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Risk of Repeat Concussion Among Patients Diagnosed at a Pediatric Care Network

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Abstract

Objective—To quantify the risk of repeat concussions for children and identify demographic and clinical aspects of the index concussion associated with repeat injury.

Study design—For this retrospective cohort study, we queried the Children's Hospital of Philadelphia healthcare network's unified electronic health record to identify all 5-to 15-year-old patients who had their first clinical visit for an index concussion at a Children's Hospital of Philadelphia location from July 2012 through June 2013. A 25% random sample (n = 536) were selected. Clinical data were abstracted for their index concussion and all concussion-related visits for 2 years following the index concussion.

Results—Overall, 16.2% (n = 87) of patients experienced at least 1 repeat concussion within 2 years of their index concussion. The risk of repeat concussion increased with patient age (9.5% for ages 5–8 years; 10.7% for ages 9–11 years; and 19.8% for ages 12–15 years). After we adjusted for other factors, risk was particularly heightened among patients whose index concussion had a longer clinical course (>30 vs 0–7 days, adjusted risk ratio 1.65 [1.01–2.69]) and greater symptom burden (>11 vs 0–2 symptoms, adjusted risk ratio 2.12 [1.12–3.72]).

Conclusions—We estimate that 1 in 6 youth diagnosed with a concussion are diagnosed with a subsequent concussion within 2 years and that several clinical characteristics of the index concussion increase this risk. Identifying factors associated with a repeat injury is essential to inform the clinical management of concussion and direct injury prevention efforts.

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Data Statement

Data sharing statement available at www.jpeds.com.

Concussion is a common childhood injury that may lead to long-term physical, behavioral, and neurocognitive effects, affecting learning and school performance.[1–4] There is increasing concern about the potential for repeat concussions among professional and high school athletes, with specific attention focused on understanding how sustaining a concussion alters future concussion risk.[1,2] Studies in animals and humans suggest that cognitive and motor deficits associated with concussion increase the risk of a second concussion and/or other injuries during the recovery period[3–5] and that repetitive mild traumatic brain injury in childhood may lead to long-term learning and neuropsychological deficits.[6,7] Addressing repeat concussion risk among youth has substantial implications for clinical practice in terms of managing exposure—particularly regarding youth sports participation—and long-term health and development.[8]

Thus far, studies have not quantified the risk of a subsequent concussion or factors associated with that risk. To date, research has focused primarily on whether individuals who sustained more than 1 concussion had poorer outcomes than those who sustained a single concussion. Findings from these studies among youth have been mixed[9]: some point to an increased number or severity of symptoms,[10,11] extended time to recovery,[12–14] and worse neuropsychological performance among those with multiple concussions,[15,16] whereas others report no differences.[17–20] However, most of these previous studies examined concussions among high school-age youth; furthermore, they were not designed specifically to quantify the risk of repeat concussion based on characteristics of the index concussion or identify patient attributes that influence risk, including age and the presence of co-occurring medical conditions, such as learning difficulties or attention-deficit/hyperactivity disorder (ADHD).[21] Thus, there is little sound evidence that healthcare providers can use to provide practical guidance to patients and families. Indeed, a National Academy of Medicine report emphasized the need for longitudinal studies with more rigorous methodology to characterize the risk and timing of multiple concussions.[22]

The objectives of this study were to estimate the risk and identify independent predictors of repeat concussion among youth. We conducted a retrospective cohort study of patients within the Children's Hospital of Philadelphia (CHOP) pediatric network diagnosed with a concussion from 5 through 15 years of age. Relevant data within CHOP's electronic health record (EHR) were abstracted for a 2-year period following this index concussion to estimate the risk of a diagnosed repeat concussion and determine how risk varies by relevant demographic factors, co-occurring conditions, and characteristics of the index concussion, including mechanism of injury, length of care, and symptom burden.

Methods

This study included patients within CHOP's pediatric network, located in southeastern Pennsylvania and southern New Jersey, with more than a million annual visits. The network supports a socioeconomically, racially, and ethnically diverse population and accepts most insurance plans, including public insurance (eg, Medicaid). CHOP uses a single, unified EHR system for all aspects of care. We queried the CHOP EHR system to identify all individuals who had a visit to a network location for a concussion during the index period of July 1, 2012, through June 30, 2013 (n = 4977). Concussion visits were defined as those

assigned an *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) diagnosis code of concussion; a full list of relevant ICD-9-CM codes has been published.[23] Patients were included regardless of previous concussion history. The population was then limited to patients who were 5–15 years old at the time of their first concussion-related visit in the index period (n = 3590; hereafter referred to as "index concussion"); the upper bound was selected to ensure that patients would still be seeking care at a pediatric practice for the entire 2-year follow-up period (with the latest possible date of repeat concussion of June 30, 2015). The population was further limited to active CHOP primary care patients (n = 2324), defined as those who had at least one primary care visit at one of CHOP's 31 primary care offices within a 2-year period before their first index concussion visit; we expect that both previous and subsequent concussions for this group would be documented in the EHR regardless of where the concussion was diagnosed. Because the study necessitated in-depth EHR review, we generated a simple random sample of 25% (n = 577) for data abstraction. Distributions of race/ethnicity, sex, age, insurance payor, location of first visit (primary care, specialty care, emergency department/urgent care, hospital), and month of visit were similar for the selected sample and overall cohort (results not shown). A flowchart depicting selection of the study cohort is shown in the Figure.

