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# BMJ Open Ten-year trends in traumatic brain injury: a retrospective cohort study of California emergency department and hospital revisits and readmissions

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## ABSTRACT

**Objective** To describe visits and visit rates of adults presenting to emergency departments (EDs) with a diagnosis of traumatic brain injury (TBI). TBI is a major cause of death and disability in the USA; yet, current literature is limited because few studies examine longer-term ED revisits and hospital readmission patterns of TBI patients across a broad spectrum of injury severity, which can help inform potential unmet healthcare needs.

**Design** We performed a retrospective cohort study.

**Setting** We analysed non-public patient-level data from California's Office of Statewide Health Planning and Development for years 2005 to 2014.

**Participants** We identified 1.2 million adult patients aged ≥18 years presenting to California EDs and hospitals with an index diagnosis of TBI.

**Primary and secondary outcome measures** Our main outcomes included revisits, readmissions and mortality over time. We also examined demographics, mechanism and severity of injury and disposition at discharge.

**Results** We found a 57.7% increase in the number of TBI ED visits, representing a 40.5% increase in TBI visit rates over the 10-year period (346–487 per 100 000 residents). During this time, there was also a 33.8% decrease in the proportion of patients admitted to the hospital. Older, publicly insured and black populations had the highest visit rates, and falls were the most common mechanism of injury (45.5% of visits). Of all patients with an index TBI visit, 40.5% of them had a revisit during the first year, with 46.7% of them seeking care at a different hospital from their initial hospital or ED visit. Additionally, of revisits within the first year, 13.4% of them resulted in hospital readmission.

**Conclusions** The large proportion of patients with TBI who are discharged directly from the ED, along with the high rates of revisits and readmissions, suggest a role for an established system for follow-up, treatment and care of TBI.

## INTRODUCTION

Although traumatic brain injury (TBI) mortality rates have decreased over the last decade,<sup>1</sup> TBI-related disability has not declined,<sup>2</sup> and TBI-related emergency

## Strengths and limitations of this study

- Our study included all adult patients with a diagnosis of traumatic brain injury (TBI) presenting to the emergency department (ED), including those discharged directly home, thereby capturing a broad spectrum of TBI severity.
- Our study uses a large administrative state database with patient identifiers, which includes all non-federal, general and acute care hospitals in the state, to evaluate longer term outcomes, including revisits, readmissions and longer term mortality.
- Our data did not include patients who experienced a head injury and did not seek care in an ED or hospital, so we may be underestimating the population of patients with mild TBI.
- Our data were limited to the population of California and may not be representative of trends in the entire USA.

department (ED) visits have increased by 70%,<sup>1</sup> with a recent report by the Centers for Disease Control and Prevention (CDC) estimating 2.8 million TBI-related ED visits in 2013.<sup>3</sup> TBI is bluntly classified as mild, moderate or severe, according to the Glasgow Coma Score (GCS), but this gross characterisation metric fails to capture pathoanatomic distinctions in this multifocal injury and the nuanced and wide-ranging outcomes that are possible.<sup>4</sup> The persistence of physical, cognitive, behavioural and emotional sequelae of TBI, even mild TBI, is well documented in both short and longer timeframes,<sup>5</sup> contributing to chronic disability for a significant number of patients.<sup>6</sup> Currently, TBI is a major cause of disability among adults under age 40 years,<sup>7</sup> underscoring the importance of better understanding TBI epidemiology, causes and outcomes.

The current evidence base of TBI has shed light on the importance of examining a spectrum of TBI severity, especially mild TBI.<sup>8–12</sup>

The literature has shown that patients with TBI of all types of severity, including mild, can experience a range of longer term symptoms and require follow-up care.<sup>13–16</sup> Some studies have looked at ED revisits and hospital readmissions; however, the majority of these studies use limited sample sizes<sup>17–19</sup> or have short follow-up periods,<sup>17–20</sup> which may only provide a limited picture of the healthcare need and utilisation after TBI.

To address these gaps, we used California non-public administrative data to answer the question: what are the incidence, demographics and outcomes, including revisits, readmissions and out-of-hospital 1-year mortality of adult TBI patients in California over a 10-year period? We employed a longitudinal approach as suggested by the International Collaboration on Mild Traumatic Brain Injury<sup>21</sup> to evaluate these numerous long-term outcomes as the sequelae of TBI can occur long after the traumatic incident or the discharge of the patient. Our study included all adult TBI patients seen in the ED, including those discharged directly home, thereby capturing patients of a broad spectrum of TBI severity.

## METHODS

### Study design and data

We performed a retrospective cohort study of all adult patients with TBI presenting to EDs and hospitals in California from 2005 to 2014. We used non-public patient-level data from the California Office of Statewide Health Planning and Development (OSHPD), which contain information from all non-federal, general and acute care hospitals in California, including date of admission, patient demographics (age, gender and race/ethnicity—defined as Hispanic, non-Hispanic white, non-Hispanic black and other), comorbidities, diagnostic and procedural information, external cause of injury codes,<sup>22</sup> disposition and total charges for admissions. Because the data only include hospitalisation charges, our results do not include charges for ED discharges. We obtained vital statistics data to track mortality until 2011, the last year available, and linked the patient-level data with OSHPD utilisation and financial files, which contain hospital-level information such as trauma centre (TC) status.

