# Concussion: Mechanisms of Injury and Trends from 1997 to 2019

DANIEL B.C. REID, MD, MPH; KALPIT N. SHAH, MD; EVAN J. BAUM, BA; ALAN H. DANIELS, MD


## ABSTRACT

**BACKGROUND:** There is limited long-term epidemiological data focused on concussions in the United States.

**METHODS:** The National Electronic Injury Surveillance System was queried from 1997 to 2019 for concussion diagnoses. National incidence rates, stratified by age and sex, were estimated. Injury mechanisms were ranked.

**RESULTS:** From 1997 to 2019, there was a 3-fold increase in the diagnosis of concussion from 82,103 (95% CI 77,650–86,555) in 1997 to 261,722 (95% CI 212,156–311,288) in 2019 ($p<0.001$). Fall-related head-injury mechanisms were most common in very young (<5 year old) and older (>65 year old) patients. Sports-related injuries were most common in those age 5–24 years old.

**CONCLUSIONS:** It remains unclear if the observed two-decade rise in reported concussions represents a true increase in incidence or is indicative of improvements in early detection, diagnosis, and treatment during this time period. Common injury mechanisms described highlight the need for improved age-specific safety recommendations.


**KEYWORDS:** concussion, head injury, epidemiology, fall, sports

## INTRODUCTION

Concussions are mild traumatic brain injuries (TBI) caused by force to the head or neck area, either with or without the loss of consciousness.[1,2] Symptoms include headache, amnesia, sleep disturbances, and emotional lability in addition to behavioral and cognitive changes.[3] A substantial proportion of concussion patients continue to demonstrate persistent neuropsychiatric sequelae even up to one year after injury.[4] Despite the financial and health strains imposed by concussion, there have been relatively few long-term epidemiological studies on concussions in the U.S. Furthermore, the studies available often focus on rates of concussion in narrow age ranges or specific sports. Such a limited focus on young athletic groups may neglect important mechanisms of injury such as non-sport related falls causing concussions in the elderly, which may be on the rise.[5]

This study seeks to better characterize the epidemiology and population trends of concussions in the U.S using the NEISS database over a 23-year period (1996–2019). Additionally, we aim to compare the rates of concussion between individual sports, organized team sports, and non-recreational activities. Understanding long-term epidemiologic trends in incidence and mechanism of injury can guide patient education, optimize age-appropriate prevention, and inform activity-specific outreach strategies.

## MATERIALS AND METHODS

The National Electronic Injury Surveillance System (NEISS) database is managed by the Consumer Product Safety Commission.[6] It comprises a sample of approximately 100 hospitals of varying sizes throughout the United States and its territories. The database comprises a nationally representative probability sample of all U.S. hospitals that have at least 6 beds and provide 24-hour emergency department (ED) services. Most, but not all U.S. states and territories, are represented. All major regions of the continental United States are represented. Hospitals are divided into 5 stratum, with 4 strata representing adult emergency departments segregated by the number of annual visits (small, medium, large, very large) and 1 strata for pediatric EDs. Individual EDs are assigned probability weights based upon the inverse probability of selection for hospitals in each stratum. These weights are updated every year to adjust for non-response, hospital mergers, and changes in NEISS sampling frame.

At each institution, trained data abstractors review clinical records for physician-diagnosed injuries and report associated products or activities. Data available in the NEISS database includes patient demographic data, diagnosis, body part injured, involvement of a product or activity, location of injury, and ED disposition. For this study, the NEISS database was queried from January 1, 1997 to December 31, 2019 for all ED visits coded as "concussion" (NEISS code 52). Using NEISS probability sampling weights in order to account for the complex sample design, national estimates for concussion, and the corresponding 95% confidence intervals, were calculated for each year from 1997-2019. All of our national estimates were evaluated for statistical reliability and determined to be at low risk of instability based on the Consumer Product Safety Commission guidelines (number

of records over 20, estimates over 1,200, and coefficient of variation over 33%). Corresponding 2019 U.S. Census intercensal estimates[7] were utilized to calculate the most recent national incidence rate estimates and associated 95% confidence intervals stratified by age and sex.

Utilizing the NEISS coding manual as well as the 2018 NEISS Product Code Comparability table,[8,9] all applicable activities and product codes were recorded over the 23-year study period. For improved comprehensibility of the data, categories of some sports injury mechanisms were created by combining appropriate NEISS codes. (**Appendix 1**)

After stratification of patients by age, specific mechanisms of injury were evaluated and the most common mechanisms according to the nationally-weighted estimates were ranked for each age group. Additionally, the team and individual sports most commonly associated with concussions were ranked. For improved comprehensibility, only sports responsible for at least 1% of the total concussions within each category were reported. Survey-adjusted Student's t-test and Rao-Scott modified chi-squared analysis were used for direct comparisons of means and proportions, respectively. Trends in hospital admission rates from 1997–2019 were evaluated using linear regression models.

