Traumatic brain injury and risk of subsequent attempted suicide and violent crime

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Abstract

Background. Traumatic brain injury (TBI) can cause long-lasting sequelae that may increase the risk of suicidal or criminal behaviour, but large-scale longitudinal studies are lacking on the link between TBI and events of suicide attempt and violent crime. This study examined the incidence of suicide attempt and violent crime following hospital contact for TBI in a nationwide cohort study.

Methods. We used nationwide register data covering all individuals aged 10+ living in Denmark during 1980–2016 ($n = 7\,783\,951$). Of these, 587 522 individuals had a hospital contact for TBI. Incidence rate ratios (IRR) were calculated by Poisson regression analyses while adjusted for relevant covariates including other fractures and psychiatric diagnoses.

Results. Individuals with TBI had higher rates of suicide attempt (females IRR, 2.78; 95% CI 2.71–2.85; males IRR, 3.00; 95% CI 2.93–3.08) compared to individuals without TBI in adjusted analyses. Multiple TBI and temporal proximity to TBI were associated with higher rates of suicide attempt. Individuals with TBI had higher rates of violent crime (females IRR, 2.43; 95% CI 2.36–2.49; males IRR, 1.80, 95% CI 1.78–1.82) compared with individuals without TBI. Higher rates of violent crime were found after multiple TBI and temporal proximity to TBI.

Conclusions. This nationwide cohort study found higher rates of suicide attempt and violent crime among individuals with prior hospital diagnosed TBI, compared with individuals without TBI. This emphasises the need for preventive efforts immediately after TBI diagnosis, which might mitigate the risks of a trajectory toward suicidal or violent behaviours.

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Introduction

Traumatic brain injury (TBI) is the leading cause of disability in people under the age of 40 years worldwide (World Health Organization, 2006). Long-term consequences of TBI include cognitive, emotional and behavioural dysregulation, such as disinhibition and aggression, which are associated with a higher risk of suicidal or criminal behaviour (Arciniegas & Wortzel, 2014; Bahraini, Simpson, Brenner, Hoffberg, & Schneider, 2013; Bellesi, Barker, Brown, & Valmaggia, 2019; Kim, 2002). Both suicide attempts and criminal offences are tied to great suffering among individuals involved as well as society in general (Hvidkjær et al., 2021; Parsonage, 2016).

TBI has been linked to both psychiatric illness and suicide (Madsen et al., 2018; Orlovska et al., 2014), but systematic reviews have only identified few studies examining the association to non-fatal suicide attempt (Bahraini et al., 2013; Fralick et al., 2019), which have methodological shortcomings including small sample sizes. Recently, a large study ($n = 157\,995$) suggested an elevated risk of suicide attempt after TBI (Chang et al., 2019), but these findings were restricted to adolescents and young adults only and were thus not representative for a broad demographic range.

Regarding TBI and criminal behaviour, cross-sectional data has revealed that up to 60% of incarcerated offenders have been exposed to TBI (Hughes et al., 2015; Shiroma, Ferguson, & Pickelsimer, 2012). Although an association between TBI and violent crime has been shown in cohort studies (Fazel, Lichtenstein, Grann, & Långström, 2011; McIsaac et al., 2016; McKinlay, Corrigan, Horwood, & Fergusson, 2014; Schofield et al., 2015; Timonen et al., 2002), a recent review highlighted the need for longitudinal cohorts that include defined measures of TBI, its severity, a non-offending comparison group, adjusted analyses, and use of criminal records

instead of self-reported data (Huw Williams et al., 2018). Furthermore, it remains to be examined whether specific types of violent crimes are linked to higher rates.

The objective of this study was to analyse whether individuals with hospital-diagnosed TBI had higher rates of subsequent suicide attempt and violent crime compared to individuals with no hospital-diagnosed TBI. The Danish registers allowed us to assess variation between rates of suicide attempt and violent crime with respect to TBI severity, multiple TBI and time since TBI in a retrospective cohort design, while controlling for important confounders. Such findings will aid the development of preventive efforts against negative trajectories after TBI.

Methods

Study design and population

A cohort study design was applied. All residents in Denmark have a unique personal identification number, which allows for the linkage of data from continuously updated national registries. Data were extracted from the Civil Registration System (Pedersen, 2011), the National Patient Register (NPR) (Lynge, Sandegaard, & Rebolj, 2011), the Psychiatric Central Research Register (PCCR) (Mors, Perto, & Mortensen, 2011), the Register of Causes of Death (Helweg-Larsen, 2011), the Database for Integrated Labour Market Research (Timmermans, 2010), and the National Criminal Register ('Criminal Codes – Statistics Denmark (In Danish),' n.d.; Jensen, Greve, Høyer, & Spencer, 2006). Diagnoses in NPR and PCCR were recorded according to the International Classification of Diseases (ICD, 8th revision until 1 January 1994 and 10th thereafter).