To calculate TBI visit rates, we obtained California population data, including sex and age from the US Census Bureau, Population Division, and race/ethnicity from the US Census Bureau, American Community Survey (ACS). We calculated visit rates by payer using population by insurance information from the US Census Bureau, Current Population Survey for 2005–2012 and the ACS for 2013–2014. The University of California, San Francisco Institutional Review Board approved this study. Our reporting of protocol conforms to the guidelines for reporting observational studies and is included in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement checklist (online supplementary Strobe checklist).

### Study population

Our study population composed of all patients aged  $\geq 18$  years presenting to California EDs and hospitals and diagnosed with TBI. Consistent with CDC reporting,<sup>3</sup> we identified records as TBI-related if they had any of the following International Classification of Diseases, Ninth Revision codes as a primary or secondary diagnosis: 800.xx, 801.xx, 803.xx, 804.xx, 850.xx – 853.xx, 854.0–1, 905.1–3 and 959.01. We identified patients using record linkage numbers (RLNs) provided in the data and linked all visits with the same RLN to track that patient over time. We defined the first visit for each patient as the index visit. If multiple visits occurred within 1 day of each other, we considered them one event as these could represent ED-to-ED or ED-to-inpatient transfers. Similar to prior studies,<sup>23–25</sup> we categorised all subsequent visits as revisits and specified readmissions as revisits that resulted in hospitalisation after the index visit.

### Patient involvement

No patients were involved in the study design or in setting the research agenda.

### Outcomes and measures

Our main outcomes included revisits (including ED visits, not only those resulting in admission), readmissions, mean and median inpatient charges during the first year and mortality (ED mortality, in-hospital mortality and out-of-hospital 1-year mortality). We also studied the time from discharge of the initial visit (whether discharged or admitted) to the next revisit and calculated a ‘time-to-return’ curve.<sup>26</sup> We collected every patient’s Injury Severity Score (ISS) for each visit, which reflects overall trauma severity (not limited to TBI), and grouped them by severity: mild (ISS  $< 9$ ), moderate (ISS 9–15) and severe (ISS  $> 15$ ).<sup>27–28</sup> We examined outcomes by whether the patient was treated at a TC, where levels I and II are TCs and levels III and IV are non-TCs, consistent with current literature.<sup>29–30</sup> These classifications are determined by OSHPD, which ranks hospitals from level I–IV based on criteria provided by California local Emergency Medical Services agencies.

### Statistical analyses

To assess TBI index visits, we calculated the numbers and population rates per 100 000 by year, both overall and within strata defined by the demographic and clinical characteristics of the sample. To assess secular patterns, we estimated negative binomial models for the numbers of visits, with robust standard errors to account for clustering by hospital, calendar year of admission as a categorical predictor and the log of the population denominator as an offset in the models for rates. In a last step, we evaluated heterogeneity and trend across years using Wald tests, based on the fitted models. To assess the independent associations of age, sex, race/ethnicity, median income, insurance, ISS, mechanism of injury and TC care (as defined above) with numbers of revisits and readmissions

within 1 year, we also used multivariate negative binomial models, again with robust SEs to account for clustering by hospital. To account for the competing risk of death, these models used the log of the follow-up time as an offset, with appropriately shorter follow-up for patients who died. Finally, to identify risk factors associated with 1-year mortality, both overall and among discharged and admitted patients, we used analogous multivariate logistic models, again with robust SEs to account for clustering by hospital. We conducted all analyses using SAS (V.9.4).

## RESULTS

We identified 1 182 809 patients aged  $\geq 18$  years with an index diagnosis of TBI and described their demographic and clinical characteristics (table 1). During our study period from 2005 to 2014, the proportion of TBI patients grew increasingly older, female, of a racial or ethnic minority, and Medicaid or Medicare insured. The number of index TBI patients grew overall by 57.7%, from 91 492 in 2005 to 144 269 in 2014 (figure 1), with a 29.5% increase in the share of index visits due to falls. Approximately 78.9% of all index TBI patients were discharged from the ED, with the share of discharged patients rising (72.9% in 2005 to 82.1% in 2014) and share of admitted patients (27.1% in 2005 to 17.9% in 2014) and their length of stays (8.2 in 2005 to 6.4 days in 2014) declining. The most common diagnosis for all patients was unspecified head injury (37.0%), while the most frequent diagnosis among admitted patients was 'subdural hematoma following injury without mention of open intracranial wound, without loss of consciousness' (7.7%). For patients who revisited the ED, the most prevalent diagnosis was hearing loss (4.1%) for all revisits and headache (2.7%) for readmissions.

When we took into account population growth, the rate of TBI visits rose, from 346 visits per 100 000 people in 2005 to 487 visits per 100 000 people in 2014, a 40.5% increase (table 2, figure 1). By 2014, the rate of TBI visits for patients aged  $\geq 85$  years was almost five times that of the average, at 2336 visits per 100 000 people, a striking 62.3% increase from the first year of the study period. The growth in TBI rates for females (59.8%) was more than double that of males (25.5%), and TBI visit rates for Hispanic and black patients both grew faster (60.2% for Hispanic and 50.2% for black) than TBI visit rates for white and other race/ethnicity patients (42.7% for white and 45.7% for other). TBI visit rates rose across all insurance payer groups except for 'other insurance', with the highest increase (65.6%) for Medicare patients, and roughly equal growth of 34% for Medicaid-insured and privately insurance patients. All trends in TBI visit rates were statistically significant at  $p < 0.001$ .