EHR Abstraction

EHR review was conducted by 5 abstractors trained by a study author. Initially, 9 test cases were reviewed by all 5 abstractors and differences were resolved until complete agreement was reached. Study data were then abstracted from each patient's EHR, including demographics, relevant clinical data for each concussion-related visit during the patient's 2-year follow-up period, history of co-occurring conditions, and documentation of concussions before the index concussion. After abstraction was complete, one study author reviewed all variables for all records and, along with the team's clinical expert, resolved discrepancies. An additional 41 patients were excluded based on abstraction (Figure). Thus, the final analytic sample included 536 primary care patients who had a first visit for the index concussion at a CHOP network location from July 1, 2012, through June 30, 2013.

Variable Definitions

The primary outcome was the diagnosis of a repeat concussion within 2 years of the first visit for the index concussion. A repeat concussion was defined as a new injury event that prompted the patient to seek medical care and resulted in the clinical diagnosis of concussion following the index concussion. New injury events were identified during the abstraction process via review of detailed provider notes indicating a distinct mechanism of injury with a concussion-related ICD-9-CM code.

The index concussion clinical course—a proxy for time to recovery—was defined as the number of days between the injury, reported at the first visit, and the last CHOP visit for the index concussion (0–7, 8–28, and ≥29 days).[24] The mechanism of injury was identified via provider notes. As detailed in a previous study,[25] we employed a structured coding system based on external causes of injury codes to categorize broad mechanisms of injury—falls, struck by person (unintentional), struck by object, other (eg, bicycle-related, assault, motor vehicle crash), and not documented/unknown[26]—and further determine whether the

concussion was sports- and recreation-related. We also ascertained all concussion-related symptoms reported by the patient or parent and documented by the provider at each concussion-related visit. Symptoms from the Post-Concussion Symptom Scale (PCSS) were grouped into 5 subcategories (1) somatic symptoms: headache, nausea, vomiting, sensitivity to light, sensitivity to noise, numbness/tingling; (2) visuo-vestibular symptoms: balance problems, dizziness, visual problems; (3) sleep symptoms: fatigue, trouble falling asleep, sleeping more than usual, sleeping less than usual, drowsiness; (4) emotional symptoms: irritability, sadness, nervousness, feeling more emotional; and (5) cognitive symptoms: feeling slowed down, feeling mentally foggy, difficulty concentrating, difficulty remembering.[27,28] For select analyses, we summed the total number of distinct reported symptoms documented during the index concussion clinical course. Several preexisting co-occurring conditions were selected a priori based on their potential association with the risk of sustaining a concussion and/or prolonged recovery.[9] Conditions were identified in the EHR via (1) the presence of relevant ICD-9-CM diagnostic codes or (2) detailed provider notes from concussion-related visits. As we were interested specifically in pre-existing conditions, a condition was determined to be present if its diagnosis was indicated in the patient's EHR at any time before or on the date of the first visit for the index concussion. Relevant conditions and associated ICD-9-CM codes included vision conditions (strabismus: 378.x; amblyopia: 368.0x; hypermetropia: 367.0; and myopia: 367.1), ADHD (314.x), migraine/headache (346.x), and anxiety (300.x). Finally, we abstracted from provider documentation the number of concussions before the index concussion.

Statistical Analyses

We estimated the proportion of patients who had repeat concussions within 1 and 2 years following the first visit for their index concussion. We compared bivariate distributions of relevant demographic and clinical characteristics among patients with and without a repeat concussion using c^2 and Wilcoxon rank-sum tests. To identify independent predictors of repeat concussion, we used log-binomial regression models to estimate directly the risk ratios (RRs) and corresponding 95% CIs. Multivariable models included age at index concussion and the presence of co-occurring conditions, as well as clinical characteristics of the index concussion that were associated with risk of repeat concussion in bivariate analyses at the $P < .10$ level. We also conducted sensitivity analyses that S patients with a documented concussion before the index concussion. Analyses were conducted using SAS 9.4 (SAS Institute Inc, Cary, North Carolina). This study was approved by CHOP's institutional review board.

Results

A total of 8.4% (n = 45) of patients were diagnosed with a repeat concussion within a year of their index concussion; 16.2% (n = 87) had a repeat concussion within 2 years, including 3.4% (n = 18) who were diagnosed with 2 additional concussions. The median (IQR) time to diagnosis of a repeat concussion was 11.8 (5.8–17.8) months. The 2-year risk of a repeat concussion did not vary by sex or insurance payor (Table I). However, risk among 12-to 15-year-olds was 1.85 times that of 9-to 11-year-olds (19.8% vs 10.7%; 95% CI 1.09–3.13). Sixteen percent of all patients in the study had a history of concussion before the index

concussion; 22.1% of these patients went on to experience a repeat concussion within 2 years of the index injury (compared with 15.1% without a history of concussion before the index concussion, $P = .11$). Overall, the 2-year repeat concussion risk was greater for patients who had ≥1 pre-existing co-occurring condition than those with no conditions (RR 1.49 [1.00−2.22]); more specifically, one-quarter or more of patients with a history of migraine/headache (28.6%) and anxiety (25.0%) had a repeat concussion.

