Epidemiology of Traumatic Brain Injury in Children 15 years and younger in South-Eastern Norway in 2015-16. Implications for prevention and follow-up needs.

Abstract:

Objective

This retrospective study aimed to describe the volume, severity, and injury mechanism of all hospital-admitted pediatric traumatic brain injury (pTBI) at Oslo University Hospital (OUH), emphasizing consequences for prevention and factors indicating a need for follow-up programs.

Method

Data were extracted from the OUH Trauma registry on 176 children, 0–15 years old, admitted to OUH in 2015 and 2016 with a pTBI diagnosis. The dataset contains demographic data, injury mechanism, type, and severity (Glasgow coma scale, GCS; abbreviated injury scale, AIS; injury severity score, ISS), ICD-10 diagnosis codes, level of treatment, and destination of discharge.

Results

79.5% had mild, 9% moderate, and 11.4% severe TBI. The incidence of hospital-treated pTBI in Oslo was 29 per 100,000 per year. The boy: girl ratio was 1.9:1, but in the young teenage group (14-15 years), the ratio was 1:1. Intracranial injury (ICI) identified on CT/MRI was associated with extended hospital stays, with a median of 6 days compared to 1 day for patients without ICI. 27% of the patients assessed as mild TBI at admission had ICI. Children below eight years of age had a higher incidence of moderate and severe ICI from trauma (53% v.s. 28% in children ≥ eight years).

Conclusion

The injury characteristics of hospital-treated pTBI are in line with other European countries, but we find the boy-girl ratio different as young teenage girls seem to be catching up with the boys. ICI and length of stay should be considered when deciding which patients need follow-up and rehabilitation.

Keywords:

Head injury

Traumatic brain injury

Pediatric brain injury

Pediatric traumatic brain injury

Intracranial injury

Epidemiology

1 Introduction

Head injuries are the single most common and potentially most severe type of injury sustained by children worldwide [1], and traumatic brain injury (TBI) affects more than three million children every year [2]. Improvement in road and car-safety, mainly in high-income countries, has contributed to a decrease in hospitalized pediatric TBI (pTBI) patients. Still, falling remains the main reason for TBI for the youngest children, while sports accidents and motor vehicle accidents are predominant reasons for injury in older children and adolescents. TBI in children thus causes potentially preventable neurological disabilities [3].

TBI has been defined as an alteration in brain function or other brain pathology evidence, caused by an external force [4]. Traditionally, the severity of TBI is evaluated by the level of unconsciousness at injury time by the Glasgow coma scale (GCS). Mild TBI can be further classified as a complicated (presence of trauma-related intracranial abnormality) or uncomplicated (absence of any traumatic intracranial injury) [5]. The abbreviated injury scale (AIS) can estimate brain injury severity by the grade of anatomic brain injury based on neuroimaging and clinical features [6]. However, the AIS is only occasionally used for the severity designation in epidemiological pTBI studies.

TBI represents a substantial challenge for the health care system due to the heterogeneity in the causes of injury, severity, and prognosis. There is great diversity regarding the outcome, and long-term treatment needs [7,8]. Compared to their adult counterparts, children with TBI warrant particular concern given the developmental consequences of early brain damage [2]. Previous studies have shown that younger age is associated with more severe outcomes following TBI, which is most pronounced for severe injuries [9].

Many studies report a male predominance for children in all age groups above three years of age and a bimodal distribution of pTBI in different age groups, with the most significant injury occurring in the very young and the teenage group [2,10]. Collin et al. refer to a significant gender difference existing from infancy, with male predominance regarding injury mechanism, mortality rates, and lack of use of protective devices [11].

A global overview of pTBI reported a median age of 6.8 years. Mild TBI constituted >80% of the cases, and severe TBI accounted for 3-7%. The mortality rate ranged from 1-7% [2]. The incidence of hospital admitted pTBI patients showed diversity, based on different inclusion of admission criteria. The incidences vary from 12 per 100 000 in Sweden to 70-75 per 100 000 in the United States [2] and in Australia [12]. In a recent European study, the main reason for pTBI admission in the intensive care unit (ICU) was road traffic incidents. Accidental falls were the most frequent cause of injury in the children admitted to a hospital ward [13].