### Trends in dispositions from ED or hospital

Although the majority of TBI index patients were discharged home from the ED, online supplementary figure 1A, B and online supplementary table 1 illustrate

steady increases to alternative sites of healthcare, including skilled nursing facilities (SNFs), intermediate rehabilitation facilities (IRFs), long-term care hospitals (LTCHs), home health services and other healthcare institutions, for patients discharged directly from the ED as well as for those following hospitalisation. While the absolute numbers are small, the proportion of patients discharged from the ED with home health services and hospice more than quintupled (0.047%–0.295%,  $p < 0.001$ ) and increased more than 10-fold (0.005%–0.057%,  $p < 0.001$ ) during the study period. Similarly, patients discharged from the hospital on their index visit increasingly used home health services (6.3%–10.5%,  $p < 0.001$ ) or an SNF or IRF (12.5%–19.3%,  $p < 0.001$ ) for recovery and decreasingly were discharged directly home (58.4%–49.0%,  $p < 0.001$ ).

### Revisits, readmissions and inpatient costs

Of all patients with an index TBI visit, 40.5% had a revisit during the first year, comprising 1 378 330 revisits (table 3). Approximately half of revisiting patients had only one revisit (49.0%); however, 13.8% had five or more revisits within the first year, and of all revisits, only 53.3% occurred at the same hospital as the index visit. Analysis of the 'time-to-return' for the first revisit after the index visit showed that 8.3% of all first revisits occurred within 1–3 days, with approximately 20% occurring in the first 2 weeks and about 34% in the first 2 months (online supplementary figure 2 and online supplementary table 2).

In our analysis of readmissions, 13.4% of all revisits in the first year resulted in hospital readmission. Slightly less than half (45.3%) of these readmissions occurred at the index visit hospital.

When examining factors associated with increased rates of revisits and readmissions, compared with the youngest cohort of patients (18–24 years), non-senior adults (25–64 years) had a 40% higher revisit rates ( $p < 0.001$ ), and all adults aged  $\geq 25$  years had greater readmission rates (relative hazard (RH) 25–44 years: 1.6; 45–64 years: 2.6; 65–84 years: 2.4; 85+ years: 2.3,  $p < 0.001$ ) (table 4). The incidence of revisit and readmission rates for black patients was 30% and 20% higher, respectively ( $p < 0.001$ ) than those of white patients. All payer categories had a higher incidence of revisit and readmission rates compared with privately insured patients: Medicare patients had 130% and 140% higher rates, respectively, and Medicaid patients had 210% and 150% higher rates, respectively (all  $p < 0.001$ ). Patients whose mechanism included 'falls' also had higher rates of revisits and readmissions (RH 1.5 and 1.6, respectively,  $p < 0.001$ ).

### Mortality

Of all patients with an index TBI visit, 9.8% died between 2005 and 2010. Of those deaths, 26.8% occurred during the index hospitalisation, 8.7% within 30 days, 6.0% between 31 days and 60 days, 28.6% within 61 days to a year and the remaining 29.9% past 1 year after the index visit (table 3). Online supplementary table 3 shows the