The risk of repeat concussion by clinical characteristics of the index concussion is shown in Table II. Risk did not vary significantly either by the mechanism of injury of the index concussion or whether the injury was sports- or recreation-related. However, risk was particularly heightened among patients with a longer clinical course for the index concussion; the median clinical course was 17 days (IQR: 5–62) for patients with a repeat concussion compared with 11 days (IQR: 4–25) for those without a repeat concussion ($P = .004$). Furthermore, compared with patients whose clinical course was 0–7 days, those with a clinical course of ≥29 days were almost twice as likely to experience a repeat concussion (RR 1.92 [1.19–3.12]). Risk was also greater among patients with a greater number of reported PCSS symptoms during their index concussion: patients with ≥11 symptoms were more than 2 and a half times as likely to have a repeat concussion compared with patients with 0–2 symptoms (RR 2.66 [1.55–4.56]). Table III (available at www.jpeds.com) shows the risks associated with specific symptoms. As there was strong correlation between the length of clinical course and number of PCSS symptoms for the index concussion (Spearman $r = 0.59$), likely because both are strong proxies for concussion severity, we constructed separate multivariable models for clinical course (Model 1) and symptoms (Model 2, Table IV). Both predicted increased risk. After we accounted for other factors, patients whose clinical course was ≥29 days had a 65% increased risk compared with patients whose course was 0–7 days (adjusted risk ratio [aRR] 1.65 [1.01–2.69]), and patients who experienced ≥11 symptoms during the course of care for their index concussion had over twice the risk of a repeat concussion compared with patients who had 0−2 symptoms (aRR 2.12 [1.21–3.72]). In both models, the presence of a co-occurring condition was not a significant predictor. In sensitivity analyses that excluded patients with documented concussions before the index concussion, aRRs for clinical course and symptoms were even stronger in magnitude (Table V; available at www.jpeds.com).

Discussion

This study of patients at a large pediatric network quantified the risk of medically diagnosed repeat concussions among youth aged 5–15 and identify intrinsic and extrinsic characteristics that might influence that risk. Overall, we estimated that 1 in 6 youth, including 1 in 5 adolescents (ie, 12-to 15-year-olds), who were diagnosed with a concussion sustained at least 1 additional diagnosed concussion within 2 years. Combined with studies indicating that multiple concussions negatively affect both short- and long-term health and development, as well as the recovery process of subsequent concussions,[10–16] these findings suggest that a substantial proportion of youth who have concussions may be experiencing a high concussion burden, leaving them at particularly heightened risk for poorer outcomes.

We also identified several factors from the index concussion that predicted an increased repeat concussion risk, including symptom burden, length of clinical course of care, and patient age, although the latter may be related to increased sports- and recreation-related exposure. Although concussion grading is not currently recommended by any professional society, previous studies have shown that both symptom burden and length of clinical course are likely correlates of concussion severity.[24,29] Our data further extend these findings by suggesting that the level of concussion severity may be related to a greater risk of repeat concussion.[24] Further investigation is needed to define more precisely these categories so that providers can advise families regarding the “severity” of their index concussion and the likelihood that it leads to elevated risk for a future injury. Until then, healthcare providers may use the practical evidence regarding these factors as they counsel concussed patients and their families about their future risk of injury.

With respect to other factors, the presence of a pre-existing co-occurring condition, particularly migraine/headache, was found to be associated with an increased risk of repeat concussion in bivariate analyses. However, we did not find that co-occurring conditions predicted repeat concussion risk over and above symptom burden and clinical course in multivariable models, indicating that the concussion itself constitutes the main risk factor. Nevertheless, some studies of adult and adolescent patients with concussion have found that pre-existing ADHD, learning difficulties, mood disorders, and psychiatric conditions were associated with a life-time history of concussion and extended concussion recovery.[11,12,19,30,31] Thus, it is important for providers to inquire about pre-existing co-occurring conditions, as this knowledge may influence the provider−family conversation about continued or future participation in sports with elevated risk for concussion. The interplay between these conditions and risk of future injury should be explored further in larger prospective studies.

Notably, risk did not vary by the mechanism of injury of the index concussion or whether that injury was sustained in sports and recreation. This reinforces the notion that all concussions, regardless of mechanism, contribute to an individual’s concussion burden and risk of subsequent injury; this finding also emphasizes the need for providers to discuss return to risk-bearing activity, such as contact sports, during follow-up concussion visits even when the index concussion was sustained outside of sports and recreation.

There are several potential limitations. First, collection of variables relied on patient data captured by existing EHR records. Thus, data were likely not compiled as systematically and consistently as they would have been if collected prospectively. However, CHOP introduced an EHR clinical decision tool in July 2012 that included a standardized template to systematically guide providers through concussion-specific assessments, diagnosis, and documentation of relevant information. Since introduction of the template, the vast majority of concussion visits have been documented using this format.[32] In addition, our abstraction process involved both an electronic data collection tool and comprehensive review of each patient’s EHR to optimize accurate capture of relevant data. Regardless, some variables that may be important in predicting risk, such as whether the patient participates in contact sports, were not captured. Without these data, we could not examine whether the increased risk of repeat concussion observed for 12-to 15-year-olds was due to increased exposure to

risk-bearing activities such as contact sports. In addition, there may also exist in our EHR-based study some ascertainment bias of those children who returned consistently to a CHOP network location as a patient. Second, although our previous study found that ADHD diagnosis is validly captured in CHOP's EHR with a high sensitivity,[33] other co-occurring conditions, in particular those that are harder for primary care providers to diagnose, may not be as reliably captured. Third, the details in the EHR on repeat concussions managed solely by non-CHOP providers are likely limited, and we were not able to capture concussions where the patient did not seek medical care. We limited this study to CHOP primary care patients, as we expected these patients to be most likely to seek treatment at a CHOP location and that there would be more complete documentation in the EHR of all concussions sustained regardless of location of care for those patients. Nevertheless, this limitation likely resulted in an underestimated risk of repeat concussion. Fourth, the concept of "time to recovery" is difficult to capture, especially outside the sports setting in which return to play is commonly used as the outcome of interest. There is no clear consensus about how to define recovery. As a proxy, we used length of clinical course categorized into clinically meaningful categories in order to reduce potential misclassification bias.[24] However, some patients may experience lingering symptoms even after they discontinue clinical care. Forty-seven percent of study patients reported at least 1 PCSS symptom at their last visit; however, this did not differ for those with and without a repeat concussion. Finally, the population of CHOP primary care patients may not be entirely representative of the underlying population of the catchment area; the majority of patients were non-Hispanic white and had private insurance. Further examination of larger nationally representative samples would capture greater diversity and allow a more specific exploration of these demographic factors.