All individuals aged 10 years or older who lived in Denmark at some point from 1 January 1980, through 31 December 2016 were included.

Exposures

Information on exposure to TBI was retrieved from the NPR. The register contains data on hospital admissions since 1977 and outpatient and emergency room contacts since 1995. TBI was categorised as mild TBI (concussions); fractures to the skull or spine (without documented structural brain injury); and severe TBI (with evidence of structural brain injury) (see eTable 1) as suggested by the American Congress of Rehabilitation Medicine and applied previously (American Congress of Rehabilitation Medicine, 1993; Christensen et al., 2009; Madsen et al., 2018). The severity of TBI was classified in mutually exclusive categories; ranging from mild TBI through skull or spine fractures to severe TBI. The onset of exposure was defined as the date of the first TBI diagnosis. Multiple diagnoses of TBI recorded within a 30-day period were considered as related to the same episode.

Outcomes

Suicide attempts were identified using ICD-8 codes (E950–E959) and ICD-10 codes (X60–X84) or where the reason for contact was indicated as a suicide attempt in NPR and PCCR.

Information on convicted violent crimes of individuals aged 15 years or older (age of criminal responsibility in Denmark) derived from the National Criminal Register. Following conducts were considered as violent (eTable 2): sexual offences, violent threats, assault, homicide, attempted homicide, robbery, arson, vandalism,

driving accidents, drunk driving, possession of a weapon in a public space, and terrorism. The date of the offence was considered as the onset time for the outcome.

Covariates

Information on sex (female, male), calendar period, age group (10–19, 20–29, …, 80+), educational level (elementary school, vocational training, high school, university degree, ongoing, or missing), socioeconomic status (employed, unemployed, disability pension, early retirement, retirement, student or other) and cohabitation status (cohabitation, no cohabitation) were obtained from the Civil Registration System and the Database for Integrated Labour Market Research. For individuals below the age of 20, we used parent's highest socioeconomic status and educational level instead of individuals own. In addition, Charlson comorbidity index (1, 2, 3, 4+) (Charlson, Pompei, Ales, & MacKenzie, 1987), non-CNS fractures (i.e. number of fracture diagnoses not involving the skull or spine; no, 1, 2, 3+), epilepsy (no, yes), and psychiatric illness diagnosed prior to TBI exposure (no, yes) were included (see eTable 1).

Follow up

Individuals were followed from 1 January 1980 until the end of a study on 31 December 2016. If a person migrated out of the country or died, they were censored at the date of the respective event. Likewise, persons were censored after experiencing the outcome of the study. If an outcome was recorded during the first hospital contact for TBI, the exposure was ignored; hence, the individual was considered unexposed but having experienced the outcome of the study.

Statistical analysis

Incidence rate ratios (IRR) with 95% confidence intervals were estimated by Poisson regression models comparing outcome rates of people exposed to TBI with those not exposed. Analyses were conducted separate for females and males due to the interaction of sex with exposure and outcome. The basic model was adjusted for age and calendar period, while the full model was additionally adjusted for educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, Charlson comorbidity index and psychiatric illness. Associations were assessed with respect to severity (mild TBI, skull fracture, severe TBI), number of distinct hospital contacts (0, 1, 2, 3, 4, ≥5); time since last hospital contact (0–6 months, >6–12 months, >1–2 years, >2–3 years, >3–4 years, >4–5 years, >5–6 years, >6 years); and patient type (ER/outpatient v. inpatient treatment). Associations to different types of violent crimes were examined in separate models. As previous studies have demonstrated a higher occurrence of psychiatric illness among people with TBI in Denmark, (Orlovska et al., 2014) we examined in analyses confined to patients with TBI (1) whether rates of outcomes were higher in individuals with pre-TBI psychiatric illness compared to those without and (2) whether post-TBI psychiatric illness might act as a mediator by comparing rates of outcomes in individuals diagnosed with and without psychiatric illness after TBI. We used adjusted IRRs to estimate the population attributable risks (PAR). To validate our primary analyses, we conducted a sensitivity analysis where the sample was restricted to individuals born in 1976 or later, allowing for lifetime coverage of hospital

Table 1. Suicide attempt incidence rates and incidence rate ratios by medical contact for traumatic brain injury