Table 1 TBI index visits per year

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	All N/mean (%/SD)	P values (trend)
<b>N</b>	91 492	93 045	98 937	101 773	122 010	123 354	128 496	138 638	140 795	144 269	1 182 809	
<b>Age (mean/SD)</b>	48.24 (22.46)	48.58 (22.54)	49.03 (22.59)	49.91 (22.75)	50.39 (22.80)	50.97 (22.92)	51.63 (23.04)	51.65 (23.02)	52.65 (23.06)	52.89 (23.16)	50.84 (22.92)	< 0.001
<b>Age categories (years)</b>												
18–24	17 037 (18.62)	17 040 (18.31)	17 560 (17.75)	17 226 (16.93)	20 465 (16.77)	19 940 (16.16)	20 263 (15.77)	21 871 (15.78)	20 712 (14.71)	21 175 (14.68)	193 289 (16.34)	
25–44	28 591 (31.25)	28 610 (30.75)	29 591 (29.91)	29 336 (28.82)	34 013 (27.88)	33 892 (27.48)	34 286 (26.68)	36 911 (26.62)	36 615 (26.01)	36 944 (25.61)	328 789 (27.80)	
45–64	21 642 (23.65)	22 318 (23.99)	24 546 (24.81)	25 676 (25.23)	31 257 (25.62)	31 591 (25.61)	32 845 (25.56)	35 341 (25.49)	35 565 (25.26)	36 144 (25.05)	296 925 (25.10)	
65–84	17 122 (18.71)	17 584 (18.90)	18 886 (19.09)	20 238 (19.89)	24 729 (20.27)	25 641 (20.79)	27 682 (21.54)	30 097 (21.71)	32 457 (23.05)	33 993 (23.56)	248 429 (21.00)	
85+	7 100 (7.76)	7 493 (8.05)	8 354 (8.44)	9 297 (9.14)	11 546 (9.46)	12 290 (9.96)	13 420 (10.44)	14 418 (10.40)	15 446 (10.97)	16 013 (11.10)	115 377 (9.75)	
<b>Sex</b>												
Male	50 238 (54.91)	50 733 (54.53)	53 618 (54.19)	54 557 (53.61)	61 412 (50.33)	62 108 (50.35)	64 750 (50.39)	69 401 (50.06)	69 222 (49.17)	70 740 (49.03)	606 779 (51.30)	
Female	40 967 (44.78)	42 298 (45.46)	45 310 (45.80)	47 211 (46.39)	60 596 (49.66)	61 243 (49.65)	63 738 (49.60)	69 230 (49.94)	71 563 (50.83)	73 520 (50.96)	575 676 (48.67)	
Missing	287 (0.314)	14 (0.015)	9 (0.009)	5 (0.005)	2 (0.002)	3 (0.002)	8 (0.006)	7 (0.005)	10 (0.007)	9 (0.006)	354 (0.030)	<0.001
<b>Race/ethnicity</b>												
NH White	54 192 (59.23)	55 274 (59.41)	58 516 (59.14)	60 252 (59.20)	73 592 (60.32)	72 261 (58.58)	74 305 (57.83)	78 458 (56.59)	78 191 (55.54)	78 466 (54.39)	683 507 (57.79)	
NH Black	6 791 (7.42)	6 712 (7.21)	7 358 (7.44)	7 633 (7.50)	9 337 (7.65)	9 734 (7.89)	10 181 (7.92)	11 279 (8.14)	11 420 (8.11)	11 715 (8.12)	92 160 (7.79)	
Hispanic	17 064 (18.65)	17 890 (19.23)	19 274 (19.48)	20 032 (19.68)	23 939 (19.62)	25 997 (21.08)	27 827 (21.66)	31 799 (22.94)	33 024 (23.46)	34 817 (24.13)	251 663 (21.28)	
Other	8 784 (9.60)	8 877 (9.54)	9 945 (10.05)	10 134 (9.96)	12 492 (10.24)	13 214 (10.71)	14 108 (10.98)	15 111 (10.90)	15 750 (11.19)	16 741 (11.60)	125 156 (10.58)	
Missing	4 661 (5.09)	4 292 (4.61)	3 844 (3.89)	3 722 (3.66)	2 650 (2.17)	2 148 (1.74)	2 075 (1.61)	1 991 (1.44)	2 410 (1.71)	2 530 (1.75)	30 323 (2.56)	
<b>Median income (SD)</b>	64 927.01 (23 271.07)	65 236.78 (23 312.40)	65 420.90 (23 369.71)	65 349.57 (23 540.03)	66 275.33 (23 836.76)	65 987.56 (23 693.14)	65 835.52 (23 690.03)	65 678.88 (23 647.27)	65 442.61 (23 487.64)	64 952.15 (23 258.91)	65 530.00 (23 526.35)	0.311
<b>Insurance</b>												
Private	30 729 (33.59)	31 952 (34.34)	33 940 (34.30)	34 828 (34.22)	43 291 (35.48)	40 797 (33.07)	41 680 (32.44)	44 240 (31.91)	42 863 (30.44)	42 976 (29.79)	387 296 (32.74)	
Medicare	23 696 (25.90)	24 724 (26.57)	27 035 (27.33)	29 430 (28.92)	35 879 (29.41)	38 014 (30.82)	41 353 (32.18)	45 415 (32.76)	48 652 (34.56)	50 565 (35.05)	364 763 (30.84)	
Medicaid	9 519 (10.40)	9 236 (9.93)	9 858 (9.96)	10 400 (10.22)	12 291 (10.07)	12 849 (10.42)	13 203 (10.28)	14 006 (10.10)	14 929 (10.60)	15 809 (11.78)	132 100 (11.17)	

Continued

**Table 1** Continued

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	All N/mean (%/SD)	P values (trend)
Self-pay/uninsured	14756 (16.13)	15228 (16.37)	16582 (16.76)	16608 (16.32)	19154 (15.70)	20018 (16.23)	20319 (15.81)	21449 (15.47)	20664 (14.68)	14787 (10.25)	179565 (15.18)	
Other	12792 (13.98)	11905 (12.79)	11522 (11.65)	10507 (10.32)	11395 (9.34)	11676 (9.47)	11941 (9.29)	13528 (9.76)	13687 (9.72)	10132 (7.02)	119085 (10.07)	
<b>ISS (mean/SD)</b>	3.73 (4.29)	3.74 (4.34)	3.80 (4.30)	3.84 (4.46)	3.79 (4.30)	3.73 (4.23)	3.65 (4.13)	3.69 (4.17)	3.71 (4.28)	3.70 (4.24)	3.73 (4.27)	<0.001
<b>ISS categories</b>												
<9	83190 (90.93)	84732 (91.07)	89755 (90.72)	92362 (90.75)	110876 (90.87)	112465 (91.17)	117731 (91.62)	126487 (91.24)	128198 (91.05)	131532 (91.17)	1 077 328 (91.08)	<0.001
9–15	4811 (5.26)	4905 (5.27)	5370 (5.43)	5495 (5.40)	6507 (5.33)	6336 (5.14)	6381 (4.97)	7288 (5.26)	7328 (5.20)	7575 (5.25)	61996 (5.24)	
≥16	3491 (3.82)	3408 (3.66)	3812 (3.85)	3916 (3.85)	4627 (3.79)	4553 (3.69)	4384 (3.41)	4863 (3.51)	5269 (3.74)	5162 (3.58)	43485 (3.68)	
<b>Injury characteristics (E-code)</b>												
Penetrating injury	878 (0.96)	952 (1.02)	910 (0.92)	971 (0.95)	937 (0.77)	922 (0.75)	919 (0.72)	1042 (0.75)	982 (0.70)	882 (0.61)	9395 (0.79)	
Falls	34820 (38.06)	37086 (39.86)	40599 (41.04)	43714 (42.95)	55228 (45.27)	58281 (47.25)	61899 (48.17)	66435 (47.92)	69408 (49.30)	71111 (49.29)	538581 (45.53)	
Any MVC	19203 (20.99)	18536 (19.92)	18579 (18.78)	17044 (16.75)	18301 (15.00)	18692 (15.15)	19272 (15.00)	20876 (15.06)	20620 (14.65)	21223 (14.71)	192346 (16.26)	
Other	23299 (25.47)	23778 (25.56)	25061 (25.33)	25426 (24.98)	31701 (25.98)	31075 (25.19)	31534 (24.54)	34388 (24.80)	32916 (23.38)	33925 (23.52)	293 103 (24.78)	
Missing	13292 (14.53)	12693 (13.64)	13788 (13.94)	14618 (14.36)	15843 (12.99)	14384 (11.66)	14872 (11.57)	15897 (11.47)	16869 (11.98)	17128 (11.87)	149384 (12.63)	
<b>Received care at level I or II TC</b>												
No	56341 (61.58)	57931 (62.26)	62499 (63.17)	65650 (64.51)	81378 (66.70)	82609 (66.97)	83777 (65.20)	90632 (65.37)	93701 (66.55)	95927 (66.49)	770445 (65.14)	
Yes	35151 (38.42)	35114 (37.74)	36438 (36.83)	36123 (35.49)	40632 (33.30)	40745 (33.03)	44719 (34.80)	48006 (34.63)	47094 (33.45)	48342 (33.51)	412364 (34.86)	
<b>Disposition of index TBI visit</b>												
Discharged from ED*	66733 (72.94)	69053 (74.21)	74522 (75.32)	77725 (76.37)	96653 (79.22)	98747 (80.05)	103086 (80.23)	112908 (81.44)	115231 (81.84)	118417 (82.08)	933075 (78.89)	
Admitted to hospital	24759 (27.06)	23992 (25.79)	24415 (24.68)	24048 (23.63)	25357 (20.78)	24607 (19.95)	25410 (19.77)	25730 (18.56)	25564 (18.16)	25852 (17.92)	249734 (21.11)	
<b>Died in the ED†</b>												
No	91266 (99.75)	92837 (99.78)	98713 (99.77)	101573 (99.80)	121824 (99.85)	123193 (99.87)					629406 (99.81)	
Yes	226 (0.25)	208 (0.22)	224 (0.23)	200 (0.20)	186 (0.15)	161 (0.13)					1205 (0.19)	
<b>LOS if admitted (mean/SD)</b>	8.15 (60.01)	7.64 (51.58)	7.31 (45.04)	7.27 (38.71)	6.50 (19.16)	6.18 (16.42)	6.60 (42.65)	6.28 (34.63)	6.53 (48.01)	6.37 (34.46)	6.87 (41.07)	<0.001