Given the potential effects of multiple concussions on health and development across the lifespan, including health consequences that appear later in life,[34] understanding concussion burden in childhood is critical. The current study demonstrated that one in six 5-to 15-year-olds who sustained an index concussion went on to experience a repeat concussion within 2 years. It also identified several factors, including age and markers of severity of the index concussion, which might influence that risk. This study provides clinicians with data to support recommendations to families regarding the need for effective prevention practices and risk management (eg, limiting contact sport participation) and informs public health conversations regarding efforts to prevent and mitigate the long-term effects of concussion. In coordination with recently released clinical guidelines for the diagnosis and management of pediatric concussions,[35,36] such discussions may lead to meaningful improvements in clinical care. Future longitudinal studies should be conducted to rigorously evaluate the short- and long-term consequences of these repeat injuries.

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Glossary

ADHD	Attention-deficit/hyperactivity disorder
aRR	Adjusted risk ratio
CHOP	Children's Hospital of Philadelphia
EHR	Electronic health record
ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
PCSS	Post-Concussion Symptom Scale
RR	Risk ratio

References

1. Stern RA, Riley DO, Daneshvar DH, Nowinski CJ, Cantu RC, McKee AC. Long-term consequences of repetitive brain trauma: chronic traumatic encephalopathy. PM R 2011;10:S460–7.
2. Swenson DM, Yard EE, Fields SK, Comstock RD. Patterns of recurrent injuries among US high school athletes, 2005–2008. Am J Sports Med 2009;37:1586–93. [PubMed: 19372270]
3. Lynall RC, Mauntel TC, Padua DA, Mihalik JP. Acute lower extremity injury rates increase after concussion in college athletes. Med Sci Sports Exerc 2015;47:2487–92. [PubMed: 26057941]
4. Lapointe AP, Nolasco L, Sosnowski A, Andrews E, Martini DN, Gates DH, et al. Biomechanical differences during a jump cut motion in those with and without a concussion history. Br J Sports Med 2017;51:A2.
5. Swaine BR, Tremblay C, Platt RW, Grimard G, Zhang X, Pless IB. Previous head injury is a risk factor for subsequent head injury in children: a longitudinal cohort study. Pediatrics 2007;119:749–58. [PubMed: 17403846]
6. Fidan E, Lewis J, Kline AE, Garman RH, Alexander H, Cheng JP, et al. Repetitive mild traumatic brain injury in the developing brain: effects on long-term functional outcome and neuropathology. J Neurotrauma 2016;33:641–51. [PubMed: 26214116]
7. Moser RS, Schatz P, Jordan BD. Prolonged effects of concussion in high school athletes. Neurosurgery 2005;57:300–6. [PubMed: 16094159]
8. DePadilla L, Miller GF, Jones SE, Peterson AB, Breiding MJ. Self-reported concussions from playing a sport or being physically active among high school students— United States, 2017. MMWR Morb Mortal Wkly Rep 2018;67:682–5. [PubMed: 29927909]
9. Iverson GL, Gardner AJ, Terry DP, Ponsford JL, Sills AK, Broshek DK, et al. Predictors of clinical recovery from concussion: a systematic review. Br J Sports Med 2017;51:941–8. [PubMed: 28566342]
10. Moser RS, Schatz P. Increased symptom reporting in young athletes based on history of previous concussions. Dev Neuropsychol 2017;42: 276–83. [PubMed: 28678608]
11. Miller JH, Gill C, Kuhn EN, Rocque BG, Menendez JY, O'Neill JA, et al. Predictors of delayed recovery following pediatric sports-related concussion: a case-control study. J Neurosurg Pediatr 2016;4:491–6.
12. Morgan CD, Zuckerman SL, Lee YM, King L, Beaird S, Sills AK, et al. Predictors of postconcussion syndrome after sports-related concussion in young athletes: a matched case-control study. J Neurosurg Pediatr 2015;15:589–98. [PubMed: 25745949]
13. Corwin DJ, Zonfrillo MR, Master CL, Arbogast KB, Grady MF, Robinson RL, et al. Characteristics of prolonged concussion recovery in a pediatric subspecialty referral population. J Pediatr 2014;165:1207–15. [PubMed: 25262302]

