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2023-02

Kuitunen , I , Ponkilainen , V , Iverson , G L , Isokuortti , H , Luoto , T M & Mattila , V M 2023 , ' Increasing incidence of pediatric mild traumatic brain injury in Finland - a nationwide register study from 1998 to 2018 ' , Injury , vol. 54 , no. 2 , pp. 540-546 . https://doi.org/10.1016/j.injury.2022.12.023

http://hdl.handle.net/10138/356792
https://doi.org/10.1016/j.injury.2022.12.023

Injury 54 (2023) 540–546

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Increasing incidence of pediatric mild traumatic brain injury in Finland – a nationwide register study from 1998 to 2018

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ARTICLE INFO

Article history:
Accepted 18 December 2022

Keywords:
Traumatic brain injury
Epidemiology
Incidence

ABSTRACT

Aim: The purpose of this study is to document the annual incidence and incidence trends of pediatric traumatic brain injury (pTBI) in Finland over the course of 21 years.

Methods: We conducted a retrospective nationwide register-based cohort study and used the Finnish Care Register and Population information statistics from 1998 to 2018. The patient group includes all patients aged <18 at the time of injury. We included all emergency department (ED) visits and subsequent inpatient admissions (meaning at least one night in the hospital) with International Classification of Diseases diagnostic code S06*. We calculated pTBI incidences per 100,000 person-years with 95% confidence intervals and the incidences were compared by incidence rate ratios (IRR), including age, diagnosis, and gender stratified analyses.

Results: A total of 71,972 patients were included with 76,785 ED visits or hospitalizations for pTBI diagnoses. The annual incidence of diagnosed pTBI was 251 (CI: 241–260) per 100,000 in 1998 and 547 (CI: 533–561) per 100,000 in 2018, indicating a 118% increase in the incidence (IRR 2.18 CI: 2.09–2.28). Boys had 32% higher incidence (IRR 1.32 CI: 1.30–1.34) than girls. The highest cumulative incidence was observed among boys aged <1 years, 525 (CI: 507–543) per 100,000, and boys had higher incidences in all age groups. The most used diagnostic code was concussion, which included 92.1% of the diagnoses followed by diffuse brain injury, which included 2.3% of the diagnoses. The increase in the incidence of diagnosed pTBI was notably high after 2010. Concussion diagnoses and pTBI cases that were discharged directly from the ED had more than a two-fold increase from 2010 to 2018, whereas the incidence of inpatient admissions for pTBI increased by 53%.

Conclusions: The overall incidence of diagnosed pTBI has increased in Finland especially since 2010. Boys have higher incidence of diagnosed pTBI in all age groups. Most of the increase was due to increase in the concussion diagnoses, which may be due to the centralization of EDs into bigger units and increased diagnostic awareness of mild pTBI.

Introduction

The incidence of documented pediatric traumatic brain injury (pTBI) has been increasing globally and the annual incidence estimates of hospitalizations for pTBI have varied between 50 and 300 per 100,000 children [1–3]. The incidences are highest among children who are less than two years old and adolescents [3]. The incidence estimate for pTBI in Europe was 349 per 100,000 children aged 0–19 in 2014 [4].

Mild TBI in children generally has a favorable outcome [5,6]. In contrast, severe TBI in children can result in death [7] or vary-

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https://doi.org/10.1016/j.injury.2022.12.023

ing degrees of functional disability [8]. Moreover, recent observational register studies have associated pTBI to worse health during long-term follow-up. For example, increased risk for epilepsy [9], increased mortality and suicides [10,11], and multiple sclerosis [12] have been reported in some studies.

Finland had a relatively low documented incidence of pTBI in comparison to other European countries, but the pTBI mortality rate was among the highest [4]. The annual pTBI incidence was reported to be 118 per 100,000 in a prospectively followed birth cohort in Northern-Finland and this study reported that during the first 30-years of life the cumulative TBI incidence was 300 per 100,000 person-years [13]. The latest register study in Finland estimated the incidence of pTBI in 2012 and found that the incidence had an increasing trend in Southern Finland [14]. The purpose of this study was to document the annual incidence and incidence trends of pTBI in Finland over the course of 21 years.