Microsoft Excel version 16.11.1 (Microsoft Corporation, 2017, Redmond, Washington) was used for data collection and visualization. All statistical analyses were performed using Stata 15.0 (StataCorp., 2017, College Station, TX). Statistical significance was defined as $p < 0.05$ *a priori*.

All data analyzed has been previously de-identified and is made publicly available by the Consumer Product Safety Commission. As such, no Institutional Review Board approval was required for this study.

## RESULTS

### Demographics, Epidemiology, and Trends Over Time

From 1997 to 2019, 136,592 patients presented to EDs with concussions, representing a national weighted estimate of 4,471,431 (95% CI 4,323,218–4,619,644). There was a 3-fold increase in the estimated incidence of concussions presenting to EDs from 82,103 (95% CI 77,650-86,555) in 1997 to 261,722 (95% CI 212,156-311,288) in 2019 ($R^2$= 0.9036, p<0.001, **Figure 1**). When stratified by age, this increase was most pronounced in those age 5-24, but occurred among all age groups (all p>0.05, **Figure 2**). Males were significantly more likely to be affected in both of these age groups than females (p<0.05, **Table 1/Figure 3**). Males age 5-14 represented the highest-risk group, presenting with 233.9 concussions per 100,000 person-years (95% CI 219.8-248.1).

In 2019, the estimated yearly incidence rate for concussions was 81.0 per 100,000 person-years, 95% CI 78.6–83.3 (**Table 1**). Overall, males presented more often (86.0 concussions per 100,000 person-years, 95% CI 82.5–89.5) than females (76.2 per 100,000 person-years, 95% CI 72.–79.4,

**Figure 1.** Yearly Concussion Estimate, 1997–2019

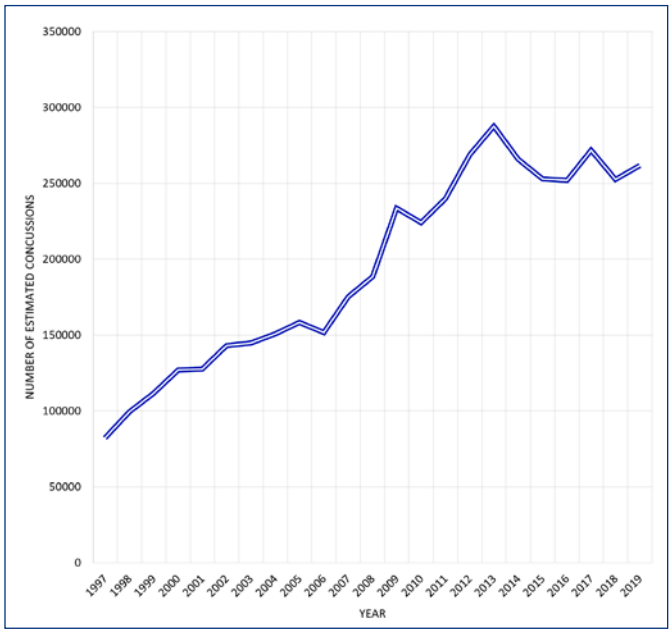
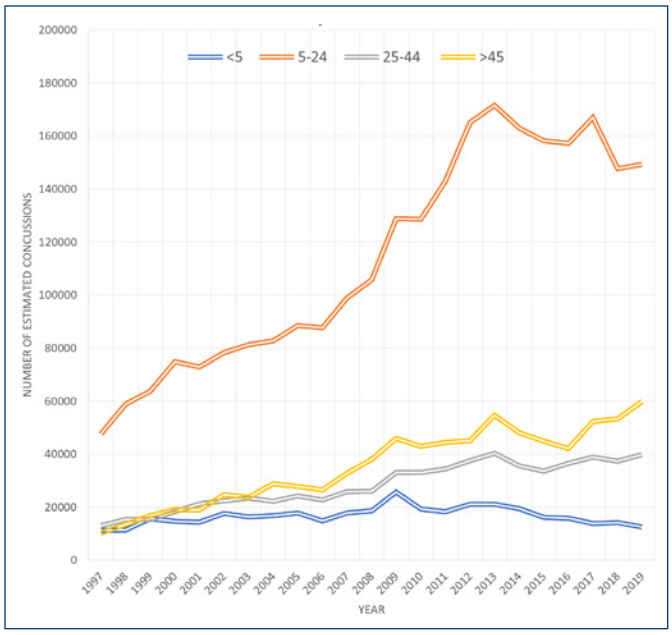