14. Castile L, Collins CL, McIlvain NM, Comstock RD. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. Br J Sports Med 2012;46:603–10. [PubMed: 22144000]
15. Covassin T, Moran R, Wilhelm K. Concussion symptoms and neurocognitive performance of high school and college athletes who incur multiple concussions. Am J Sports Med 2013;41:2885–9. [PubMed: 23959963]
16. Colvin AC, Mullen J, Lovell MR, West RV, Collins MW, Groh M. The role of concussion history and gender in recovery from soccer-related concussion. Am J Sports Med 2009;37:1699–704. [PubMed: 19460813]
17. Currie DW, Comstock RD, Fields SK, Cantu RC. A paired comparison of initial and recurrent concussions sustained by us high school athletes within a single athletic season. J Head Trauma Rehabil 2017;32:90–7. [PubMed: 27120295]
18. Lau BC, Collins MW, Lovell MR. Cutoff scores in neurocognitive testing and symptom clusters that predict protracted recovery from concussions in high school athletes. Neurosurgery 2012;70:371–9. [PubMed: 21841522]
19. Heyer GL, Schaffer CE, Rose SC, Young JA, McNally KA, Fischer AN. Specific factors influence postconcussion symptom duration among youth referred to a sports concussion clinic. J Pediatr 2016;174:33–8. [PubMed: 27056449]
20. Baker JG, Leddy JJ, Darling SR, Rieger BP, Mashtare TL, Sharma T, et al. Factors associated with problems for adolescents returning to the class-room after sport-related concussion. Clin Pediatr (Phila) 2015;54:961–8. [PubMed: 26084537]
21. Iverson GL, Wojtowicz M, Brooks BL, Maxwell BA, Atkins JE, Zafonte R, et al. High school athletes with ADHD and learning difficulties have a greater lifetime concussion history. J Atten Disord 2016.
22. Institute of Medicine. Sports-related concussions in youth: improving the science, changing the culture Washington (DC): National Academies Press; 2014.
23. Arbogast KB, Curry AE, Pfeiffer MR, Zonfrillo MR, Haarbauer-Krupa J, Breiding MJ, et al. Point of healthcare entry for youth concussion within a large pediatric care network. JAMA Pediatr 2016;170:e160294. [PubMed: 27244368]
24. Zemek R, Barrowman N, Freedman SB, Gravel J, Gagnon I, McGahern C, et al. Clinical risk score for persistent postconcussion symptoms among children with acute concussion in the ED. JAMA 2016;315:1014–25. [PubMed: 26954410]
25. Haarbauer-Krupa J, Arbogast KB, Metzger KB, Greenspan AI, Kessler R, Curry AE, et al. Variations in mechanisms of injury for children with concussion. J Pediatr 2018;197:241–8. [PubMed: 29627189]
26. Centers for Disease Control and Prevention. ICD-9-CM official guide-lines for coding and reporting Atlanta (GA): Centers for Medicare & Medicaid Services; 2011.
27. Lovell MR, Iverson GL, Collins MW, Podell K, Johnston KM, Pardini D, et al. Measurement of symptoms following sports-related concussion: reliability and normative data for the Post-Concussion Scale. Appl Neuropsychol 2006;13:166–74. [PubMed: 17361669]
28. Howell DR, Kriz P, Mannix RC, Kirchberg T, Master CL, Meehan WP. Concussion symptom profiles among child, adolescent, and young adult athletes. Clin J Sport Med 2018, in press.
29. Meehan WP, Mannix RC, Stracciolini A, Elbin RJ, Collins MW. Symptom severity predicts prolonged recovery after sport-related concussion, but age and amnesia do not. J Pediatr 2013;163:721–5. [PubMed: 23628374]
30. Mautner K, Sussman WI, Axtman M, Al-Farsi Y, Al-Adawi S. Relationship of attention deficit hyperactivity disorder and postconcussion recovery in youth athletes. Clin J Sport Med 2015;25:355–60. [PubMed: 25353721]
31. Guerriero RM, Kuemmerle K, Pepin MJ, Taylor AM, Wolff R, Meehan WP. The association between premorbid conditions in school-aged children with prolonged concussion recovery. J Child Neurol 2018;33:168–73. [PubMed: 29334854]
32. Arbogast KB, Curry AE, Metzger KB, Kessler RS, Bell JM, Haarbauer-Krupa J, et al. Improving primary care provider practices in youth concussion management. Clin Pediatr (Phila) 2017;56:9.

33. Gruschow SM, Yerys BE, Power TJ, Durbin DR, Curry AE. Validation of the use of electronic health records for classification of ADHD status. J Atten Disord 2016, in press.

34. Manley G, Gardner AJ, Schneider KJ, Guskiewicz KM, Bailes J, Cantu RC, et al. A systematic review of potential long-term effects of sport-related concussion. Br J Sports Med 2017;51:969–77. [PubMed: 28455362]

35. McCrory P, Meeuwisse W, Dvořák J, Aubry M, Bailes J, Broglio S, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med 2017;51:838–47. [PubMed: 28446457]

36. Lumba-Brown A, Yeates KO, Sarmiento K, et al. Centers for Disease Control and Prevention guideline on the diagnosis and management of mild traumatic brain injury amoung children. JAMA Pediatr 2018;172:e182853. [PubMed: 30193284]