Many studies over the past decade have provided valuable information about the epidemiology, outcome, and health care needs following adult TBI in Norway and formed the basis for improved clinical management and rehabilitation services for adults with TBI [14-16]. Studies by Heskestadet al. and Andelic et al. looked at the TBI incidence for all ages in the Stavanger region (the South-Western part of Norway) in 2009 [17], and hospitalized TBI patients from the capital of Norway, Oslo in 2005/2006, respectively [14]. Few studies have, however, addressed the Norwegian pTBI population. One exception is a study by Olsen et al. [18], which estimated the incidence and mortality of moderate and severe pTBI (71 patients 0-16 years of age) from 2004-2014 for Mid-Norway. The incidence estimates were 2.4 and 2.5 per 100 000 inhabitants for moderate and severe pTBI, respectively.

None of these studies have focused on pTBI of all severity levels. It would be helpful to have updated knowledge about all pTBI related hospitalization to understand the extent of brain injury of all severity levels and identifying the high-risk groups in the child population. Studies from Norway may be of international interest because of a well-organized public trauma system with a highly developed infrastructure enabling pTBI patients to be transferred to the trauma centers for definitive treatment and a publicly funded welfare and -healthcare system. Still, there are deficiencies in the follow-up after hospital care since neurorehabilitation healthcare for children is less developed than the offer for the adult population nationwide. More detailed knowledge of all severity levels of pTBI would help provide an essential indicator of the impact of injuries on hospital resources, thereby enable improved plans for acute and post-acute pTBI care systems.

1.1 Objectives

This study`s main objective was to investigate the volume and burden of hospital-admitted pediatric TBI by describing incidence and injury characteristics, including injury mechanism and distribution of all severity levels of pediatric TBI in the South East region of Norway. Based on previous studies stating that younger age is associated with worse cognitive outcomes following TBI [9,19,] we also explored age effects on injury mechanism and level of intracranial injury (ICI). An additional aim was to assess which factors are associated with the hospitalization duration and a likely need for follow-up programs and rehabilitation.

2 Methods

2.1 Study region

Oslo University Hospital (OUH) is the primary hospital for Oslo's pediatric population and a Trauma Referral Hospital for the South East region of Norway. This region comprises 57 % (2,9 million of the population of Norway [20], and approximately 570 000 children 0-15 years of age [21]. All children residing in Oslo that suffer from a TBI, including those presenting with signs of concussion and clinical indication for computerized tomography (CT) scan or short -time (6- 24 hours) observation, are referred to OUH. Also, patients with TBI in need of neurosurgical evaluation or treatment from the South-Eastern region residing outside of Oslo are referred directly to OUH. Patients with mild TBI residing outside of Oslo are usually admitted to their local hospital for observation.

We had oversight over pTBI of all severity grades for Oslo residents, and the incidence is therefore estimated separately for Oslo.

2.2 Data source

Data were extracted from the Trauma registry at OUH (TR-OUS) from January 2015 through December 2016. TR-OUS includes all patients admitted with all traumas that trigger the trauma team activation or have an Injury Severity Score (ISS) of 9 or higher (moderate to severe injuries). A certified AIS specialist with access to medical records has manually coded the AIS-08 scores.

2.2.1 *Inclusion*

The dataset included hospital-admitted pTBI at OUH from 1 January 2015 to 31 December 2016, selected by AIS 2008: AIS head ≥ 1 and age group 0 years up to and including 15 years of age. AIS head ≥ 1 extracts all patients registered with a head injury, regardless of GCS and ICD-10 diagnosis codes.

The extracted data set contains age, sex, municipality, date and time of accident and discharge, location of the injury, injury mechanism and severity (GCS [6], AIS [6], ISS [6]), all diagnosis codes and procedure codes (ICD-10) during the hospital stay, level of hospital treatment and transition of care (admission to ICU or ward), length of hospital stay and destination of discharge.

GCS is based on clinical examination bedside: assessing best eye, verbal, and motor response. GCS is scaled by the following classification: mild (GCS 13-15), moderate (GCS 9-12), and severe TBI (GCS 3-8) [6]. The GCS value was recorded at arrival time in the hospital, mostly at triage in the emergency department. Pediatric GCS was used for infants and toddlers [22].

AIS head is an anatomic brain injury severity score based on CT or magnetic resonance imaging (MRI), operative, and autopsy findings. The score can not be calculated at the scene of trauma and requires a manual review of the patient`s medical record. AIS code is by description divided in 1:minor, 2: moderate, 3: serious, 4: severe, 5: critical, 6: maximal (currently untreatable) [23]. In the literature, grade 1-2 has been categorized as mild TBI, 3-4 as moderate, and 5-6 as severe TBI [6].

The AIS-08 scores define cerebral concussion grade 1 as mild concussion, no loss of consciousness (LOC), and grade 2 concussion with brief (observed) LOC. All intracranial injury is categorized in grade 3 and above, except tiny brain contusions and lacerations and intracranial extracerebral hemorrhage (grade 2).