Continued

Table 1 Continued

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	All N/mean (%/SD)	P values (trend)
<b>Inpatient mortality if admitted†</b>												<0.001
No	23219 (93.78)	22538 (93.94)	22881 (93.72)	22605 (94.00)	23953 (94.46)	23272 (94.57)					138468 (94.08)	
Yes	1541 (6.22)	1454 (6.06)	1534 (6.28)	1443 (6.00)	1404 (5.54)	1335 (5.43)					8711 (5.92)	

Percentages may not sum to 100% due to rounding error.

†This includes patients who died in the ED (for more details, please refer to online supplementary table 1).

‡ED death and in-hospital death censored to 2010 because overall mortality analysis is restricted for index patients until 31 December 2010 since out-of-hospital 1-year mortality is available only until 31 December 2011.

ED, emergency department; ISS, Injury Severity Score; LOS, length of stay; MVC, motor vehicle collision; NH, non-Hispanic; TBI, traumatic brain injury; TC, trauma centre.

odds of mortality at 1 year among all the patient characteristics examined. Overall, patients who had a higher likelihood of mortality were older, male, white, publicly insured, injured through penetrating injury or falls and treated at a level I or II TC.

Sensitivity analyses of the regressions on death were done by stratifying discharged and admitted patients (online supplementary table 3), which showed a smaller range of likelihood of mortality for admitted patients but otherwise similar directions for all variables.

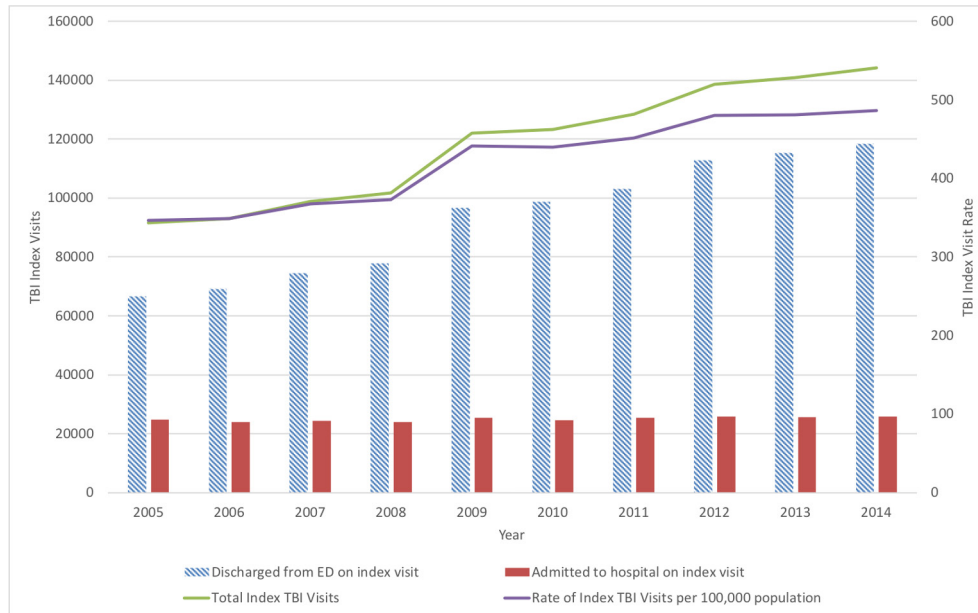
## DISCUSSION

From our study of 1.2 million patients presenting to EDs and hospitals with an index diagnosis of TBI between 2005 and 2014, we found that total index TBI visits grew by 57.7%, and even when adjusted for the population, the per capita rate of index TBI visits rose 40.5% in the past 10 years alone, with a rate of 487 index TBI visits per 100 000 population in 2014. These visit rate results follow the same general trend as in other studies, though our results may be smaller given that we only count index TBI visits.<sup>1 3 31</sup>