	n	IR per 100 000 PY (95% CI)	Basic adjusted IRR (95% CI)[a]	Fully adjusted IRR (95% CI)[b]
Females				
No contact for TBI	63 368	75.6 (75.0–76.2)	1 [Reference]	1 [Reference]
Any contact for TBI	7701	214.9 (210.1–219.7)	2.92 (2.85–2.99)	2.78 (2.71–2.85)
Mild TBI	6667	226.0 (220.6–231.5)	3.01 (2.93–3.09)	2.84 (2.76–2.91)
Skull fracture	257	173.3 (152.1–194.5)	2.31 (2.04–2.61)	2.42 (2.14–2.73)
Severe TBI	777	160.1 (148.8–171.4)	2.49 (2.32–2.68)	2.45 (2.29–2.64)
Males				
No contact for TBI	43 316	54.4 (53.9–54.9)	1 [Reference]	1 [Reference]
Any contact for TBI	9917	183.1 (179.5–186.7)	3.53 (3.45–3.61)	3.00 (2.93–3.08)
Mild TBI	8227	193.1 (188.9–197.3)	3.63 (3.54–3.72)	3.07 (2.99–3.15)
Skull fracture	431	158.0 (143.0–172.9)	3.02 (2.75–3.32)	2.66 (2.42–2.93)
Severe TBI	1259	142.6 (134.7–150.4)	3.14 (2.96–3.32)	2.73 (2.58–2.89)

CI, confidence interval; IR, incidence rate; IRR, incidence rate ratio; PY, person-years; TBI, traumatic brain injury.
[a]Basic adjusted: Adjusted for calendar period, and age group.
[b]Fully adjusted: Adjusted for calendar period, age group, educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, Charlson comorbidity index, and psychiatric illness.

admissions. Another sensitivity analysis further adjusted for parental background (educational level, socioeconomic status, suicidal or criminal behaviour and psychiatric illness).

All data processing and analyses were performed using SAS version 9.4. An anonymised data set was used for the analyses, and the project was approved by the Danish Data Protection Agency (RHP-2012-021).

Results

The study population consisted of 7 783 951 individuals (3 833 579 females and 3 950 372 males) who lived in Denmark at some point during 1980–2016 and were observed for a total of 172 398 267 person-years. In all, 587 522 individuals received a diagnosis of TBI where 443 971 (5.7%) were diagnosed with mild TBI, 24 800 (0.3%) with a skull fracture, and 118 751 (1.5%) with severe TBI. The median age at first diagnosis was 29 [interquartile range (IQR): 14–57] for females and 25 (IQR: 14–47) for males.

Suicide attempt

During the 37-year follow-up, 124 302 individuals (57% females) had at least one suicide attempt, of which 17 618 (14%) had experienced a TBI beforehand (eTables 3 and 4). The incidence rate of suicide attempt was 214.9 (95% CI 210.1–219.7) per 100 000 person-years for females with TBI *v.* 75.6 (95% CI 75.0–76.2) for those without (Table 1). The corresponding rates for males were 183.1 (95% CI 179.5–186.7) and 54.4 (95% CI 53.9–54.9), respectively. A higher IRR of suicide attempt was found for individuals with TBI (females IRR, 2.78; 95% CI 2.71–2.85; males IRR, 3.00; 95% CI 2.93–3.08) when compared to those without TBI. Higher IRRs were found for females exposed to mild TBI (2.84; 95% CI 2.76–2.91) than severe TBI (2.45; 95% CI 2.29–2.64) relative to females not exposed to TBI (*p* < 0.001). Males exposed to mild TBI also had higher IRRs (3.07,
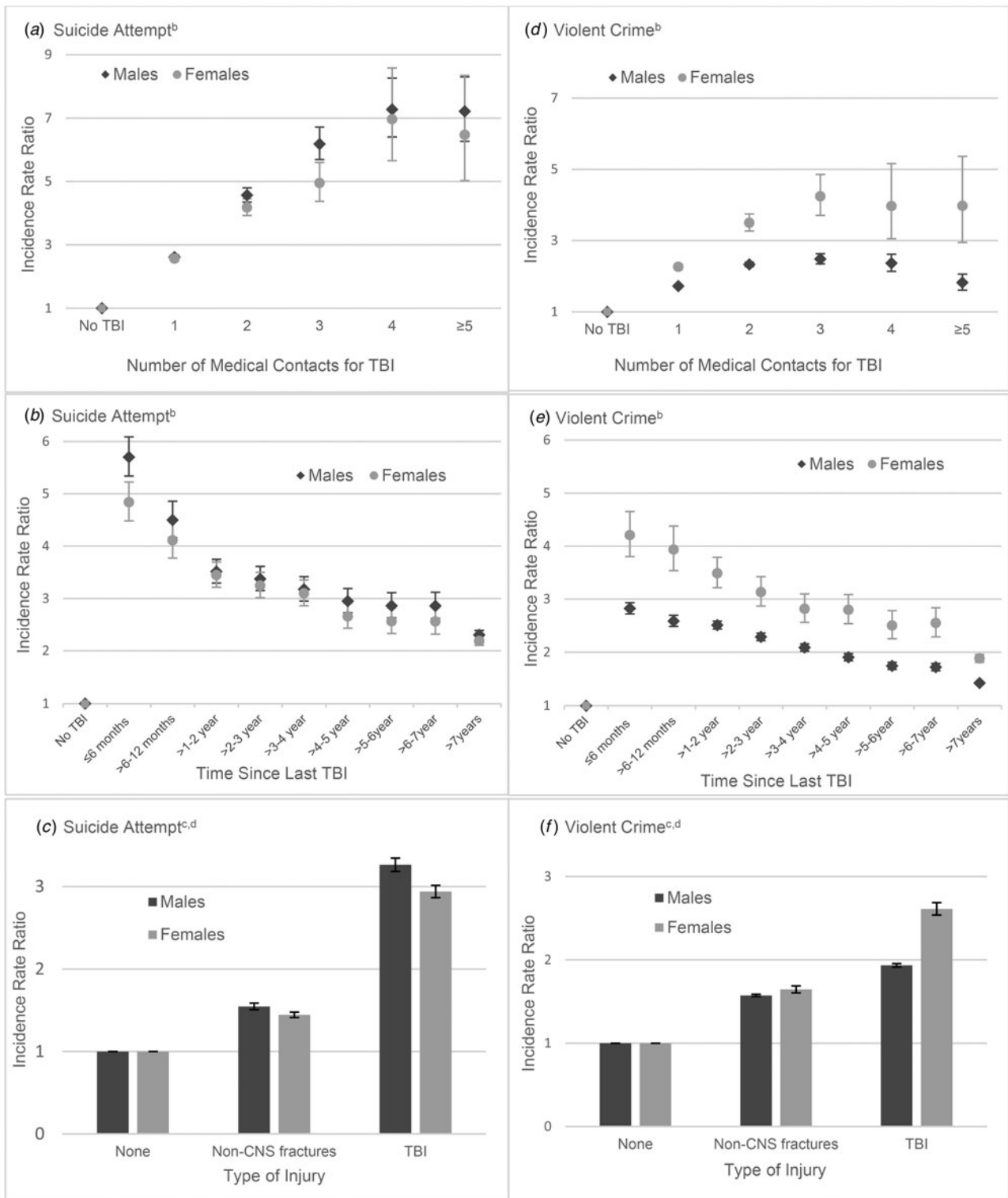
95% CI 2.99–3.15) than those with severe TBI (2.73, 95% CI 2.58–2.89; *p* < 0.001) relative to males not exposed (*p* < 0.001).