Materials and methods

We conducted a retrospective register-based nationwide cohort study in Finland. Data were gathered from two nationwide registers for the study period from January 1998 to December 2018. We used the Finnish Care Register for Healthcare and the Population Information Register.

We gathered all pediatric (age <18 years) patients recorded as having a TBI each year from the Finnish Care Register. The Finnish Care Register is maintained by the Finnish Institute of Health and Welfare, and it includes information on all specialized health care (secondary and tertiary level units) visits, procedures, and inpatient admissions in Finland. The register has been shown to have excellent coverage and validity [15,29,30]. We included all emergency department (ED) visits and subsequent inpatient admissions (meaning at least one night in the hospital) with an International Classification of Diseases-10th Edition (ICD-10) diagnostic code of S06* (i.e., S06.0, S06.1, S06.2, S06.3, S06.4, S06.5, S06.6, S06.7, S06.8, S06.9). The diagnostic code S06.8 was grouped with S06.9 because both represent “intracranial injury, unspecified” and they are used interchangeably. If a patient had multiple S06* diagnoses in the same visit, the patient was classified according to the most severe of these. Patients were stratified based on whether they were discharged from the ED or they had inpatient admissions from the ED. Inpatient admissions also included transfers from the ED to a different hospital for admission because neurosurgery units have been centralized into five tertiary centers in Finland. In addition, there are 25 secondary level trauma units included in this study, without neurosurgery, but with a 24/7 surgical ED.

We also analyzed co-occurring fractures in addition to pTBIs that were reported to the register in the same visit. These injuries were categorized based on the ICD-10 diagnostic codes for fractures as follows: skull fractures S02*, fractures of spine and pelvis (S12*, S22*, and S32*), upper extremity fractures (S42*, S52*, and S62*), and lower extremity fractures (S72*, S82*, and S92*).

We calculated the incidence per 100,000 person years for pTBI and compared the incidences by incidence rate ratios (IRR) with 95% confidence intervals (CI). Age stratification was based on the developmental milestones: children aged less than 1 year are generally unable to walk, and the injuries are mostly falls or abuse, 1–6 years represent preschool aged children, 7–12 years are in lower elementary school, and 13–17 in upper elementary school and high school. In the incidence calculations, if a patient sustained more than one TBI those were calculated separately if there was at least a year between the injury episodes (the register does not stratify acute injuries and follow-up visits in specialized healthcare). We used the number of children in each age and gender group at the end of the year as the denominator in the incidence analysis. The population information (number of children at the end of the year by gender and age in Finland) was gathered from the open-access register of Statistics Finland [16].

The ethical committee evaluation was waived because according to the Finnish research legislation it is not needed for register-based retrospective studies. Our study data was pseudonymized by Statistics Finland and none of the authors had access to the pseudonymization key. The data are handled and stored in a safe remote controlling environment, which requires two-phase identification on every login. Permission was granted from the Finnish data authority Findata to gain access to the Care Register (permission number: THL/2058/14.02.00/2020), and from Statistics Finland to gain access to the Population Information (TK/380/07.03.00/2020).

Results

There were 71,972 patients (57.7% boys) and 76,785 specialized healthcare ED visits or inpatient admissions for pTBI. Median age at the time of the pTBI was 7 years (interquartile range 3 - 13). The overall incidence of pTBI during the whole period was 332 (CI 330 – 335) per 100,000 person-years. The annual incidence of pTBI was 251 (CI: 241 - 260) per 100,000 in 1998 and 547 (CI: 533 - 561) per 100,000 in 2018, indicating a 118% increase in the incidence (IRR 2.18 CI: 2.09 – 2.28; Fig. 1). The highest recorded yearly incidence of 581 (CI: 567 – 596) per 100,000 was in 2017.