The vast majority of patients (78.9%) were discharged directly from the ED, with over 90% of all patients classified as only 'mildly' injured according to ISS criteria, which are similar to findings from other studies<sup>13 15 32</sup> and highlight the continual need of understanding the sequelae of mild TBI. Some literature has found that a minority of patients with TBI are discharged from the ED,<sup>10 16</sup> but these studies typically contain limited sample sizes suggesting that TBI studies with limited sample sizes may not always be representative of TBI samples from large administrative datasets such as OSHPD and may not capture the broad spectrum of TBI severity.

At the beginning of the study period in 2005, we found a high rate of index TBI visits for patients aged 85+ years, at 1439 visits per 100 000 population aged 85+ years, which was more than quadruple the average. By 2014, the rate of index TBI visits for patients aged 85+ years had increased to 2336 per 100 000, the largest growth in any age group. Consistent with other studies,<sup>3 8 33</sup> falls accounted for the preponderance of TBI (45.5%) and were the primary driver of the growth in TBI visit rates. The CDC's TBI surveillance summary confirmed that while overall TBI-related deaths have decreased over time, fall-related TBI incidence in the geriatric population is the fastest growing of all demographic segments, and fall-related deaths have increased.<sup>3</sup> This evidence combined with our findings suggest that more robust fall prevention efforts for elders such as the initiation of fall prevention programmes, including implementing strategies to reduce home hazards,<sup>34</sup> addressing medication alterations and providing physical training could be beneficial in preventing fall-related TBIs.<sup>35</sup>

When we examined TBI trends by payer, we found that the total number of index TBI visits by Medicaid patients increased 171% during the study period. This can be partly attributed to the Medicaid expansion<sup>36</sup> as the rate of TBI



**Figure 1** TBI visits overtime in California, 2005–2014. Notes: discharged from ED on index visit includes patients who died in the ED (for more details, please refer to online supplementary table 1). ED, emergency department; TBI, traumatic brain injury.

visits per Medicaid enrollee increased by 20% from 2013 to 2014. These results can suggest a number of trends, including increased willingness to visit the ED for TBI, greater insurance coverage (ie, Medicaid expansion) for a population that may be more likely to sustain TBI and/or increased general incidence of TBI. In addition, while

our finding of a higher likelihood of mortality for Medicaid-insured patients compared with privately insured patients is consistent with the literature,<sup>37</sup> our finding that Medicaid-insured patients with TBI have a higher likelihood of mortality than Medicare-insured patients with TBI suggests that the Medicaid-insured population may

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	P values (trend)
<b>Total</b>	346.27	349.13	367.60	373.03	441.00	439.73	451.65	480.47	481.35	486.56	<0.001
<b>Age (years)</b>											
18–24	462.41	460.43	469.25	451.82	527.13	507.03	509.62	544.72	515.43	530.08	<0.001
25–44	269.24	270.45	281.30	279.23	324.12	322.36	324.01	345.91	339.73	338.75	<0.001
45–64	261.39	262.62	281.95	288.26	342.51	338.63	346.20	369.62	368.29	370.17	<0.001
65–84	511.71	523.40	553.87	578.92	690.82	698.73	732.98	760.40	786.00	790.39	<0.001
85+	1439.46	1460.60	1554.52	1657.49	1974.20	2024.33	2134.20	2219.88	2312.78	2335.91	<0.001
<b>Sex</b>											
Male	386.01	386.51	404.49	406.05	450.84	449.90	462.45	488.61	480.74	484.59	<0.001
Female	305.55	312.75	331.73	340.95	431.44	429.85	441.12	472.52	481.87	488.40	<0.001
<b>Race/ethnicity</b>											
NH White	439.40	431.66	457.32	471.62	580.81	578.22	594.58	627.36	624.69	627.09	<0.001
NH Black	461.72	418.70	453.01	469.05	574.36	592.66	615.80	678.15	677.84	693.64	<0.001
Hispanic	211.70	209.23	221.32	226.01	266.24	277.84	289.65	324.93	330.59	339.14	<0.001
Other	217.27	209.08	231.78	233.36	283.77	281.13	293.81	304.81	309.87	316.44	<0.001
<b>Insurance</b>											
Private	205.08	206.54	216.78	225.07	300.45	275.23	284.50	286.36	290.86	275.40	<0.001
Medicaid	620.52	609.82	652.61	660.14	623.55	682.91	634.17	657.36	689.26	830.14	<0.001
Medicare	576.30	623.83	667.63	699.84	817.63	828.07	874.96	941.79	958.39	954.24	<0.001
Uninsured	283.04	287.66	307.30	293.70	303.45	321.59	316.64	363.78	354.63	346.30	<0.001
Other	1561.69	1670.26	1742.13	1445.67	1323.74	1221.92	1317.12	1470.57	1278.08	920.25	<0.001

NH, non-Hispanic; TBI, traumatic brain injury.



