 5-year average of 209.2; this is a 23% decrease in average game concussion incidence (230.7 in

Table 1. Concussion incidence by year, 2015-2019^a

	2015	2016	2017	2018	2019	5-Year Average (Column %)
Season						
Offseason	5	5	10	5	8	6.6 (2.5)
Preseason	83	71	92	80	79	81.0 (31.1)
Regular season	192	172	190	135	145	166.8 (64.1)
Postseason	4	7	10	3	6	6.0 (2.3)
Team activity ^b						
Game	241	217	234	164	190	209.2 (80.3)
Practice	43	38	67	58	48	50.8 (19.5)
Conditioning/other	0	0	1	1	0	0.4 (0.2)

^aConcussions reported as not sport-related are excluded.

^bPractice includes walk throughs; conditioning/other includes any conditioning activity, weight training, run sessions, individual training (n = 1; 2018 preseason) or concussions reported during other team activities (n = 1; 2017 preseason).

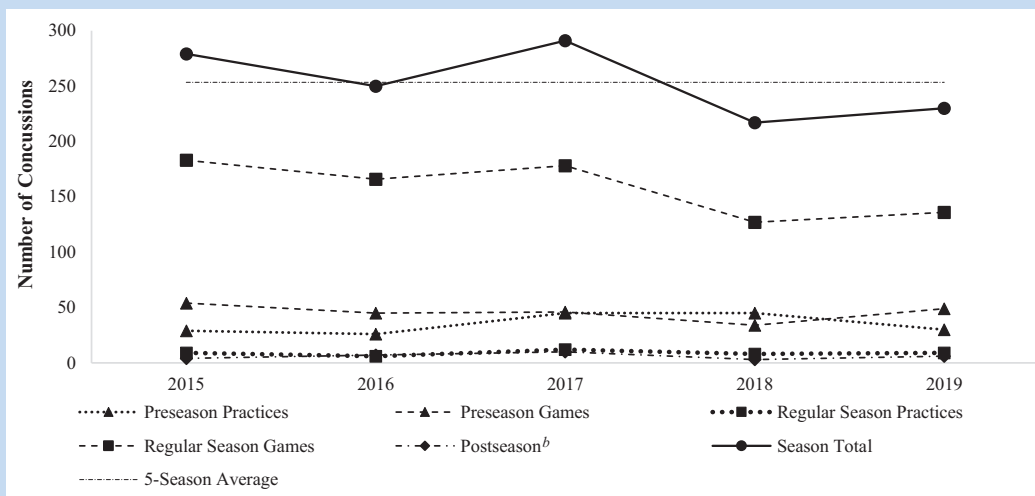


Figure 1. Concussion Incidence in the National Football League, 2015-2019,^a as reported by medical staff to National Football League (NFL) electronic health records. Game concussion numbers decreased meaningfully in the last 2 years of the study period, reflecting a 23% decrease in average annual game concussion incidence.

^aThis figure includes only concussions that occurred during in-season NFL club practices and games. Offseason (n = 5 in 2015, n = 5 in 2016, n = 10 in 2017, n = 5 in 2018, n = 8 in 2019), conditioning (n = 1 in 2018 preseason), other team activities (n = 1 in 2017 preseason), and non-sport-related concussions are not shown.

^bAll postseason concussions occurred in games except for n = 1 in 2016 and n = 1 in 2019.

2015-2017 to 177.0 in 2018-2019; $P < 0.01$). For the 5-year study period, the number of preseason games ranged between 64 (2016, 2017) and 65 (2015, 2018, 2019), while the number of regular season games (n = 256) and postseason games (n = 11) remained constant each year.