**Figure 2.** Yearly Concussion Estimates, Stratified by Age, 1997–2019

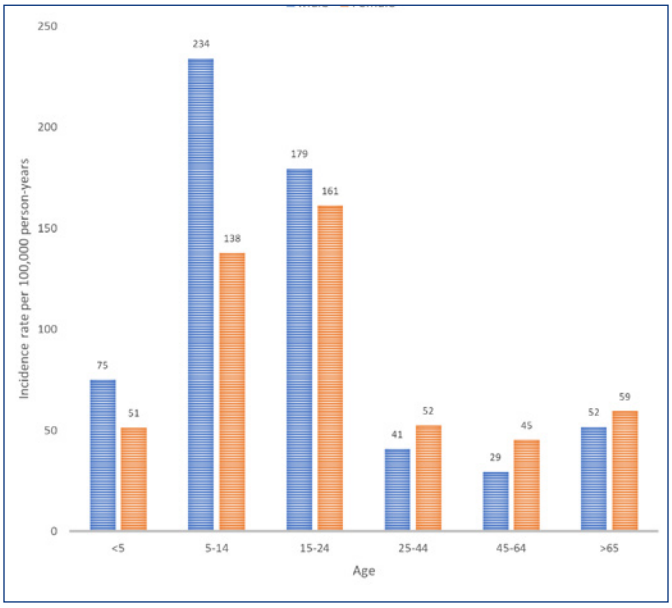



p<0.001); however, this varied by age group (**Table 1**). In those younger than 25, males were more at risk, making up 58.7% of all concussions, whereas females were more at significantly increased risk among those 25 or older, making up 64.3% of all concussion in this group (p<0.001). The highest incidence rate of concussion was in children age 5–14 (186.4 per 100,000 person-years, 95% CI 177.3–195.4), followed by young adults age 15-24 (170.4 per 100,000 person-years, 95% CI 161.6-179.2), (**Figure 2**).

**Table 1.** Number of Cases, National Weighted Estimates, and Incidence Rate of Concussion Stratified by Age and Gender in 2019

| Age/Sex | n (2019) | Estimate (2019) | Incidence/100,000 Person-Years |
|---|---|---|---|
| **<5** | 656 | 12,615 | 63.3 |
| Male | 389 | 7,642 | 75.0 |
| Female | 267 | 4,999 | 51.3 |
| **5–14** | 3,559 | 77,234 | 186.4 |
| Male | 2,255 | 48,994 | 233.9 |
| Female | 1,304 | 28,240 | 137.8 |
| **15–24** | 2,324 | 72,157 | 170.4 |
| Male | 1,222 | 38,447 | 179.4 |
| Female | 1,102 | 33,710 | 161.2 |
| **25–44** | 928 | 31,276 | 36.6 |
| Male | 414 | 17,378 | 40.8 |
| Female | 514 | 22,482 | 52.3 |
| **45–64** | 709 | 31,276 | 37.6 |
| Male | 278 | 11,830 | 29.4 |
| Female | 431 | 19,446 | 45.2 |
| **≥65** | 565 | 28,554 | 55.9 |
| Male | 220 | 11,908 | 51.6 |
| Female | 345 | 16,646 | 59.4 |
| **ALL** | 8,741 | 261,722 | 81.0 |
| Male | 4,778 | 136,226 | 86.0 |
| Female | 3,963 | 125,496 | 76.2 |

**Figure 3.** Incidence Rate for Concussion, Stratified by Age and Gender, 2019




## Most Common Mechanisms of Injury

The most common mechanisms of injury varied substantially by age (**Table 2**). Fall-related head-injury mechanisms such as floors, stairs, beds, and chairs/couches were most common in very young (<5 year old) and older (>65 year old) patients. Conversely, sports-related injuries were especially common in children, adolescents and young adults (age 5–24). Football was the most common cause of concussion in this population, accounting for 16.4% of all concussions sustained by 5–14 year olds and 18.3% of all concussions in 15–24 year olds.