The age-stratified incidence was highest in patients less than one year old (Table 1). Similarly, the increase was highest in this age group (+207%); the incidence was 304 (CI: 262 – 351) in 1998 and 932 (CI: 850 – 1021) in 2018 (IRR 3.07 CI: 2.58 – 3.65) (Table 3). The increase was 116% among children aged 1–6 years (IRR 2.16 CI: 2.01 – 2.32), 85% among children aged 7–12 years (IRR 1.85 CI: 1.70 – 2.01), and 138% among children aged 13–17 years (IRR 2.38 CI: 2.18 – 2.60) (Fig. 2). The gender stratified incidence was higher in boys (Fig. 2), which was seen in all age groups (Table 2).

The most common diagnosis was concussion, and this included 92.1% of the pTBI cases (Table 2 and Fig. 3). The incidence of concussion was 306 (CI: 304 - 309) per 100,000 person years. The incidence of the second most common diagnosis (diffuse brain injury) was 7.6 (CI: 7.3 - 8.0) per 100,000 person years. The increase in incidence over time was highest in concussion diagnoses, while the incidence of all other diagnoses remained fairly similar throughout the study period (Appendix 1). The increase in concussion diagnoses was most notable around the year 2010 and thereafter.

The incidence of inpatient admissions for pTBI was 123 (CI: 117 – 129) in 1998 and 188 (CI: 180 – 197) in 2018, indicating a 53% increase (IRR 1.53 CI 1.43 – 1.64). The incidence of patients with pTBIs that were discharged directly from the ED was 155 (CI: 148 – 162) in 1998 and 410 (CI: 398 – 423) in 2018. The increase in the incidence was 161% (IRR 2.61 CI: 2.51 – 2.81). There was a clear change in the incidence of patients starting in 2010 that was seen more prominently in patients being discharged directly from the ED (Fig. 4). Those patients admitted to inpatient units had higher proportions of fractures than those discharged from the ED (Table 3).

Discussion

The incidence of pTBI increased substantially in Finland from 1998 to 2018. This increase was the mostly the result of documented mild injuries (concussions), but inpatient admissions for pTBI also increased by more than 50%. The increasing incidence was observed in both boys and girls and in all age groups. The incidence was higher among boys in all age groups. The incidences of