Overall injury severity was assessed ISS. The ISS severity is categorized as <9 (minor), 9-15 (serious), 16-24 (severe), 25-75 (critical). ISS is calculated by taking the highest AIS from the three most severely injured body regions, square each, and add these numbers [6]. There are six body regions in all (head, face, thorax, abdomen, extremities, and external/other). There is one exception: If AIS is 6, the number is not squared but gives ISS 75 points directly.

Traditionally the GCS [6] defines the injury severity evaluated by the level of unconsciousness at injury time or later. Mild TBI has been classified as a complicated mild TBI (presence of trauma-related intracranial abnormality) or uncomplicated (absence of any traumatic intracranial injury) [5]. AIS head is a consensus-derived, global severity scoring system for assessing TBI severity, based on medical records and radiology. AIS head can be used to approximate the definition of brain injury severity [3]. ISS is an internationally recognized anatomical scoring system for overall trauma severity [24]. Brown et al. found that the ISS is less predictive of mortality in children than in adults, and that level of AIS head is most important regarding predicting severe outcomes and mortality in children [24]. A comparison of AIS head and GCS scores as indicators of brain injury severity in retrospective data has shown that AIS and GCS are more highly inter-correlated when a brain injury is severe, but in mild and moderate cases of brain injury, AIS is less predictive of the GCS value [6].

2.2.2 Statistical analysis

The incidence of hospitalized pTBI patients residing in Oslo was calculated based on information from Statistic Norway [25] on the pediatric population of Oslo in 2015/2016: 234.471 people aged 0-15 years as the denominator, and new cases of pTBI registered in TR-OUS, as the numerator.

The chi-squared test was used to compare the boy: girl ratio in each of the other age groups to the oldest group. Medians and interquartile range (IQR) were used in Table 1 to describe mild, moderate, and severe pTBI by age at injury, and describe GCS, AIS head, ISS, and hospital stay in Table 2.

When comparing GCS and AIS head scores combined in the youngest (0-7 years of age) to the eldest (8-15 years of age) group, we used the Mann-Whitney U test (Table 3). We used the Chi-Square test when analyzing combined values for the site of injury, CT at admission, and CT/MRI findings for the youngest and eldest group.

The Mann-Whitney U test was used to compare the length of hospital stay for mild TBI with or without CT/MRI pathology.

All statistical analyses were performed with IBM SPSS Statistics, version 26 (IBM Corp.Armonk, N.Y., USA, 2019).

3. Results

The Trauma Registry recorded 306 patients aged 0-15 years in 2015 and 2016. Approximately one-third of these, i.e., 90 (29%) and 86 (28%), respectively, were admitted with a head injury had a head injury (AIS head ≥ 1). Of these 176 children, two patients had AIS = 1 with scalp injury only.

The 176 children were classified by GCS at admission, and 140 (79.5%) had a mild TBI (GCS 13-15). Of the mild TBI group, 27% had complicated mild TBI (ICI on MRI), and 14% had skull fractures (Figure 1). 16 (9%) had a moderate TBI (GCS 9-12) and 20 (11.4%) had severe TBI (GCS 3-8). Three patients (1.7%) died within 24 hours after admission.

When classified by AIS head, 108 (61%) had mild TBI (AIS head ≤ 2), and 68 patients (39%), i.e., 19% more than bases on GCS), had moderate and severe TBI (AIS head ≥ 3). The median age was 10 years (CI ± 0.73).

3.1 Incidence

Of the 176 patients, 68 (38.6%) were residents of Oslo. 93 patients (52.8%) were admitted from other parts of the South-Eastern health region of Norway, and 15 patients (8.5%) were either from elsewhere in Norway or from other countries.

The incidence of hospitalized patients with pTBI residing in Oslo 2015/16 was 29 per 100 000 per year. For mild pTBI, the incidence assessed by GCS 13-15 (n=60) was 25.6 pr 100 000 per year, and by AIS head < 3 (n = 51) was 21.8 per100 000 per year. For moderate and severe pTBI evaluated by GCS ≤12 (n = 8), the incidence was 3.4 per 100 000 per year, while assessed by AIS head ≥ 3 (n = 17), the incidence was 7.3 per 100 000 per year.

3.2 Boy: girl ratio

The overall boy: girl ratio in this sample was 1.9:1. The ratio was approximately 2.4:1 in all age groups other than the oldest group (14-15 years), where the ratio was 1:1. The lack of male predominance in the teenage group (14-15 years of age) was specific for this age group, as the ratio differed significantly from all other groups (Table 1).