Regular Season Game Concussions

There were 790 concussions across 4,657,243 player-plays and 114,428 player-games in NFL regular season games from 2015 to 2019. The game injury rate per 10,000 player-plays was highest in 2015 (1.94; 95% CI, 1.67-2.24) and 2017 (1.92; 95% CI,

Table 2. Rate of regular season game-related concussions in the National Football League, 2015-2019

	Game Concussions, n (Column %)	Game Concussions Occurring on Special Teams Plays, n (%)	No. of Player-Plays	Concussion Rate per 10,000 Player-Plays (95% CI)
Overall	790 (100.0)		4,657,243	1.70 (1.58-1.82)
Year				
2015	183 (23.2)	30 (16.4)	945,187	1.94 (1.67-2.24)
2016	166 (21.0)	34 (20.5)	936,413	1.77 (1.52-2.06)
2017	178 (22.5)	30 (16.9)	926,284	1.92 (1.66-2.23)
2018	127 (16.1)	25 (19.7)	921,101	1.38 (1.16-1.64)
2019	136 (17.2)	26 (19.1)	928,258	1.47 (1.24-1.73)
Roster position				
Offensive line	128 (16.2)	5 (3.9)	948,903	1.35 (1.13-1.60)
Running back	52 (6.6)	17 (32.7)	266,448	1.95 (1.49-2.56)
Tight end	79 (10.0)	15 (19.0)	281,443	2.81 (2.25-3.50)
Quarterback	29 (3.7)	0 (0.0)	177,715	1.63 (1.13-2.35)
Wide receiver	118 (14.9)	20 (16.9)	504,756	2.34 (1.95-2.80)
Defensive secondary	227 (28.7)	43 (18.9)	1,057,706	2.15 (1.88-2.44)
Defensive line	51 (6.5)	6 (11.8)	644,919	0.79 (0.60-1.04)
Linebacker	99 (12.5)	32 (32.3)	704,235	1.41 (1.15-1.71)
Special teams ^a	7 (0.9)	7 (100.0)	71,118	0.98 (0.47-2.06)

^aIncludes kicker, punter, long snapper.

1.66-2.23), followed by 2016 (1.77; 95% CI, 1.52-2.06), with lowest rates in 2018 (1.38; 95% CI, 1.16-1.64) and 2019 (1.47; 95% CI, 1.24-1.73) (Table 2).

Over the study period, defensive secondary (cornerbacks, safeties, and generic defensive backs) and offensive linemen had the most concussions (defensive secondary: n = 227, 28.7%; offensive linemen: n = 128, 16.2%) (Table 2). Across all positions, between 3.9% and 32.7% of concussions occurred while playing special teams, with running backs and linebackers sustaining the largest proportion of concussions on special teams plays. Of running back concussions on special teams plays, 82.4% (14/17) were during kickoffs. Of linebacker concussions on special teams plays, 68.8% (22/32) were on kickoffs. Accounting for varying on-field exposure for each roster position by calculating concussion rates per 10,000 player-plays, rates were highest for tight ends (2.81; 95% CI, 2.25-3.50) and wide receivers (2.34; 95% CI, 1.95-2.80) (Table 2). While most regular season game concussions were sustained on

running and passing plays (n = 40.6, 78.8 per season, respectively), the highest rate per play was on kickoffs (0.69/100 plays).

Position

Concussion counts are highest in defensive secondary (n = 227), offensive linemen (n = 128), and wide receivers (n = 118), based on roster position. While special teams plays represent a relatively small number of total plays, they represent a disproportionate number of concussions. Running backs (32.7%) and linebackers (32.3%) had the highest proportion of concussions occurring on special teams plays, while offensive linemen and quarterbacks had the lowest rates, reflecting their limited participation on special teams. Among defensive secondary players, the concussion rate markedly decreased by 41% from 2015 (2.55 per 10,000 player-plays) to 2019 (1.50 per 10,000 player-plays; IRR [95% CI] for 2015 vs 2019 = 1.70 [1.10-2.64]).

Table 3. Risk of concussions in the National Football League, 2015-2019

Year	Concussions, n	No. of Injured Players	One-Season Concussion Risk, % (95% CI) ^a
2015	284	263	8.0 (7.1-9.0)
2016	255	242	7.4 (6.5-8.3)
2017	302	277	8.3 (7.4-9.3)
2018	223	206	6.2 (5.4-7.1)
2019	238	226	7.1 (6.3-8.1)
5-year average	260.4	242.8	7.4 (7.0-7.8)

^aPlayer-seasons denominator used for total one-season concussion risk calculations was n = 16,403, defined as the sum of unique player signings within each National Football League season from 2015 to 2018 (2015 = 3278; 2016 = 3288; 2017 = 3337; 2018 = 3333; 2019 = 3167).