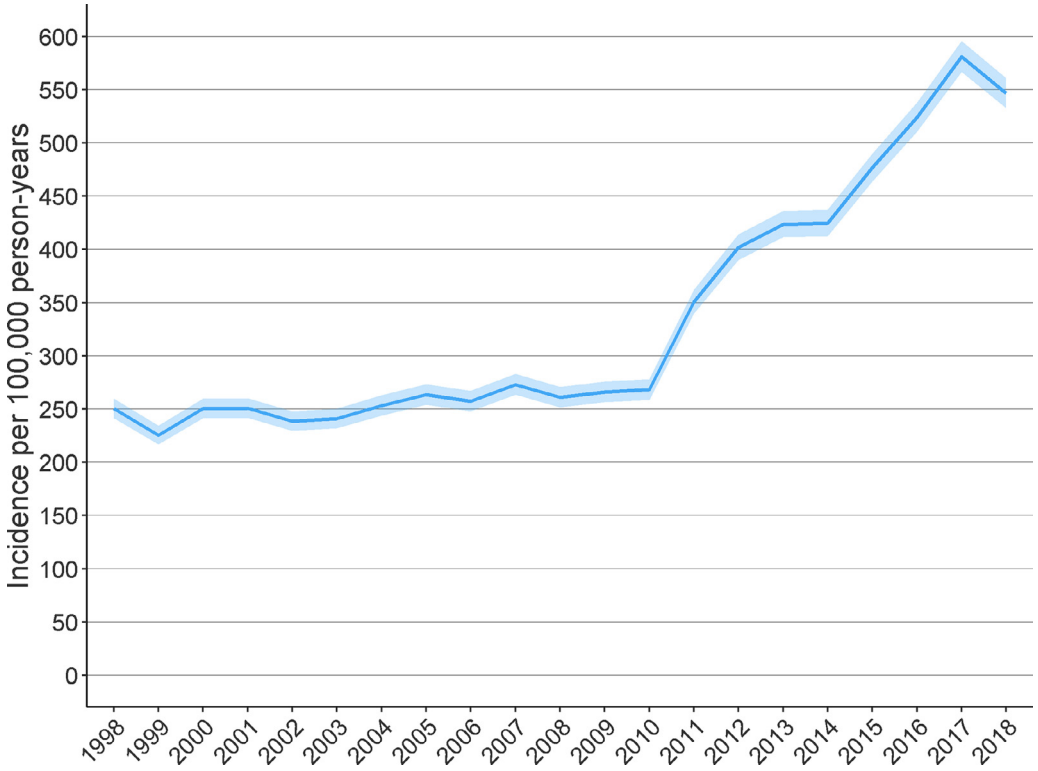

Fig. 1. The yearly incidence with 95% confidence intervals of pediatric traumatic brain injury in specialized healthcare per 100,000 person-years in Finland from 1998 to 2018.

Table 1
Cumulative gender and age-stratified incidence per 100,000 person-years of pediatric traumatic brain injury in Finland from 1998 to 2018.

	Total				Boys				Girls			
	n	Person-years	Incidence	95% CI	n	Person-years	Incidence	95% CI	n	Person-years	Incidence	95% CI
Total	76,785	23,083,153	333	(330 - 335)	44,538	11,790,037	378	(374 - 381)	32,347	11,292,845	286	(283 - 290)
<1 years	6127	1201,050	510	(497 - 523)	3221	613,968	525	(507 - 543)	2906	587,081	495	(477 - 513)
1–6 years	28,334	7488,884	378	(374 - 383)	15,556	3826,087	407	(400 - 413)	12,778	3662,797	349	(343 - 355)
7–12 years	21,321	7752,658	275	(271 - 279)	13,677	3958,199	346	(340 - 351)	7644	3794,459	201	(197 - 206)
13–17 years	21,003	6640,560	316	(312 - 321)	12,084	3392,052	356	(350 - 363)	8919	3248,508	275	(269 - 280)

Table 2
International Classification of Diseases-10th Edition (ICD-10) diagnosis code specific incidences per 100,000 person-years with 95% confidence intervals of pediatric traumatic brain injuries in Finland from 1998 to 2018.

ICD-10 code	Diagnosis	N	%	Incidence	95% CI
S06.0	Concussion / Commotio cerebri	70,786	92.1	306	(304 - 309)
S06.1	Traumatic cerebral edema	210	0.3	0.9	(0.8 - 1.0)
S06.2	Diffuse brain injury	1757	2.3	7.6	(7.3 - 8.0)
S06.3	Focal brain injury	1173	1.5	5.1	(4.8 - 5.4)
S06.4	Epidural hemorrhage	401	0.5	1.7	(1.6 - 1.9)
S06.5	Traumatic subdural hemorrhage	818	1.1	3.5	(3.3 - 3.8)
S06.6	Traumatic subarachnoid hemorrhage	414	0.5	1.8	(1.6 - 2.0)
S06.7	Intracranial injury with prolonged coma	59	0.1	0.3	(0.2 - 0.3)
S06.9	Intracranial injury, unspecified	1167	1.5	5.1	(4.8 - 5.6)

other TBI diagnoses, such as diffuse brain injury and hemorrhages, have not been increasing.

Compared to previously published studies, we found that the incidences of pTBI were higher among boys in all age groups. In the past, this gender difference has been reported to begin to increase after three years of age, mostly due to behavioral characteristics (more risk taking), more contact sports, and light vehicle injuries [3]. However, some studies have reported that male infants are more intensive in playing and movement, although there is no difference in motoric skills between sexes in infancy [17,18] and this intensity could partially explain their greater pTBI rates. Unintentional fall injuries are more common in male infants [19,20], and injury related mortality is higher in male infants [21,22]. Previous literature has reported that the majority of the severe pTBI cases in infants are due to abuse and that the incidence of abusive head injuries has increased, at least in the USA [23,24]. It should be examined in the future whether male infants may have increased risk for abusive injuries or whether this finding is due to other factors. There are several possible reasons why the incidence rates for concussions have increased dramatically since 2010. First, there have been structural changes in the Finnish healthcare system with centralization of EDs. Previously many small towns had their own

Fig. 2. Age and gender stratified yearly incidences per 100,000 person-years with 95% confidence intervals of pediatric traumatic brain injury in Finland from 1998 to 2018.