Having multiple hospital contacts for TBI was associated with higher rates of suicide attempt in a dose-response association up to four TBI's (*p* ≤ 0.05; Fig. 1*a* and e Table 7). Relative to no TBI the IRR for females with one TBI was 2.57 (2.50–2.64), two TBIs 4.18 (3.93–4.45), three TBIs 4.95 (4.38–5.60), four TBIs 6.97 (5.66–8.58) and five or more TBIs 6.48 (5.02–8.34). The corresponding IRRs for males were; for one TBI 2.61 (2.54–2.68), two TBIs 4.57 (4.35–4.80), three TBIs 6.18 (5.69–6.72), four TBIs 7.27 (6.40–8.26) and five or more TBIs 7.21 (6.27–8.20). IRR was highest in the first 6 months after hospital contact for TBI (females IRR, 4.71; 95% CI 4.36–5.09; males IRR, 5.61; 95% CI 5.25–5.99) compared to those without TBI (Fig. 1*b*). Compared to people with no TBI or fractures, those with TBI had higher IRRs (females IRR, 2.73; 95% CI 2.66–2.80; males IRR, 3.03; 95% CI 2.96–3.10) than those with non-CNS fractures (females IRR, 1.44; 95% CI 1.40–1.47; males IRR, 1.54; 95% CI 1.50–1.58) (*p* < 0.001; Fig. 1*c*).

Individuals diagnosed with psychiatric illness before their TBI had higher rates of suicide attempt (females IRR, 5.24; 95% CI 4.92–5.57; males IRR, 3.18; 95% CI 2.96–3.27) (Table 2) than those with TBI only. Likewise, individuals first diagnosed with the psychiatric illness after TBI had higher IRR's (females IRR, 14.81; 95% CI 14.02–15.65; males IRR, 12.44; 95% CI 11.88–13.03) than those with TBI only.

PAR for females and males with TBI were 6.8% (95% CI 6.6–7.1) and 11.3% (95% CI 10.9–11.7) for suicide attempts, respectively. This indicates the proportion of total suicide attempts, which could be avoided if it was possible to reduce TBI, under the assumption that the association is causal and not due to confounding.