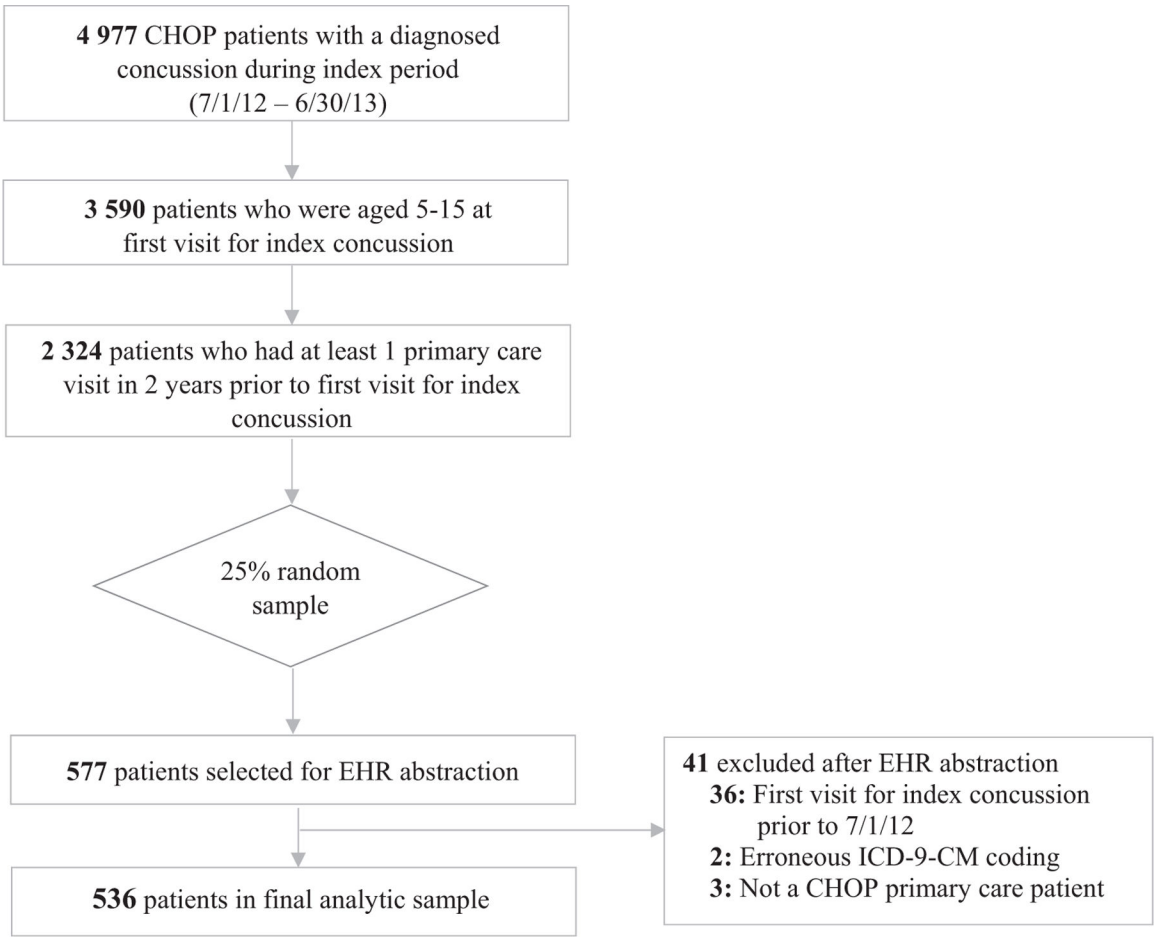

Figure.
Flowchart depicting selection of study cohort.

Table I.

Demographic and clinical characteristics among patients, overall and by whether the patient experienced a repeat concussion within 2 years of the index concussion

	Overall population	Experienced a repeat concussion		
		Yes	No	
Characteristic	**N (%)**	**n (%)**	**n (%)**	**RR (95% CI)**
Overall	536 (100)	87 (16.2)	449 (83.8)	
Demographic characteristics				
Sex				
Male	293 (54.7)	45 (15.4)	248 (84.6)	ref
Female	243 (45.3)	42 (17.3)	201 (82.7)	1.13 (0.77–1.65)
Race/ethnicity				
Non-Hispanic white	399 (74.4)	76 (19.0)	323 (81.0)	2.45 (1.22–4.92)
Other	103 (19.2)	8 (7.8)	95 (92.2)	ref
Unknown	34 (6.3)	3 (8.8)	31 (91.2)	
Age at index concussion, y				
5–8	63 (11.8)	6 (9.5)	57 (90.5)	0.89 (0.36–2.18)
9–11	140 (26.1)	15 (10.7)	125 (89.3)	ref
12–15	333 (62.1)	66 (19.8)	267 (80.2)	1.85 (1.09–3.13)
Insurance payor				
Private	458 (85.4)	77 (16.8)	381 (83.2)	ref
Public/self pay	78 (14.6)	10 (12.8)	68 (87.2)	0.76 (0.41–1.41)
Clinical characteristics				
History of concussion before index concussion				
No	450 (84.0)	68 (15.1)	382 (84.9)	ref
Yes	86 (16.0)	19 (22.1)	67 (77.9)	1.46 (0.93–2.30)
Pre-existing co-occurring condition *				
No	396 (73.9)	57 (14.4)	339 (85.6)	ref
Yes	140 (26.1)	30 (21.4)	110 (78.6)	1.49 (1.00–2.22)
Pre-existing co-occurring vision problem				
No	478 (89.2)	76 (15.9)	402 (84.1)	ref
Yes	58 (10.8)	11 (19.0)	47 (81.0)	1.19 (0.67–2.11)
Pre-existing co-occurring ADHD				
No	489 (91.2)	80 (16.4)	409 (83.6)	ref
Yes	47 (8.8)	7 (14.9)	40 (85.1)	0.91 (0.45–1.86)
Pre-existing co-occurring migraine/headache				
No	501 (93.5)	77 (15.4)	424 (84.6)	ref
Yes	35 (6.5)	10 (28.6)	25 (71.4)	1.86 (1.06–3.26)
Pre-existing co-occurring anxiety				
No	508 (94.8)	80 (15.7)	428 (84.3)	ref
Yes	28 (5.2)	7 (25.0)	21 (75.0)	1.59 (0.81, 3.11)

* Pre-existing co-occurring conditions include vision problems, ADHD, migraine/headache, and anxiety.

Table II.

Distribution of clinical characteristics of the index concussion, overall and by whether the patient experienced a repeat concussion within 2 years of the index concussion