Table 1. Boy:girl ratio by age groups

Age (years)	Total number (boys/girls)	Boy: Girl ratio	p value
0-4	41 (29/12)	2.4:1	0.049
5-9	45 (32/13)	2.5:1	0.039
10-13	44 (31/13)	2.4:1	0.048
14-15	46 (23/23)	1:1 (ref)	

The p-value for chi-square tests comparing the boy: girl ratio of each of the younger groups to the 14-15 year group (ref = reference group)

3.3 Injury Characteristics

3.3.1 GCS and AIS

When divided into severity levels by GCS evaluation at admission, all groups had a proportion of patients with ICI and patients without any neuroradiological findings. Even in the severe TBI group, 20% of patients were without ICI. In the group defined as mild TBI at admission, 27% had ICI on MRI, and 14% had isolated fractures in the skull or the facial bones (Figure 1)

Twenty-eight of the patients had no CT scan at arrival. Of these, 25 patients had an MRI performed later during their hospitalization. Twenty-one of these had mild TBI assessed by GCS (13-15), of which MRI scans showed pathology corresponding to moderate TBI as categorized by AIS head (score 3 or 4) in 16 patients, and severe TBI in two patients (AIS head 5) (Table 3). Among these were four of five toddlers exposed to intentional injury (Table 2).

Table 2. Demographic and injury characteristics in the sample according to injury severity estimated at admission

Assessed by GCS:	**Mild TBI** n = 140 Median [IQR]	**Moderate TBI** n = 16 Median [IQR]	**Severe TBI** n = 20 Median [IQR]
Age at injury (years)	10 [5.0, 14.0]	10 [5.0, 13.5]	8 [4.25, 13.25]
Gender (boy / girl)	93 / 47	10 / 6	12 / 8

GCS	15 [14.0, 15.0]	11.5 [10.0, 12.0]	6 [4.25, 7.0]
AIS head	2.0 [1.0, 3.0]	2.5 [1.0, 3.0]	5 [3.0, 5.0]
ISS	5 [2.0, 10.0]	7 [1.25, 21.25]	25 [9.0, 26.0]
Hospital stay (days)	1 [1.0, 4.0]	3 [1.0, 15.75]	10 [2.0, 30.75]
Site of injury (n)			
Domestic	29	2	4
Indoors	9	0	2
Outdoors	102	14	14
Mechanism of injury (n)			
Traffic accident	43	8	4
Fall	68	7	12
Violence	8	0	1
Other	21	1	3
Discharge (n)			
Home	131	13	11
Rehab unit	1	3	5
Other care	8	0	1
Dead	0	0	3

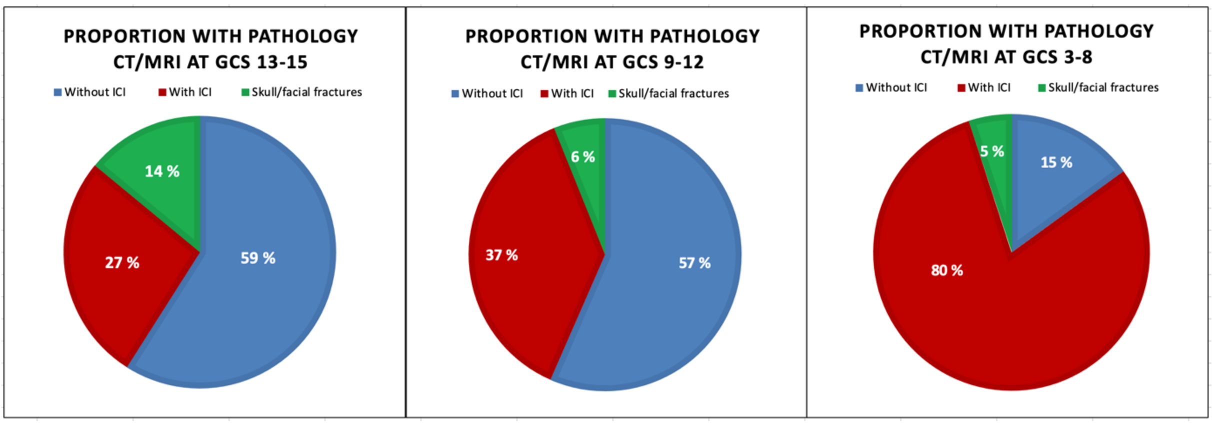
GCS = Glasgow coma scale, AIS = abbreviated injury scale

rehab unit = rehabilitation

other care = primary hospital, alternative care, dead

other mechanisms = accidents in sports, a massive object falling over the child, sledding accidents.