Concussion Risk

During the study period, an average of 243 NFL players sustained a concussion per season of participation, resulting in a 7% one-season risk of one or more concussions (Table 3). Approximately 6.8% of NFL players who sustained a concussion went on to sustain a second concussion during the same season (offseason through postseason; 83 players with multiple concussions in a season of 1004 players overall, and 1214 player-seasons with at least one incident concussion).

DISCUSSION

This study aimed to present accurate, EHR-based NFL concussion incidence across the 2015 to 2019 seasons. Of the 1302 concussions reported from 2015 to 2019, 80% occurred in games, with a rate of 70.6 and 61.7 concussions per 100 games in preseason and regular season, respectively. Notably, the average incidence of game concussions decreased by 23% from 2015-2017 to 2018-2019.

During both preseason and regular season, more concussions generally occurred in games compared with practices. One notable exception was 2018, in which preseason practice concussions exceeded preseason game concussions. Additionally, while the majority of concussions occurred in game settings, preseason games had higher concussion rates than regular season games over the 5-year study period. There were more regular season concussions than preseason concussions for all 5 seasons of this study. The most dramatic increase in practice concussion rates (76.3%) occurred in between the 2016 and 2017 seasons. Conditioning activities demonstrated a very low incidence of concussion throughout all seasons, with only 1 concussion reported in this time.

In regular season games, tight ends and wide receivers had the highest concussion rate. When looking at the type of play in which the concussion was sustained, running backs and linebackers sustained the largest proportion of concussions on

special teams plays (32.7% and 32.3%, respectively); of concussions on special teams plays, 82.4% and 68.8% were during kickoffs among running backs and linebackers, respectively. Furthermore, while most regular season game concussions were sustained on running and passing plays, the highest rate per play was on kickoffs. This latter finding is consistent with that of Casson and Viano,⁸ who studied regular season game concussions across 2 time epochs, 1996-2001 and 2002-2007, and found a high relative risk of concussion among special teams players.

Incidence Trends

The overall one-season risk of concussion across the 5 years of this study was 7.4%, with a similar risk of repeat concussion of 6.8%. A lower concussion incidence was observed in 2018 and 2019 compared with 2015-2017. The one-season concussion risk ranged from 7.4% to 8.3% in 2015-2017, and decreased to 6.2% and 7.1% in 2018 and 2019, respectively.

Detecting and diagnosing concussions was a point of emphasis for the NFL in the years covered in this study. Multiple systematic changes were developed, initiated, and in some cases, enhanced (Figure 2) in an attempt to better identify and reduce concussions. First, injury reporting was overhauled in 2015 with the launch of a centralized clinical EHR alongside a suite of reporting audits scanning media and reviewing data quality to ensure complete and accurate information for all diagnosed concussions.¹⁴ Second, the AT Spotter²⁴ and Unaffiliated Neurotrauma Consultant²⁵ programs were launched to provide extra sets of eyes for concussion detection. Third, and in parallel, beginning before the 2018 season, concussion reduction efforts and detailed injury reviews occurred each season with each club, with focused discussions on concussion reduction strategies at all levels of club personnel. At this time, evidence-based rule changes targeting high-risk play types were implemented, including restrictions on lowering the head while tackling and the elimination of specific practice drills and