		Experienced a repeat concussion		
	Overall population	Yes	No	
Characteristic	N (%)	n (%)	n (%)	RR (95% CI)
Overall	536 (100)	87 (16.2)	449 (83.8)	
Clinical characteristics				
Mechanism of injury				
Struck object	171 (31.9)	30 (17.5)	141 (82.5)	ref
Struck person	130 (24.3)	25 (19.2)	105 (80.8)	1.10 (0.68–1.77)
Fall	164 (30.6)	25 (15.2)	139 (84.8)	0.87 (0.53–1.41)
Other	43 (8.0)	4 (9.3)	39 (90.7)	0.53 (0.20–1.42)
Not documented	28 (5.2)	3 (10.7)	25 (89.3)	n/a
Sports- and recreation-related injury				
No	126 (23.5)	15 (11.9)	111 (88.1)	ref
Yes	374 (69.8)	68 (18.2)	306 (81.8)	0.93 (0.33–2.64)
Unknown	36 (6.7)	4 (11.1)	32 (88.9)	n/a
Clinical course of care, d				
0–7	189 (35.3)	24 (12.7)	165 (87.3)	ref
8–28	219 (40.9)	32 (14.6)	187 (85.4)	1.15 (0.70–1.88)
≥29	127 (23.7)	31 (24.4)	96 (75.6)	1.92 (1.19–3.12)
Missing	1 (0.2)	0 (0)	1 (100)	n/a
Number of distinct PCSS symptoms reported				
0–2	162 (30.2)	20 (12.3)	142 (87.7)	ref
3–6	207 (38.6)	26 (12.6)	181 (87.4)	1.02 (0.59–1.76)
7–10	103 (19.2)	20 (19.4)	83 (80.6)	1.57 (0.89–2.78)
≥11	64 (11.9)	21 (32.8)	43 (67.2)	2.66 (1.55–4.56)
PCSS symptoms				
Somatic				
No	28 (5.2)	2 (7.1)	26 (92.9)	ref
Yes	508 (94.8)	85 (16.7)	423 (83.3)	2.34 (0.61–9.03)
Visio-vestibular				
No	165 (30.8)	19 (11.5)	146 (88.5)	ref
Yes	371 (69.2)	68 (18.3)	303 (81.7)	1.59 (0.99–2.56)
Sleep				
No	268 (50.0)	34 (12.7)	234 (87.3)	ref
Yes	268 (50.0)	53 (19.8)	215 (80.2)	1.56 (1.05–2.32)
Emotional				
No	431 (80.4)	62 (14.4)	369 (85.6)	ref
Yes	105 (19.6)	25 (23.8)	80 (76.2)	1.66 (1.10–2.50)
Cognitive				
No	328 (61.2)	42 (12.8)	286 (87.2)	ref
Yes	208 (38.8)	45 (21.6)	163 (78.4)	1.69 (1.15–2.48)

Table III.

Distribution of distinct PCSS and other symptoms of the index concussion, overall and by whether the patient experienced a repeat concussion within 2 years of the index concussion

	Overall population	Experienced a repeat concussion		
		Yes	No	
Symptom	**N (%)**	**n (%)**	**n (%)**	**RR (95% CI)**
Overall	536 (100)	87 (16.2)	449 (83.8)	
Somatic symptoms				
Headache				
No	44 (8.2)	4 (9.1)	40 (90.9)	ref
Yes	492 (91.8)	83 (16.9)	409 (83.1)	1.86 (0.71–4.82)
Sensitivity to light				
No	321 (59.9)	38 (11.8)	283 (88.2)	ref
Yes	215 (40.1)	49 (22.8)	166 (77.2)	1.93 (1.31–2.83)
Nausea				
No	346 (64.6)	47 (13.6)	299 (86.4)	ref
Yes	190 (35.4)	40 (21.1)	150 (78.9)	1.55 (1.06–2.27)
Sensitivity to noise				
No	393 (73.3)	50 (12.7)	343 (87.3)	ref
Yes	143 (26.7)	37 (25.9)	106 (74.1)	2.03 (1.39–2.97)
Vomiting				
No	488 (91.0)	78 (16.0)	410 (84.0)	ref
Yes	48 (9.0)	9 (18.8)	39 (81.3)	1.17 (0.63–2.19)
Numbness or tingling				
No	522 (97.4)	85 (16.3)	437 (83.7)	ref
Yes	14 (2.6)	2 (14.3)	12 (85.7)	0.88 (0.24–3.21)
Visio-vestibular symptoms				
Dizziness				
No	210 (39.2)	25 (11.9)	185 (88.1)	ref
Yes	326 (60.8)	62 (19.0)	264 (81.0)	1.60 (1.04–2.46)
Vision problems				
No	370 (69.0)	50 (13.5)	320 (86.5)	ref
Yes	166 (31.0)	37 (22.3)	129 (77.7)	1.65 (1.12–2.42)
Balance problems				
No	381 (71.1)	56 (14.7)	325 (85.3)	ref
Yes	155 (28.9)	31 (20.0)	124 (80.0)	1.36 (0.91–2.02)
Sleep symptoms				
Fatigue				
No	354 (66.0)	46 (13.0)	308 (87.0)	ref
Yes	182 (34.0)	41 (22.5)	141 (77.5)	1.73 (1.18–2.54)
Drowsiness				
No	405 (75.6)	58 (14.3)	347 (85.7)	ref
Yes	131 (24.4)	29 (22.1)	102 (77.9)	1.55 (1.04–2.31)
Sleeping more than usual				
No	431 (80.4)	65 (15.1)	366 (84.9)	ref
Yes	105 (19.6)	22 (21.0)	83 (79.0)	1.39 (0.90–2.14)
Difficulty falling asleep				