In a sensitivity analysis, where the sample was restricted to individuals born after 1976 to have a complete follow-up from birth, associations between TBI and suicide attempt (females IRR, 3.20; 95% CI 3.04–3.38; males IRR, 3.13; 95% CI 2.99–3.27) remained (eTable 9). When further adjusting for parental

(a) Suicide Attempt[b] — Incidence Rate Ratio vs Number of Medical Contacts for TBI (Males, Females)

(b) Suicide Attempt[b] — Incidence Rate Ratio vs Time Since Last TBI (Males, Females)

(c) Suicide Attempt[c,d] — Incidence Rate Ratio vs Type of Injury (None, Non-CNS fractures, TBI; Males, Females)

(d) Violent Crime[b] — Incidence Rate Ratio vs Number of Medical Contacts for TBI (Males, Females)

(e) Violent Crime[b] — Incidence Rate Ratio vs Time Since Last TBI (Males, Females)

(f) Violent Crime[c,d] — Incidence Rate Ratio vs Type of Injury (None, Non-CNS fractures, TBI; Males, Females)

[a]See eTables 6 and 7 for precise data estimates. Error bars indicate 95% confidence intervals. Analyses were conducted separately for each sex; therefore, it is not possible to compare the IRRs for males and females directly as they have different reference groups. [b]Adjusted for age, calendar period, educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, Charlson comorbidity index, and psychiatric illness. [c]Adjusted for all characteristics listed in footnote b except non-CNS fractures (i.e. fractures not involving the skull or spine). [d]Individuals registered with both TBI and non-CNS fractures were considered in the TBI group from date of TBI.

Fig. 1. Incidence rate ratios of suicide attempt and violent crime in individuals with TBI, 1980–2016[a].

Table 2. Suicide attempt and violent crime incidence rates and incidence rate ratios among individuals with TBI, according to the timing of first psychiatric diagnosis

	n	IR per 100 000 PY (95% CI)	Basic adjusted IRR (95% CI)[a]	Fully adjusted IRR (95% CI)[b]
Suicide attempt: females with TBI				
Psychiatric illness before diagnosis of TBI				
No	6074	178.9 (174.4–183.4)	1 [Reference]	1 [Reference]
Yes	1627	866.4 (824.3–908.5)	6.53 (6.17–6.93)	5.24 (4.92–5.57)
First psychiatric illness after diagnosis of TBI				
No	3149	101.0 (97.5–104.5)	1 [Reference]	1 [Reference]
Yes	2925	1056.7 (1018.4–1095.0)	15.37 (14.56–16.23)	14.81 (14.02–15.65)
Suicide attempt: males with TBI				
Psychiatric illness before diagnosis of TBI				
No	8078	156.0 (152.6–159.4)	1 [Reference]	1 [Reference]
Yes	1839	771.1 (735.8–806.3)	5.55 (5.27–5.85)	4.37 (4.13–4.62)
First psychiatric illness after diagnosis of TBI				
No	4299	89.8 (87.1–92.5)	1 [Reference]	1 [Reference]
Yes	3779	962.3 (931.6–993.0)	12.86 (12.29–13.45)	12.44 (11.88–13.03)
Violent crimes: females with TBI				
Psychiatric illness before diagnosis of TBI				
No	5372	158.3 (154.1–162.5)	1 [Reference]	1 [Reference]
Yes	1128	518.4 (488.1–548.6)	4.18 (3.91–4.47)	3.18 (2.96–3.41)
First psychiatric illness after diagnosis of TBI				
No	3877	125.4 (121.4–129.3)	1 [Reference]	1 [Reference]
Yes	1495	495.9 (470.7–521.0)	4.34 (4.08–4.61)	4.02 (3.77–4.27)
Violent crimes: males with TBI				
Psychiatric illness before diagnosis of TBI				
No	43 125	1065.7 (1055.7–1075.8)	1 [Reference]	1 [Reference]
Yes	2826	1982.7 (1909.6–2055.8)	2.74 (2.63–2.85)	2.25 (2.16–2.35)
First psychiatric illness after diagnosis of TBI				
No	38 115	1002.0 (991.9–1012.0)	1 [Reference]	1 [Reference]
Yes	5010	2065.1 (2007.9–2122.3)	2.57 (2.49–2.64)	2.38 (2.31–2.45)

CI, confidence interval; IR, incidence rate; IRR, incidence rate ratio; PY, person-years; TBI, traumatic brain injury.
[a]Basic adjusted: Adjusted for calendar period, and age group.
[b]Fully adjusted: Adjusted for calendar period, age group, educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, and Charlson comorbidity index.

background information, such as socioeconomic status and suicidal behaviour, associations also remained (females IRR, 2.55; 95% CI 2.46–2.65; males IRR, 3.27; 95% CI 3.10–3.45).

Violent crime

In all, 494 348 individuals (11% females) were convicted of one or more violent crimes, of which 52 451 (11%) had experienced a TBI beforehand (eTables 5 and 6). Female incidence rates were 180.0 (95% CI 175.6–184.4) per 100 000 person-years for those with TBI compared to 59.8 (95% CI 59.2–60.3) among those without (Table 3). For males, the corresponding rates were 1096.9 (95% CI 1086.9–1107.0) and 531.1 (95% CI 529.4–532.7), respectively. Higher IRRs of violent crime were found for females (IRR, 2.43; 95% CI 2.36–2.49) and males (IRR, 1.80, 95% CI 1.78–1.82) with TBI compared with individuals without TBI. When assessing

rates for different types of crimes, higher rates were obtained for people with TBI across all groups (Table 4).