Table 3
Co-occurring fracturs in pTBI patients discharged from emergency departments and those admitted as inpatients.

	Inpatient admission		Discharged from the ED	
	n	%	n	%
Total	31,941		52,645	
No other injury (fracture)	29,943	93.7	51,613	98.0
Skull fracture	801	2.5	402	0.8
Upper extremity fracture	686	2.2	398	0.8
Lower extremity fracture	275	0.9	128	0.2
Spine or pelvic fracture	236	0.7	104	0.2

primary care facilities that operated continuously (7 days per week and overnight), but these were closed during the 2010s and the patients were guided to larger specialized ED units. This has led to administrative changes in coding and reporting of injuries because primary care facilities do not report to the Care register and bigger centralized ED's (specialized healthcare units) report all visits to the Care register. Second, greater education and awareness of mild TBI/concussion among physicians has likely resulted in more diagnoses as Finland published a current care practice guideline on TBI in December 2008. A similar increase and timing in the TBI incidence trend was observed in a recent Finnish study on young adults, which indicates that this change is not only seen in children [25]. Furthermore, two major studies on pTBI and imaging rules were published in 2009 and 2010 which may have influenced the practices in Finland and led to increased admission to ED's from primary care [26,27]. Finally, public awareness of, and concern about, concussion and mild TBI has increased in Finland over the past decade. This makes it more likely that parents will seek healthcare for their children following a mild head injury. Furthermore, it is possible that some minor head injuries especially in infants are diagnosed as pTBIs because the pTBI diagnosis in infants is difficult and minor head injuries are common [28]. However, it should be noted that it is possible that the incidence of severe pTBI has also increased, but far less than mild pTBI. Although there was practically no increase during the study period in diagnoses other than concussion (S06.0), inpatient admissions for pTBI increased by 53%. This register-based study cannot address, however, whether this increase is a true increase in the rates of more severe injuries, illustrates a lower threshold for inpatient admissions than in the past, or both.

The main strength of our study is the excellent coverage and quality of the included registers [15,29,30]. Finland has used the ICD-10 classification since 1998 and the coding measures have remained similar throughout the study period. Another strength is the universal healthcare in Finland, in which all specialized healthcare visits are free for children. The visit charges are covered by the social insurance system, which is funded by universal social insurance fees, which every Finnish person is obligated to pay based on their annual income [31]. Therefore, our data should have limited patient selection bias due to socioeconomic status and we were able to use the whole pediatric population of Finland as the denominator in the incidence calculations.

This study has limitations and methodological factors that could have influenced the results. First the registry data likely includes diagnostic errors based on the coding from the clinicians treating the patients. Second, we included repeat injuries by classifying visits that were at least one year apart as new injuries. It is possible that some proportion of these injuries may have been longer-term follow-up visits in specialized care, but the focusing on only one pTBI per patient would result in an underestimate of the true injury incidence. Third, we do not have information on injuries that were managed by providers in primary care. Primary care providers treat many children and adolescents with mild injuries, and thus the rate of milder injuries presented in this study is likely an underestimation of the true incidence. Moreover, we could not examine whether changes in incidence were related to specific mechanisms of injury because this information was not