**Table 2.** Most Common Injury Mechanisms Leading to Concussion by Age 1997–2019

| Rank | Age | | | | | |
|---|---|---|---|---|---|---|
| | <5 | 5 to 14 | 15 to 24 | 25 to 44 | 45 to 64 | ≥65 |
| 1st | Floors (13.1%) | Football (16.4%) | Football (18.3%) | Stairs (11.5%) | Stairs (14.2%) | Floors (22.7%) |
| 2nd | Stairs (11.4%) | Bicycles (8.3%) | Basketball (8.8%) | Floors (8.0%) | Floors (11.4%) | Stairs (14.6%) |
| 3rd | Beds (8.4%) | Basketball (7.6%) | Soccer (8.2%) | Bicycles (7.2%) | Bicycles (8.3%) | Beds (6.0%) |
| 4th | Couches (5.2%) | Floors (6.1%) | Bicycles (4.6%) | Baths/ Showers (4.0%) | Ladders (4.7%) | Chairs (3.9%) |
| 5th | Tables (4.9%) | Soccer (5.4%) | Stairs (3.9%) | Horseback Riding (3.2%) | Horseback Riding (4.0%) | Baths/ Showers (3.4%) |

Some injury mechanisms were unique to specific age groups. For example, injuries from beds were only commonly seen in those <5 years old and >65 years old. Injuries from tables and couches were only seen in those <5 years old. Concussions cases by horseback riding were only seen commonly in those 25–64. Concussions related to wheelchairs (2.4%), crutches, canes, and walkers (2.1%) were only seen in those > 65 years old.

## Sports-Related Concussions

From 1997 to 2019, there were an estimated 753,295 (95% CI 743,151–763,438) concussions caused by individual sports and an estimated 1,139,529 (95% CI 1,128,781–1,150,270) injuries related to team sports that resulted in an ED visit. The most common individual sport responsible for ED visits was cycling, representing 292,111 (95% CI 284,720–299,501) concussions or 38.8% of all individual sport-related injuries during the study period. Additional common individual sports leading to concussion were horseback riding (11.3%), skateboard/scooter riding (10.3%), and snowboarding (8.9%). The most common team sport that led to an ED evaluation for concussion was football, which was responsible for an estimated 458,613 (95% CI 449,683–467,543) cases, or 40.3% of all team sport-related injuries. This was

**Table 3.** Most Common Team and Individual Sports Associated with Concussions

| | Estimated Frequency 1997–2019 | Percent |
|---|---|---|
| **Individual Sport** | | |
| Cycling | 292,111 | 38.8% |
| Horseback Riding | 85,285 | 11.3% |
| Skateboard/Scooter | 77,671 | 10.3% |
| Snowboarding | 67,169 | 8.9% |
| Snow Skiing | 60,262 | 8.0% |
| Wrestling | 40,979 | 5.4% |
| Exercise (without equipment) | 22,848 | 3.0% |
| Martial Arts | 12,549 | 1.7% |
| Boxing | 11,313 | 1.5% |
| In-line Skating | 11,252 | 1.5% |
| Exercise equipment (excl. weight lifting and gymnastic equipment) | 10,761 | 1.4% |
| Gymnastics | 10,356 | 1.4% |
| Dancing | 9,136 | 1.2% |
| Swimming | 8,824 | 1.1% |
| Other | 32,777 | 4.3% |
| **Team Sport** | | |
| Football | 458,613 | 40.3% |
| Basketball | 211,139 | 18.5% |
| Soccer | 184,385 | 16.2% |
| Baseball/Softball | 146.405 | 12.9% |
| Hockey | 42,261 | 3.7% |
| Cheerleading | 30,968 | 2.7% |
| Volleyball | 25,556 | 2.2% |
| Lacrosse | 20,962 | 1.8% |
| Rugby | 18,351 | 1.6% |

followed by basketball (18.5%), soccer (16.2%), baseball/softball (12.9%), and hockey (3.7%). Patients presenting with concussions from team sports were younger than those injured during individual sports (mean age 16.1 versus 22.8, p<0.001). (**Table 3**)

## DISCUSSION

This investigation utilized the NEISS database to identify the national incidence of concussions presenting to EDs in the U.S. from 1997 to 2019. The reported incidence has been rising over the last two decades, reaching a peak in 2013. The observed 3-fold rise over the 23-year study period is particularly pronounced in the 5- to 24-year-old age group, but occurred across all ages. It remains unclear whether this represents a true increase in concussion rate, the effects of greater public awareness and diagnosis, or a combination thereof.

The Centers for Disease Control launched the *Heads Up* initiative in 2003, a program aimed at raising concussion awareness in healthcare providers, youth sports' coaches, and athletes. A 10-year analysis of the program demonstrated better identification of concussive symptoms by coaches, as well as better management of concussion by healthcare professionals.[10] Similarly, the modern surge in social networking has been shown to increase concussion awareness and peer-to-peer support, particularly in young adults.[11] Regardless of the cause, this upsurge in diagnosed concussions over the last 2 decades indicates a need for further understanding of the demographics most affected and the mechanisms that lead to concussions. Better epidemiologic data may lead to improvements in preventative measures, diagnosis, treatment strategies, and utilization of finite resources.