Multiple hospital contacts for TBI was associated with higher crime rates in a dose-response association up to three TBI's (*p* < 0.05; Fig. 1*d* and e Table 8). Relative to no TBI the IRR for females with one TBI was 2.26 (2.20–2.33), two TBIs 3.50 (3.27–3.75), three TBIs 4.24 (3.71–4.86), four TBIs 3.97 (3.05–5.16) and five or more TBIs 3.98 (2.95–5.37). The corresponding IRRs for males were; for one TBI 1.72 (1.70–1.74), two TBIs 2.33 (2.27–2.39), three TBIs 2.49 (2.35–2.63), four TBIs 2.37 (2.14–2.62) and five or more TBIs 1.82 (1.61–2.06). However, males with 4 TBI's had higher IRR (2.37; 95% CI 2.14–2.62) than males with ≥5 TBI's relative to no TBI (*p* < 0.001). The IRR was highest in the first 6 months after a hospital contact for TBI (females IRR, 4.21; 95% CI 3.80–4.65; males IRR, 2.83; 95% CI 2.72–2.94) compared to those without TBI (Fig. 1*e*). In comparison to people

Table 3. Violent crime incidence rates and incidence rate ratios by medical contact for traumatic brain injury

	n	IR per 100 000 PY (95% CI)	Basic adjusted IRR (95% CI)[a]	Fully adjusted IRR (95% CI)[b]
Females				
No contact for TBI	50 160	59.8 (59.2–60.3)	1 [Reference]	1 [Reference]
Any contact for TBI	6500	180.0 (175.6–184.4)	2.67 (2.60–2.74)	2.43 (2.36–2.49)
Mild TBI	5484	184.4 (179.5–189.2)	2.69 (2.61–2.76)	2.43 (2.35–2.50)
Skull fracture	235	158.5 (138.2–178.8)	2.44 (2.15–2.78)	2.36 (2.08–2.68)
Severe TBI	781	159.9 (148.7–171.1)	2.66 (2.47–2.85)	2.45 (2.28–2.63)
Males				
No contact for TBI	391 737	531.1 (529.4–532.7)	1 [Reference]	1 [Reference]
Any contact for TBI	45 951	1096.9 (1086.9–1107.0)	1.95 (1.93–1.97)	1.80 (1.78–1.82)
Mild TBI	37 538	1139.4 (1127.9–1150.9)	1.94 (1.92–1.96)	1.80 (1.78–1.82)
Skull fracture	2177	1030.3 (987.0–1073.6)	1.88 (1.80–1.96)	1.75 (1.68–1.83)
Severe TBI	6236	912.7 (890.0–935.3)	2.03 (1.98–2.08)	1.81 (1.77–1.86)

CI, confidence interval; IR, incidence rate; IRR, incidence rate ratio; PY, person-years; TBI, traumatic brain injury.
[a]Basic adjusted: Adjusted for calendar period, and age group.
[b]Fully adjusted: Adjusted for calendar period, age group, educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, Charlson comorbidity index, and psychiatric illness.

with no TBI or fracture, elevated rates were noted for those with TBI (females IRR, 2.00; 95% CI 1.89–2.12; males IRR, 1.93; 95% CI 1.91–1.96) and those with non-CNS fractures (females IRR, 1.65; 95% CI 1.60–1.69; males IRR, 1.57; 95% CI 1.56–1.59; Fig. 1*f*). For males, a lower crime rate was noted for those whose TBI required inpatient treatment (IRR, 0.92; 95% CI 0.90–0.94) than for those exclusively treated in ER or outpatient settings.

Individuals with psychiatric illness before TBI had higher rates of violent crime (IRR for females, 3.18; 95% CI 2.96–3.41; IRR for males, 2.25; 95% CI 2.26–2.35) than those with TBI only. Likewise, individuals first diagnosed with the psychiatric illness after TBI had higher rates (females IRR, 4.02; 95% CI 3.77–4.27; males IRR, 2.38; 95% CI 2.31–2.45; Table 2) than those with TBI only.

PAR for violent crime of 5.6% (95% CI 5.3–5.8) and 4.1% (95% CI 4.0–4.2) were found for TBI-exposed females and males, denoting the proportion of crimes that might be avoided if it was possible to reduce TBI incidents to zero, under the assumption that the association is causal and not due to confounding

The association between TBI and violent crime (females IRR, 2.43; 95% CI 2.31–2.55; males IRR, 2.20; 95% CI 2.17–2.23) remained when restricting the sample to those with complete data on background factors (eTable 9). Also, when further adjusting for parental background, such as socioeconomic status and criminal behaviour (females IRR, 2.55; 95% CI 2.46–2.65; males IRR, 3.37; 95% CI 3.10–3.45).