		Experienced a repeat concussion		
	Overall population	Yes	No	
Symptom	**N (%)**	**n (%)**	**n (%)**	**RR (95% CI)**
No	461 (86.0)	66 (14.3)	395 (85.7)	ref
Yes	75 (14.0)	21 (28.0)	54 (72.0)	1.96 (1.28–2.99)
Sleeping less than usual				
No	494 (92.2)	74 (15.0)	420 (85.0)	ref
Yes	42 (7.8)	13 (31.0)	29 (69.0)	2.07 (1.26–3.40)
Emotional symptoms				
Irritability				
No	462 (86.2)	64 (13.9)	398 (86.1)	ref
Yes	74 (13.8)	23 (31.1)	51 (68.9)	2.24 (1.49–3.38)
Emotional lability				
No	480 (89.6)	76 (15.8)	404 (84.2)	ref
Yes	56 (10.4)	11 (19.6)	45 (80.4)	1.24 (0.70–2.19)
Sadness				
No	504 (94.0)	77 (15.3)	427 (84.7)	ref
Yes	32 (6.0)	10 (31.3)	22 (68.8)	2.05 (1.18–3.56)
Nervousness				
No	504 (94.0)	77 (15.3)	427 (84.7)	ref
Yes	32 (6.0)	10 (31.3)	22 (68.8)	2.05 (1.18–3.56)
Cognitive symptoms				
Difficulty concentrating				
No	387 (72.2)	52 (13.4)	335 (86.6)	ref
Yes	149 (27.8)	35 (23.5)	114 (76.5)	1.75 (1.19–2.57)
Feeling foggy				
No	410 (76.5)	53 (12.9)	357 (87.1)	ref
Yes	126 (23.5)	34 (27.0)	92 (73.0)	2.09 (1.43, 3.06)
Feeling slowed down				
No	447 (83.4)	61 (13.6)	386 (86.4)	ref
Yes	89 (16.6)	26 (29.2)	63 (70.8)	2.14 (1.44–3.19)
Difficulty remembering				
No	454 (84.7)	64 (14.1)	390 (85.9)	ref
Yes	82 (15.3)	23 (28.0)	59 (72.0)	1.99 (1.31–3.01)
Other symptoms				
Confusion				
No	456 (85.1)	71 (15.6)	385 (84.4)	ref
Yes	80 (14.9)	16 (20.0)	64 (80.0)	1.28 (0.79–2.09)
Disorientation				
No	466 (86.9)	72 (15.5)	394 (84.5)	ref
Yes	70 (13.1)	15 (21.4)	55 (78.6)	1.39 (0.84–2.28)
Neck pain				
No	481 (89.7)	70 (14.6)	411 (85.4)	ref
Yes	55 (10.3)	17 (30.9)	38 (69.1)	2.12 (1.35–3.33)
Loss of consciousness				
No	496 (92.5)	82 (16.5)	414 (83.5)	ref
Yes	40 (7.5)	5 (12.5)	35 (87.5)	0.76 (0.33–1.76)
Amnesia				

		Experienced a repeat concussion		
	Overall population	Yes	No	
Symptom	**N (%)**	**n (%)**	**n (%)**	**RR (95% CI)**
No	499 (93.1)	76 (15.2)	423 (84.8)	ref
Yes	37 (6.9)	11 (29.7)	26 (70.3)	1.95 (1.14–3.34)
Tinnitus (ringing in ears)				
No	513 (95.7)	82 (16.0)	431 (84.0)	ref
Yes	23 (4.3)	5 (21.7)	18 (78.3)	1.36 (0.61–3.03)
Personality changes				
No	524 (97.8)	85 (16.2)	439 (83.8)	ref
Yes	12 (2.2)	2 (16.7)	10 (83.3)	1.03 (0.29–3.70)

Table IV.

aRRs and 95% CIs of the association between relevant factors from the index concussion and the risk of repeat concussion within 2 years of the index concussion (n = 536)

	Model 1*	Model 2†
Factor	**RR (95% CI)**	**RR (95% CI)**
Age at index concussion, y		
5–8	0.91 (0.37–2.24)	0.96 (0.39–2.35)
9–11	ref	ref
12–15	1.74 (1.03–2.94)	1.68 (0.99–2.84)
Pre-existing co-occurring condition‡		
No	ref	ref
Yes	1.36 (0.91–2.02)	1.32 (0.89–1.96)
Clinical course of care, d		
0–7	ref	
8–28	1.06 (0.65–1.74)	
≥29	1.65 (1.01–2.69)	
Number of distinct PCSS symptoms reported		
0–2		ref
3–6		0.91 (0.52–1.57)
7–10		1.36 (0.77–2.42)
≥11		2.12 (1.21–3.71)

*Model 1 includes age at index concussion, pre-existing co-occurring conditions, and clinical course of care; it does not include number of PCSS symptoms.

†Model 2 includes age at index concussion, pre-existing co-occurring conditions, and number of PCSS symptoms; it does not include clinical course of care.

‡Co-occurring conditions include vision problems, ADHD, migraine/headache, and anxiety.

Table V.

aRR and 95% CIs of the association between relevant factors from the index concussion and the risk of repeat concussion within 2 years of the index concussion, among patients without a history of concussion before index concussion (n = 450)

	Model 1*	Model 2†
Factor	**RR (95% CI)**	**RR (95% CI)**
Age at index concussion, y		
5–8	0.95 (0.35–2.61)	1.08 (0.39–2.96)
9–11	ref	ref
12–15	1.84 (1.00–3.40)	1.73 (0.94–3.19)
Pre-existing co-occurring condition‡		
No	ref	ref
Yes	1.25 (0.79–1.99)	1.18 (0.75–1.85)
Clinical course of care, d		
0–7	ref	
8–28	1.30 (0.72–2.33)	
≥29	2.00 (1.12–3.60)	
Number of distinct PCSS symptoms reported		
0–2		ref
3–6		1.31 (0.67–2.58)
7–10		2.06 (1.02–4.13)
≥11		3.38 (1.69–6.79)

*Model 1 includes age at index concussion, pre-existing co-occurring conditions, and clinical course of care; it does not include number of PCSS symptoms.

†Model 2 includes age at index concussion, pre-existing co-occurring conditions, and number of PCSS symptoms; it does not include clinical course of care.

‡Co-occurring conditions include vision problems, ADHD, migraine/headache, and anxiety.