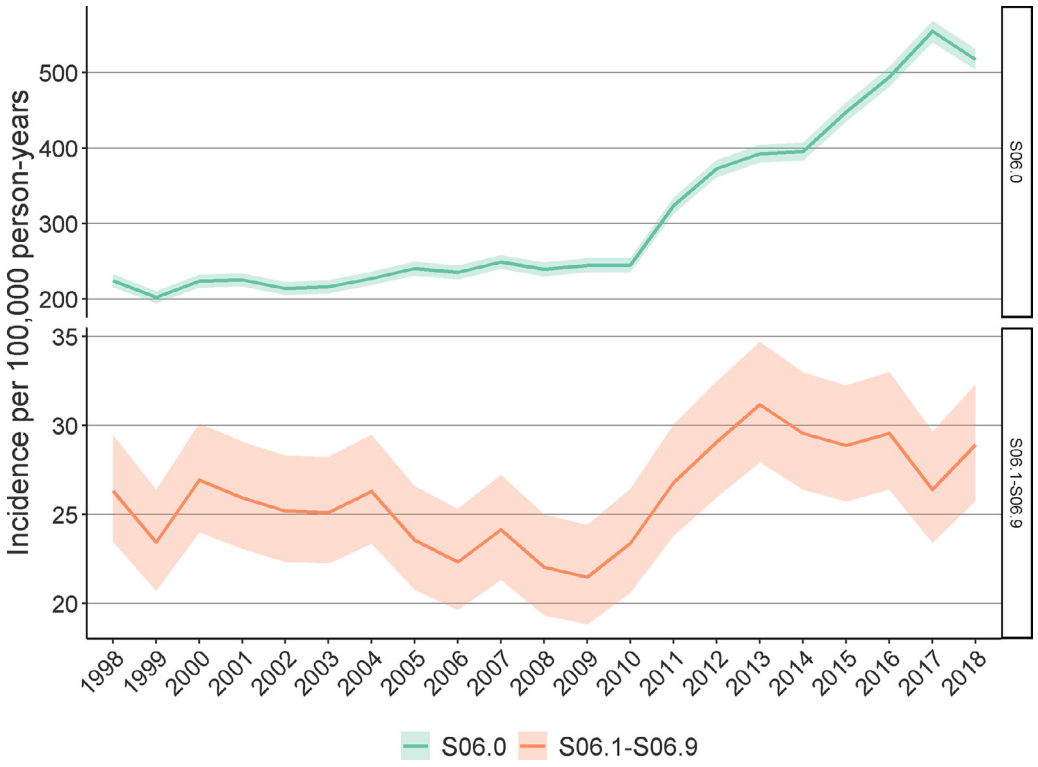

Fig. 3. Diagnosis-stratified yearly incidences with 95% confidence intervals per 100,000 person-years of pediatric traumatic brain injury in Finland from 1998 to 2018. Note: S06.0 = Concussion / Commotio cerebri, S06.1-S06.9 = All other diagnoses (see Table 2).