Discussion

We found that TBI was associated with elevated rates of suicide attempt and violent crime. Rates were highest within the first 6 months after a hospital contact for TBI, suggesting a temporal proximity association, and also higher after multiple TBI contacts. Associations could be mediated by psychiatric illness, as rates of suicide attempt and violent crime were higher among individuals who were diagnosed with a psychiatric illness following TBI than those with TBI but no psychiatric illness.

TBI is a major public health concern; although 76% of the exposed in this study were classified as mild TBI, these can still result in long-term consequences (Ryan & Warden, 2003; Sariaslan, Sharp, D'Onofrio, Larsson, & Fazel, 2016). The high prevalence of TBI globally emphasises the importance for preventing TBI to mitigate sequalae, especially for high-risk groups such as veterans or victims of traffic accidents (Feigin et al., 2013; Peeters et al., 2015). The importance of informing physicians and patients about the risk of adverse outcomes after TBI are emphasised by the fact that 14% of all people with a suicide attempt and 11% of those with a violent crime had experienced a TBI beforehand. Further, PAR estimates indicate that as many as 11% of suicide attempts and 6% of violent crimes in Denmark may be avoided by preventing TBI, if the association is causal. These high-risk estimates are from a high welfare Scandinavian country with access to free health care and good possibilities of rehabilitation after brain injury. Thus, the risk of suicide attempt and violence ascribed to TBI could potentially be higher in areas with less possibility and lower quality of treatment after TBI.

To our knowledge, this is the first nationwide study to assess rates of suicide attempt after TBI for all age groups. The rate ratios for suicide attempt obtained in this study were lower than those reported for young persons (Chang et al., 2019). In addition to sample differences, we accounted for an extensive list of potential confounders, such as other injuries and epilepsy, which might explain the difference. In contrast to earlier reports on suicidal behaviour, we found an inverse association with the severity of TBI (Chang et al., 2019; Madsen et al., 2018). It is possible that the severity of the TBI might have affected the person's likelihood of having a suicide attempt because of, for instance, serious disabilities as a result of the TBI, increased medical attention averted adverse mental health outcomes, or suicidal acts tended to be fatal rather than non-fatal after severe TBI.

Our findings regarding the risk of violent crime after TBI support previous findings although levels of risk differed (Fazel et al., 2011; McIsaac et al., 2016; McKinlay et al., 2014; Schofield et al., 2015; Timonen et al., 2002). The difference could be due to diverging measures (e.g. self-reported crimes (McKinlay et al., 2014) or

Table 4. Specific violent crimes incidence rates and incidence rate ratios in individuals with and without a traumatic brain injury diagnosis

	Females		Males	
	No TBI	TBI	No TBI	TBI
Sexual offence				
n	702	80	22 219	3301
IR (95% CI)[a]	0.8 (0.8–0.9)	2.1 (1.7–2.6)	45.7 (45.2–46.1)	130.8 (127.8–133.9)
IRR (95% CI)[b]	1 [Reference]	1.63 (1.27–2.10)	1 [Reference]	1.56 (1.50–1.62)
Violence[c]				
n	15 965	2690	125 902	22 939
IR (95% CI)[a]	18.9 (18.6–19.2)	72.3 (69.6–75.0)	160.6 (159.7–161.5)	449.3 (443.4–455.1)
RR (95% CI)[b]	1 [Reference]	2.67 (2.56–2.79)	1 [Reference]	2.16 (2.13–2.20)
Homicide or attempted homicide				
n	1930	325	12 015	2940
IR (95% CI)[a]	2.3 (2.2–2.4)	8.6 (7.7–9.6)	15.0 (14.7–15.3)	52.3 (50.4–54.2)
IRR (95% CI)[b]	1 [Reference]	3.03 (2.67–3.44)	1 [Reference]	1.87 (1.79–1.96)
Arson				
n	1146	219	5819	1460
IR (95% CI)[a]	1.4 (5.8–5.1)	5.8 (5.1–6.6)	7.3 (26.1–24.8)	26.1 (24.8–27.4)
IRR (95% CI)[b]	1 [Reference]	3.49 (2.99–4.07)	1 [Reference]	2.79 (2.62–2.97)
Robbery				
n	1495	326	17 339	4112
IR (95% CI)[a]	1.8 (1.7–1.9)	8.7 (7.7–9.6)	21.7 (21.4–22.0)	74.3 (72.0–76.6)
IRR (95% CI)[b]	1 [Reference]	3.68 (3.24–4.18)	1 [Reference]	2.51 (2.42–2.60)
Vandalism				
n	5410	961	63 285	11 544
IR (95% CI)[a]	6.4 (6.2–6.6)	25.7 (24.0–27.3)	80.0 (79.3–80.6)	216.8 (212.8–220.8)
IRR (95% CI)[b]	1 [Reference]	3.29 (3.06–3.54)	1 [Reference]	2.44 (2.39–2.49)
Driving Accidents or Drunk driving				
n	27 701	3730	242 987	35 104
IR (95% CI)[a]	32.7 (32.3–33.1)	99.1 (95.9–102.3)	303.2 (302.0–304.4)	624.2 (617.7–630.8)
IRR (95% CI)[b]	1 [Reference]	2.73 (2.63–2.83)	1 [Reference]	1.82 (1.80–1.84)
Possession of weapon				
n	3686	595	50 367	9422
IR (95% CI)[a]	4.4 (4.2–4.5)	15.8 (14.6–17.1)	63.4 (62.9–64.0)	173.9 (170.4–177.4)
IRR (95% CI)[b]	1 [Reference]	2.45 (2.23–2.68)	1 [Reference]	1.96 (1.92–2.01)