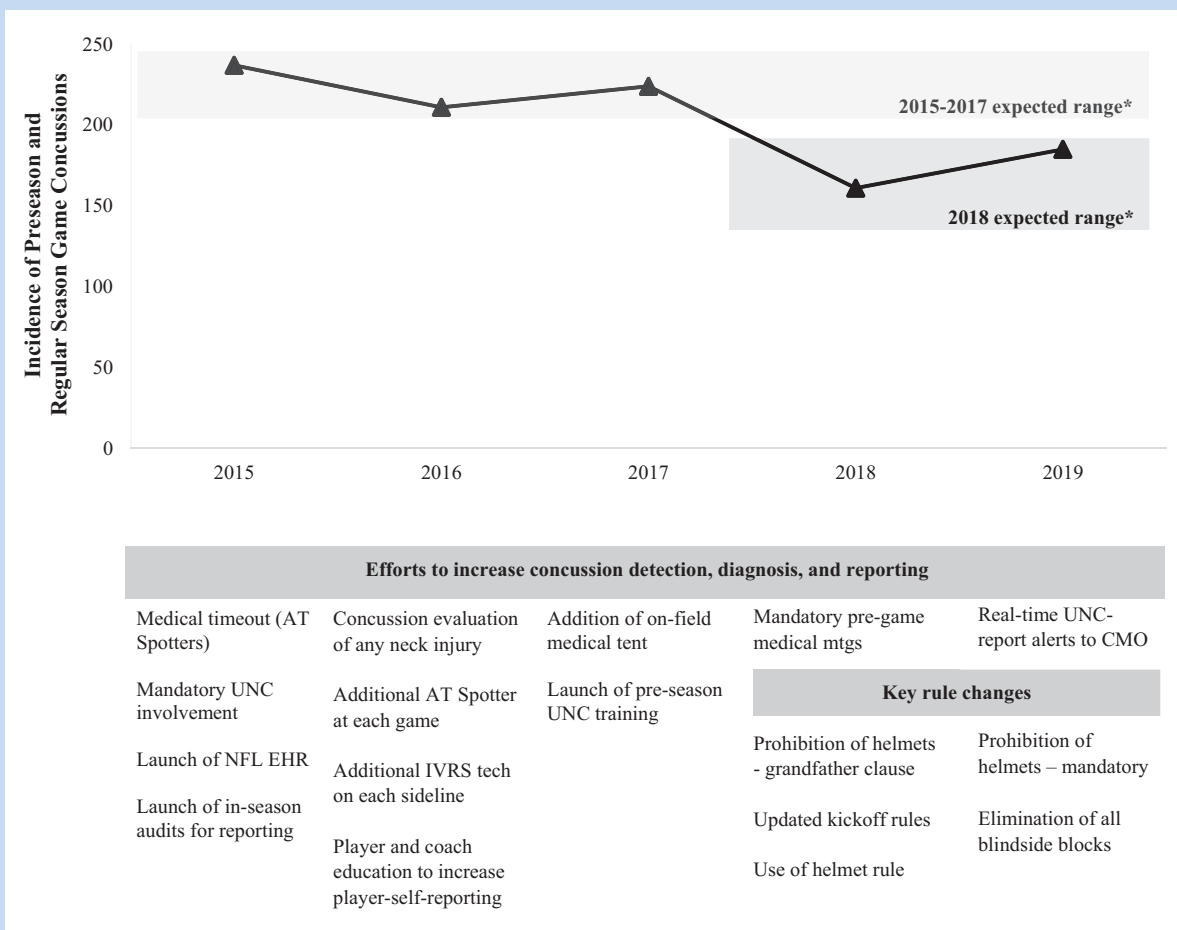


Figure 2. Incidence of National Football League preseason and regular season game concussions, 2015-2019. Over the study period, multiple systematic changes were developed, initiated, and in some cases, enhanced in an attempt to better identify, diagnose, report, and reduce concussions. AT, athletic trainer; UNC, unaffiliated neurotrauma consultant; CMO, chief medical officer; EHR, electronic health record; IVRS, injury video review system.

*The expected range for concussions was calculated using log-Poisson regression with generalized estimating equations to account for within-club correlations in observed injury rates per game. The range was computed using the 2015 through 2017 seasons compared with 2018.

in-game blind-side blocks. Changes to the kickoff, which eliminated running starts and wedge blocks, were piloted and subsequently implemented. Extensive laboratory testing on commercially available helmets,¹ subsequent distribution of results to players and staff in a poster format, and instantiation of rules mandating helmet transitions out of poorly performing helmets led to movement of players into higher performing helmets. These efforts led to 99% of players wearing better performing helmets by the 2019 season.¹⁹ Finally, targeted education for players and teams occurred before the 2018 and 2019 seasons to emphasize concussion reduction strategies for both practices and games.