**Table 3** Outcomes of patients with TBI: all-cause revisits and readmissions

	N	%
<b>Hospital revisits (any ED visit or hospital readmission)</b>		
Total revisits	5 572 379	
Revisits within 1 year of index visit	1 378 330	24.74
Total patients with ≥1 revisit within 1 year of index visit	479 225	40.52
<i>Patients by number of revisits within 1 year of index visit</i>		
1 revisit	234 583	48.95
2 revisits	99 931	20.85
3 revisits	50 297	10.50
4 revisits	28 379	5.92
5–9 revisits	45 976	9.59
≥10 revisits	20 059	4.19
<i>Revisited the same hospital as index visit?</i>		
Yes	734 777	53.31
No	643 553	46.69
<b>Hospital readmissions</b>		
Total readmissions	1 484 359	
Readmissions within 1 year of index visit	185 061	12.47
Total patients with ≥1 readmission within 1 year of index visit	89 957	7.61
<i>Patients by number of readmissions within 1 year of index visit</i>		
1 readmission	49 225	54.72
2 readmissions	19 360	21.52
3 readmissions	9 402	10.45
5 readmissions	4 902	5.45
5–9 readmissions	6 223	6.92
≥10 readmissions	845	0.94
<i>Readmitted at the same hospital as index visit?</i>		
Yes	83 755	45.26
No	101 306	54.74
<b>Mortality*</b>		
Total deaths from 2005 to 2010	61 627	9.77
<i>Died within...?</i>		
Index hospitalisation	16 511	2.62
30 days after index visit	5 354	0.85
31–60 days after index visit	3 702	0.59
61 days–1 year after index visit	17 643	2.80

Percentages may not sum to 100% due to rounding error.

\*Includes only patients with vital statistics data of 2011, most current from the Office of Statewide Health Planning and Development.

ED, emergency department.

be receiving inadequate follow-up care such as rehabilitation programmes or have greater concomitant life-threatening injuries and comorbidities.<sup>37 38</sup>

Our findings on TBI trends by race/ethnicity showed that although the number of visits by Hispanic patients

more than doubled, the TBI visit rate for Hispanics was only half as large as the visit rates for white and black patients. This result combined with our findings that minority race/ethnic groups were associated with lower rates of revisit and readmission and lower likelihood of mortality, which are consistent with another study,<sup>39</sup> likely point to an ageing white population. It is possible that a large share of the black population may also be ageing into the elderly category (age 65 years and over), the age group with the highest TBI visit rate and associated with higher rates of revisit and readmission. However, in conjunction with our findings of a slightly reduced likelihood of mortality for black patients, consistent with the literature,<sup>39</sup> the results more likely suggest a combination of factors aside from ageing, such as greater incidence of assault or violence,<sup>40</sup> greater likelihood of being a blue-collar worker<sup>41</sup> or reduced access or usage of follow-up care.<sup>37</sup> These findings point to potential unobserved consequences of TBI for black patients, which may affect long-term health and have indirect socioeconomic consequences.

Our study tracked ED and hospital revisits and readmissions of all patients with TBI following any ED visit during the study period using a large administrative state database. Because 40.5% of patients had at least one revisit within the first year, current patient care and discharge practices, including patient education regarding potential sequelae of TBI at the index visit may not be adequate.<sup>42</sup> Overall, the high frequency of ED revisits and subsequent hospitalisations within the first year provides evidence of delayed symptoms and sequelae experienced by TBI patients,<sup>43</sup> contributing to the difficulty of providing adequate patient care at the index visit. Our findings, along with increasing evidence from other studies,<sup>9 42 44 45</sup> suggest that many mild TBI cases that do not require hospitalisation should likely not be considered uncomplicated, one-time events and may require an established system of multidisciplinary follow-up care.<sup>14</sup> Because we found that only 13.4% of revisits resulted in readmission, organising a system of outpatient TBI care to appropriately treat this high proportion of returning patients, particularly those revisiting within 3 days following discharge, could be of great health and economic value.<sup>46</sup> In particular, our findings that approximately half of all revisits and readmissions did not occur at the hospital of the index visit serve as potential evidence of poor TBI-specific follow-up care and the need for more comprehensive discharge instructions. While there are some reports of postacute rehabilitation for TBI-diagnosed patients and some models of community-integrated rehabilitation, many of these are focused on military personnel and are not widely available for civilian populations.<sup>47</sup> Our findings suggest that implementation of established systems of community-based TBI-specific care could potentially benefit patients and decrease healthcare utilisation.

Our study marks a starting point to understand the changing characteristics of patients with TBI, including trends in revisits and readmissions, which can help inform