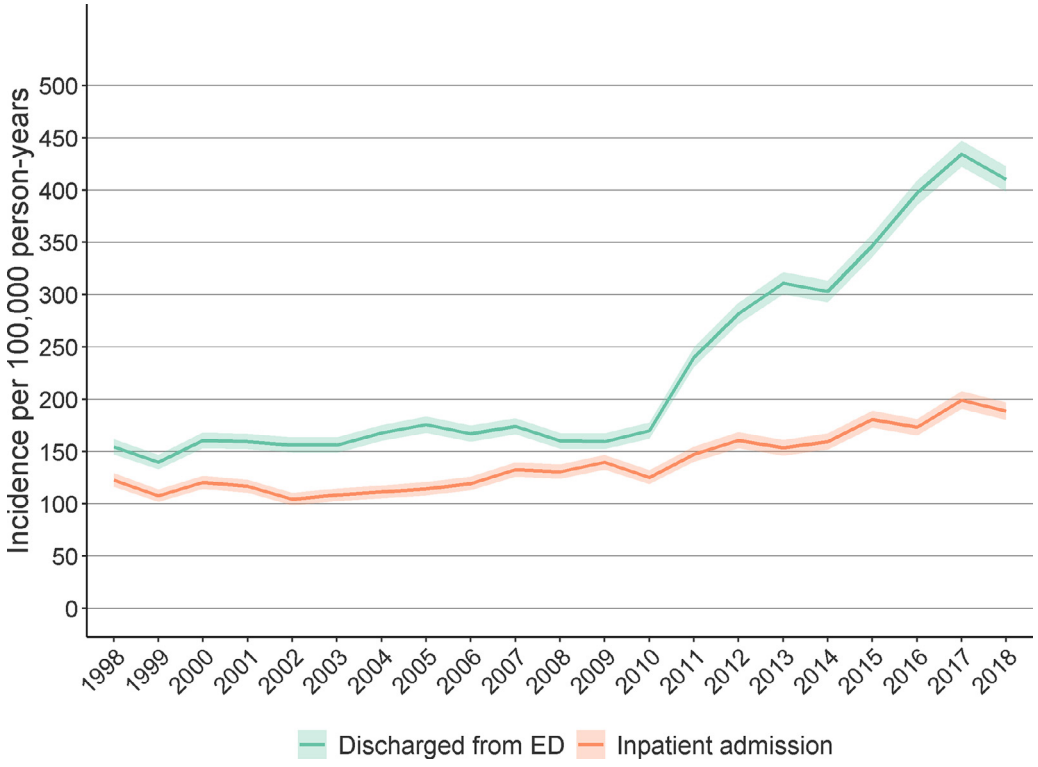

Fig. 4. Incidence of ED visits and inpatient admissions due to pediatric traumatic brain injuries per 100,000 person-years with 95% confidence intervals in Finland in 1998 - 2018. Inpatient admissions mean that at least one night was spent in the hospital. Discharged from emergency department, that the patient was not admitted to ward.

available. We also did not have access to demographic characteristics of the children and families, such as parental education or socioeconomic status. The register also does not include Glasgow Coma Scale ratings, or other severity indicators such as duration of posttraumatic amnesia, or whether the patient was brought by ambulance or parents to the ED.

Future research could examine longitudinal changes in the use of neuroimaging in Finland to determine if the use of imaging is associated with variations in the incidence of pTBI. Finland has undergone a centralization of EDs, which has now ended, so future research can determine whether the incidence rates stabilize. The incidence of neurosurgery for pTBI and short-, medium-, and long-term clinical outcomes of patients with pTBIs can be addressed in future studies. Moreover, short-, medium-, and long-term mortality following pTBI can be examined through future studies.

Author contributions

IK and VM had the original idea. IK, VP and VM gathered the data. VP analyzed the data with IK. VP was in charge of the visualization and GI provided the ideas for figures with IK. VM provided resources and supervised the project with TL. GI, HI, TL provided clinical expertise. IK wrote the initial draft. All authors participated in critical revisions. All authors have approved the final version to be submitted.

Data availability statement

Due to Finnish law regarding secondary use of routinely collected patient information, these data cannot be shared. Currently, it is not possible for researchers living outside of Finland to gain access to Finnish register data.

Funding

This study has received research funding from Maire Taponen's Foundation, Sohlbergs Foundation, and Yrjö Jahnsson's Foundation.

Conclusions

In conclusion, we report a dramatic increase in the annual incidence of diagnosed pTBI in Finland, most notable since 2010. The increase was driven mostly by documented mild TBIs/concussions, especially in infants and young children—but in all ages. The increase likely reflects structural changes to the Finnish healthcare system, but also greater knowledge, awareness, and concern about mild injuries amongst parents, extended families, adolescents, and health care providers.

Declaration of Competing Interest

Grant Iverson, Ph.D. serves as a scientific advisor for NanoDX®, Sway Operations, LLC, and Highmark, Inc. He has a clinical and consulting practice in forensic neuropsychology, including expert testimony, involving individuals who have sustained mild TBIs. He has received past research funding from several test publishing companies, including ImPACT Applications, Inc., CNS Vital Signs, and Psychological Assessment Resources (PAR, Inc.). He acknowledges unrestricted philanthropic support from ImPACT Applications, Inc., the Mooney-Reed Charitable Foundation, the National Rugby League, and the Spaulding Research Institute. None of the above entities were involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication. Teemu Luoto has received speaker's fees from Orion Corporation, Novartis Finland, and the Finnish Medical Society Duodecim. Teemu Luoto has also accepted research grants from the Finnish Brain Foundation sr, the Emil Aaltonen Foundation sr, the Maire Taponen Foundation, the Science Fund of the City of Tampere, and the Finnish Medical Society Duodecim. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgements

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.12.023.

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