This study reported a 5-year concussion rate of 1.70 concussions per 10,000 player-plays (95% CI: 1.58-1.82). Calculated differently, this is 69.0 concussions per 10,000 player-games (95% CI: 64.4-74.0) over 5 years, ranging from a low of 55.5 (95% CI: 46.6-66,0) in 2018 to 80.0 (95% CI:

69.2-92.5) in 2015. Noting different methodologies in rate calculations, the National Collegiate Athletic Association football concussion rate was reported as 6.71 per 10,000 AEs overall, with a game rate of 30.07 per 10,000 AE, which is lower than the rates found among NFL athletes in this study.⁴³ A recent Ivy League–Big Ten study also reported lower rates: 12.6 concussions per 10,000 AEs overall and a game rate of 36.8 per 10,000 AEs.³⁴ However, the findings should be tempered in that different methodologies in rate calculations are a driver of some (but likely not all) of the differences observed here, as the NFL calculations exclude roster player from the denominator on a per-game basis if he did not participate in at least one play in the game, compared with the collegiate calculations which include all roster players regardless of participating, and noting larger rosters among collegiate teams.

Previously published NFL concussion studies used publicly available data,²⁸ which may be incomplete, inaccurate, and/or

lack medically relevant information about injuries. For example, a study by Dai et al¹² identified 558 NFL concussions between the 2012 and 2015 seasons while actual NFL data indicated 619 concussions. A detailed analysis of the study by Dai et al¹² indicates that neither practice nor game concussions during the preseason, bye weeks, or postseason were included; these are remarkable omissions since they represent a key component of concussion incidence in the NFL. This underestimate illustrates the all-too-frequent inadequacy of using publicly reported injury data for research on NFL injuries, as they focus on injuries that impact player availability for games and are not reported by medical staff with accurate knowledge of diagnosis and return to play. Given these limitations of publicly available data, studies based on such information likely draw erroneous, biased conclusions.

Limitations

Despite efforts to diagnose and report all concussions, concussion can be a difficult-to-diagnose injury, especially given the fast-paced sport setting, an injury that often relies on the self-report of symptoms, and one which has few definitive and specific signs and lacks a reliable diagnostic biomarker. Thus, it is possible that concussions may have been missed. The use of a central, mandated, audited EHR database, however, mitigates this potential for under-ascertainment of injury. Risk calculations were based on player signings as the denominator, which captures the total number of individuals who participated in any NFL football activity each season and accounts for players entering and exiting the NFL throughout the season. While it reflects the true number of exposed players, this calculation of risk is lower than estimates based on team roster size (ie, AEs). For example, the 2019 data show an 8.8% risk of concussion if taken from 1472 static regular season roster spots, compared with 6.4% out of the 2025 players who were on a regular season roster at any point in the year. Concussion rates were calculated from actual player participation at a per-play level using the linkage between the NFL EHR and GSIS. This granularity of participation data allows for more specificity in rate calculations, which is beneficial particularly for understanding rates by position. However, similar exposure data are unavailable for practices, precluding calculation of practice concussion rates. Finally, this is a retrospective, observational study, which cannot discern cause and effect relationships. More specifically, the multidimensional, league-wide efforts implemented or enhanced since 2015, including direct player and club education, rule and equipment changes, and programmatic efforts at enhanced concussion detection, are viewed as possible explanatory mechanisms for the observed trend, and serve as hypotheses for future empirical study.

CONCLUSION

The results presented in this study indicate that the concussion incidence in the NFL is lower than in prior years. Concussions in the NFL remain a key focus for player safety and injury

prevention. The decreased incidence observed in 2018 and 2019 has provided a new benchmark from which to work toward further reduction in concussive injury in the NFL.

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