IR, incidence rate; IRR, incidence rate ratio; TBI, traumatic brain injury.
[a]Rate per 100 000 person-years.
[b]Adjusted for calendar period, age group, educational level, socioeconomic status, cohabitation status, non-CNS fractures, epilepsy, Charlson comorbidity index, and psychiatric illness.
[c]Including assault, aggravated assault, threats, homicide and attempted homicide.

including all types of crimes (McIsaac et al., 2016)), small sample size (Timonen et al., 2002), or a less comprehensive assessment for potential confounders (Fazel et al., 2011; McKinlay et al., 2014; Timonen et al., 2002). Associations for different types of violent crimes have, to our knowledge, not been examined before, and we found elevated rates for all types of crime after TBI. Previous findings stratified by sex (McIsaac et al., 2016; Schofield et al., 2015) did not report differences between males and females with respect to risk of violent crime after TBI

when comparing those with and without TBI. Even though females had lower, absolute rates of violent crime than males, we observed the highest increase in the IRR among females with TBI compared to females without TBI. This could suggest that females' risk of violent crime might be stronger affected by TBI, possibly due to the low base rate of violent crimes among females without TBI, whereas the base crime rate among males without TBI is rather high (i.e. there is a ceiling effect for males).

While our findings cannot establish causality, they support the perception that sequalae of TBI, such as behavioural dysregulation, psychiatric symptoms, aggression or disinhibition, could lead to suicidal or criminal behaviour (Arciniegas & Wortzel, 2014; Bahraini et al., 2013; Bellesi et al., 2019; Kim, 2002; Orlovska et al., 2014). It is also possible that individuals with risk-taking behaviours or substance abuse, which both are associated with suicidal and criminal behaviours, are more prone to accidents and TBI (Huw Williams et al., 2018; Weil, Corrigan, & Karelina, 2018). The fact that having multiple TBI episodes was linked to elevated rates of suicide attempt and violent crime, could support a hypothesis of a behavioural phenotype. This was further explored by accounting for proneness to accidents; firstly, by controlling for non-CNS fractures and, secondly, by comparing those with TBI with non-CNS fractures. However, the higher rates of both outcomes for individuals with TBI than for those with non-CNS fractures suggest that a behavioural phenotype is not the only explanation for increased rates after TBI. To explore whether heredity might be a driving force for the association, we adjusted for parental psychiatric illness and suicidal or criminal behaviour in a sensitivity analysis; however, this did not alter the results.

Strengths and limitations

This study had several strengths. First, a large nationwide cohort was studied over a long period with no or little loss to follow-up (Pedersen, 2011). Second, the precision of estimates was improved by using records, such as diagnoses and verdicts, rather than self-reported data, adjusting for potential confounders, and using time-varying covariates, while presenting separate estimates for males and females. Third, longitudinal data ensured that TBI exposure occurred prior to the outcomes of the study, hence, avoiding potential reverse causation.

Limitations should also be noted. First, mild TBI could be under-recorded as some individuals might not seek hospital treatment and ER and outpatient contacts were not recorded prior to 1995. Second, suicide attempts (Morthorst, Soegaard, Nordentoft, & Erlangsen, 2016) and violent crimes were likely under-recorded; implying that our estimates might be conservative. Third, information on provided treatment for TBI was not available, which may impact the risk of outcomes. Fourth, as NPR was initiated in 1977, individuals with TBI or suicide attempt prior to this time could bias results in a conservative direction; yet, sensitivity analysis with lifetime follow-up supported the overall results. Fifth, the first time of diagnosis of psychiatric illness might not reflect the true time of onset of illness and some psychiatric disorders might not be treated in hospital settings. Therefore, information about psychopathology as well as additional covariates, such as suicidal thoughts, home violence or early behavioural problems might have added further value to our analyses.

Conclusion

In this nationwide, registry-based cohort study, we found that individuals with hospital contact for TBI had increased rates of suicide attempt and violent crime, when compared to the general population without TBI. Rates were highest in the time shortly after diagnosis, suggesting that preventive efforts at the time of or soon after TBI diagnosis may help mitigate the trajectories toward suicidal or violent behaviour.

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