**Table 4** Negative binomial regression for revisits and readmissions

	Revisit		Readmission	
	RH (95% CI)	P values	RH (95% CI)	P values
<b>Age (years)</b>				
18–24	Ref		Ref	
25–44	1.35 (1.33 to 1.36)	<0.001	1.61 (1.58 to 1.65)	<0.001
45–64	1.41 (1.39 to 1.44)	<0.001	2.56 (2.51 to 2.62)	<0.001
65–84	0.90 (0.88 to 0.92)	<0.001	2.38 (2.32 to 2.45)	<0.001
85+	0.84 (0.82 to 0.86)	<0.001	2.33 (2.27 to 2.40)	<0.001
<b>Sex</b>				
Male	0.86 (0.86 to 0.87)	<0.001	0.97 (0.96 to 0.98)	<0.001
Female	Ref		Ref	
Missing	1.12 (0.93 to 1.36)	0.223	1.47 (1.21 to 1.79)	<0.001
<b>Race/ethnicity</b>				
NH White	Ref		Ref	
NH Black	1.30 (1.28 to 1.32)	<0.001	1.22 (1.20 to 1.25)	<0.001
Hispanic	0.88 (0.87 to 0.89)	<0.001	0.90 (0.89 to 0.91)	<0.001
Other	0.65 (0.64 to 0.66)	<0.001	0.74 (0.72 to 0.75)	<0.001
Missing	0.82 (0.79 to 0.84)	<0.001	0.84 (0.81 to 0.86)	<0.001
<b>Median income</b>	1.00 (1.00 to 1.00)	<0.001	1.00 (1.00 to 1.00)	<0.001
<b>Insurance</b>				
Private	Ref		Ref	
Medicare	2.31 (2.27 to 2.35)	<0.001	2.44 (2.39 to 2.49)	<0.001
Medicaid	3.09 (3.05 to 3.14)	<0.001	2.53 (2.48 to 2.57)	<0.001
Uninsured	1.69 (1.66 to 1.72)	<0.001	1.21 (1.19 to 1.24)	<0.001
Other	1.45 (1.43 to 1.48)	<0.001	1.15 (1.12 to 1.17)	<0.001
<b>Severity categories</b>				
<9	Ref		Ref	
9–15	1.01 (1.00 to 1.03)	0.130	1.02 (1.00 to 1.04)	0.092
≥16	1.00 (0.98 to 1.02)	0.791	1.01 (0.98 to 1.03)	0.554
<b>Injury characteristics (E-code)</b>				
Penetrating injury	1.05 (1.00 to 1.10)	0.053	1.06 (1.00 to 1.13)	0.069
Falls	1.54 (1.52 to 1.57)	<0.001	1.55 (1.52 to 1.58)	<0.001
Any MVC	Ref		Ref	
Other	1.24 (1.23 to 1.26)	<0.001	1.04 (1.02 to 1.06)	<0.001
Missing	1.71 (1.69 to 1.74)	<0.001	1.67 (1.64 to 1.70)	<0.001
<b>Received care at level I or II TC</b>				
No	Ref		Ref	
Yes	0.97 (0.96 to 0.97)	<0.001	1.15 (1.14 to 1.16)	<0.001

MVC, motor vehicle collision; NH, non-Hispanic; RH, relative hazard; TC, trauma centre.

strategies to improve our ability to assess and provide quality care for TBI-diagnosed patients. Future studies will further elucidate the nature of revisits and readmissions to provide better insight for both ED and inpatient providers.

### Limitations

Our study includes several limitations. First, patients with TBI frequently suffer concomitant injuries, which make it difficult to evaluate only patients with isolated head trauma

and to fully assess whether outcomes and revisits resulted from brain injury, other traumatic injury or comorbidities. Second, we based our inclusion criteria on prior work,<sup>3</sup> and as with any coded diagnosis data, codes may not always precisely reflect the nature of the visit and could potentially overestimate the number of patients diagnosed with TBI. Consequently, some of our findings should be taken in this context; for example, the higher mortality rate in TCs.

While we did adjust for trauma severity using standard risk adjustment in trauma literature,<sup>48–50</sup> it is clear that administrative data, no matter how complete, can never capture the full picture of a patient's precise condition. Since patients with more severe trauma are more likely to be taken to a TC, the finding of a higher mortality rate at TCs is unsurprising. Third, our data do not include patients who experienced a head injury and did not seek care in an ED or hospital, but rather potentially sought care from their primary care doctors or elsewhere (or perhaps died before they were taken to a hospital), and so we may be underestimating the population of patients with TBI. Fourth, we did not have clinical information such as patient neurological status or imaging results, and while we did classify the general severity of overall trauma with ISS metrics,<sup>27 28</sup> we could not identify whether the head injury itself was classified as mild, moderate or severe according to the commonly used GCS. Finally, our data set is limited to the population of the state of California and may not be representative of trends in the entire USA. However, given that California represents 12% of the US population and has a broad spectrum of socioeconomic and racial/ethnic diversity, these findings may be informative for others interested in trends in TBI care and management.

Overall, as most TBI studies focus on hospitalised patients, or those who at least received a head CT scan,<sup>51</sup> our study distinctively uses a larger universe of patients diagnosed with TBI who may not have even obtained an initial head CT. Our study greatly expands the evidence derived from previous studies as we did not restrict our sample to a certain subgroup of a specific age,<sup>52 53</sup> cause or severity of injury or region,<sup>54</sup> and instead used all California adult patient hospital TBI cases, including those discharged directly from the ED.

## CONCLUSIONS

We find an increasing number of patients presenting to EDs and hospitals with a diagnosis of TBI over the past decade, especially among the elderly, with falls being the predominant mechanism of injury. The highest TBI visit rates were among the elderly, publicly insured and black populations. The proportion of patients discharged directly from the ED has steadily grown over time, with an increasing number of discharged patients (both from the ED and the hospital) discharged to alternative forms of healthcare, such as SNF, IRF, LTCH and home health services. Importantly, there are substantial revisits and readmissions for patients with TBI index visits, with greater incidence of revisit and readmission rates among black, publicly insured and fall-injured patients. These findings suggest that understanding the entire universe of patients across the severity spectrum of TBI—especially those discharged without follow-up care—will be critically important in TBI prevention efforts as well in the design of improvements to follow-up, care and rehabilitation of these patients.

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