The highest rate of ED visits for concussions was found in the 5- to 24-year-old age range, with football being the most common mechanism of injury. Other significant mechanisms of injury in this age range included bicycles, basketball, and soccer. This closely coincides with trends described by Buzas et al.[12], who reported a rank order of concussion in 4-to 13-year-old children including football, followed by basketball, soccer, and baseball. Their study did not stratify by sex or include concussions that resulted from individual sports or non-sport mechanisms of injury. The rise in sport-related concussions in this age demographic parallels increased participation rates in these sports.[13] When comparing sports-related concussions in males versus females, it is important to note that some sports, such as ice hockey, have different contact rules for men's and women's competition. It has been noted that even in sports that limit or restrict contact, such as soccer, basketball, and women's ice hockey, the majority of injuries still occur via player contact.[14] Based on this data, targeted outreach to prevent concussions in this age group could include initiatives to increase bicycle helmet use, promote head protection or limit head contact in youth soccer and basketball, and eliminate or reduce full contact football practices.[14–16]

Females sought medical attention at EDs for concussions at significantly greater rates than males in the 45–64 and >65 age groups, with the most common mechanisms including falls on floors, stairs, beds/bedframes, and bathtubs/showers. Interventions in this age group designed to reduce the rate of concussion may include appropriate patient and caregiver education, gait assessment to identify those who may benefit from physical therapy, balance and strength exercises, and removal of home hazards such as loose rugs and bathmats.[17] Appropriate discontinuation of psychotropic medications and reduction in polypharmacy have also been associated with decreased falls in the elderly.[17] Similar mechanisms of injury related to falls in the home were observed in the age group <5 years. Prevention in this group may include parent education, improvement in home safety measures, limiting use of bunk beds, maintaining playground equipment, and

use of stationary activity centers in place of infant walkers.[18]

Strengths of this study include the ability to calculate accurate nationwide estimates for concussions presenting to EDs through NEISS probability-sampling weights. Furthermore, the study encompasses a relatively long 23-year study period, which allows us to analyze trends over time. However, there are several potential study limitations that should be noted. This study only evaluates the incidence of patients presenting to EDs for concussive symptoms, thus the true incidence of concussion may be higher than our estimates. Patients may self-treat their symptoms or be assessed in a non-emergency setting by primary care physicians, pediatricians, athletic trainers, or at urgent care centers. These patients would not have been captured in this database. Additionally, beyond basic demographic data, the NEISS database does not offer specific patient characteristics which may have added another layer of sophistication in the analysis. Furthermore, the database also does not provide specific narrative data regarding the injury mechanism, method of treatment undertaken, or patient-specific subjective and objective outcomes measures. Finally, the accuracy of the data included in NEISS is ultimately dependent upon accurate coding. While the NEISS coding manual utilized a single code for concussion throughout the study period which may result in improved coding consistency, as with any large coding-reliant database, variations in interpretation of diagnostic criteria among physicians and coders may still affect the underlying accuracy of the data.

## CONCLUSIONS

This study underscores the importance of concussions as an increasingly prevalent and important clinical problem affecting all age groups with substantial implications for public health. We observed a significant increase in the incidence of concussions presenting to EDs between 1997 and 2019 in all age groups. It remains unclear whether this is secondary to a true rise on concussion rates or more likely due to increasing public awareness and earlier presentation, diagnosis, and treatment of patients following concussion. This investigation highlights common age-specific injury mechanisms and may inform possible future avenues for age-specific concussion prevention measures. Further research is necessary to evaluate the effectiveness of such interventions.

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### Authors


Daniel B.C. Reid, MD, MPH, Department of Orthopaedic Surgery, Warren Alpert Medical School of Brown University, Providence, RI.

Kalpit N. Shah, MD, Department of Orthopaedic Surgery, Warren Alpert Medical School of Brown University, Providence, RI.

Evan J. Baum, BA, Warren Alpert Medical School of Brown University, Providence, RI.

Alan H. Daniels, MD, Department of Orthopaedic Surgery, Warren Alpert Medical School of Brown University, Providence, RI.


### Correspondence


Daniel B.C. Reid, MD, MPH
Department of Orthopaedic Surgery
Warren Alpert Medical School of Brown University
2 Dudley Street, Providence, RI 02905
401-444-4030, Fax 401-444-6182
daniel_b_reid@brown.edu