Fig. 1. Neuroradiology in all TBI severity levels on CT or MRI.



The proportion of neuroradiological findings of ICI v.s. skull/facial fractures v.s. no intracranial pathology at three severity levels according to GCS.

(ICI = intracranial injury, CT = computerized tomography, MRI = magnetic resonance imaging)

3.3.2 Mechanism of injury

The leading cause of TBI among children admitted to OUH was falls (49%).
Transportation accidents contributed to 31% of pTBI, mainly due to falling off a bike or being hit by a car or bicycle as a pedestrian. The violence group consisted of children 0-2 years old exposed to intentional injury and boys between 9 and 15 years of age assaulted by peers (Table 3).

Table 3. Injury characteristics of the youngest versus the oldest groups

	0–7 years (n = 74)	**8–15 years (n = 102)**	**p value**
GCS 13-15	57 (77%)	83 (81.4%)	0.282
GCS 9-12	8 (11%)	8 (7.8%)	
GCS 3-8	9 (12%)	11(10.8%)	
AIS head 1-2	35 (47%)	73 (72%)	0.002
AIS head 3-4	30 (41%)	21 (20.5%)	
AIS head 5-6	9 (12%)	8 (7.8%)	
CT at admission			
Normal	31 (42%)	65 (64%)	0.059
Intracranial injury	25 (34%)	27 (26%)	
CT at admission not performed	18 (24%)	10 (10%)	0.009
CT/MRI findings			
Normal	27 (36%)	65 (63%)	< 0.001
Intracranial injury	47 (63%)	34 (33%)	
Neuroimaging not performed	0	3 (3%)	---
Site of injury			
Domestic	27 (36.5%)	8 (7.8%)	<0.001
Indoors	2 (3%)	9 (8.8%)	
Outdoors	45(60.8%)	85 (83.3%)	
Mechanism of injury			
Traffic accident, n = 55 (31%)	17 (23%)	38 (37%)	
Pedestrian hit by car/bike/bus	6	8	
Biker* hit by car/bus	1	5	
Riding a bike*	4	21	
Passenger	6	4	
Fall, n = 87 (49%)	42 (57%)	44 (43%)	
Sport/leisure	0	22	

Domestic	15	5
Outdoors	12	9
>2 meters	15	8
Violence, n = 9 (5%)	5 (7%)	4 (4%)
Other mechanism, n = 26 (15%)	10 (14%)	16 (16%)
Accidents sport	1	6
Object falling over	2	4
Blunt trauma during sport/play	1	4
Sledding accidents	4	2
Penetrating injury	2	0
Discharged to		
Home	67 (91%)	88 (86%)
Other hospitals	3	4
Rehab	1	8
Other care	2	0
Dead	1	2

GCS = Glasgow coma scale, AIS = abbreviated injury scale; p-value for 0–7 v.s. 8–15 from the Mann-Whitney U test (combined analyzes of GCS and AIS head) and the chi-square test (combined analyzes for the site of injury, CT at admission, and CT/MR findings).

3.3.3 Mechanism causing the most severe TBIs

Of the total patients, 174 had blunt head traumas, while only two had penetrating head trauma. Fall was a leading contributor to severe injuries (Table 2).

To estimate the mechanisms leading to the most severe injuries, we looked at the 17 patients with brain injury classified to 5-6 (critical, maximal) as assessed by AIS head (Table 3). The group had GCS ranking from 3-15, including 11 patients with GCS 3-8 (severe). ISS scores varied from 25-75 (severe, mainly multi-trauma patients), with a mean of 32,5.

Transport accidents (n = 5) leading to severe TBI were high energy trauma involving car accidents (passenger or hit by a car), horseback riding, skateboard, and electric bicycle accidents. Falls (n = 9) were divided into being caused by fall from over 2 m or lower falls with an impact on hard surfaces in the age group 2-8 years, and accidents with falls in alpine slopes for the teenagers. Other reasons (n = 3) were fatal accidents during play and intentional injury (Table 3).

3.3.4 Length of stay and discharge

Of the 176 TBI patients, three died within 24 hours after admission. Length of stay (LOS) varied from 0 – 84 days, with 103 patients (59%) were discharged within the second day. LOS was over 7 days for 18 % of the patients. The mean LOS for all 176 patients was 5,8 days (SD 10,7), with a median of 2 days (CI ± 1.6).

Patients with ICI, as demonstrated by CT or MRI-scans, had a median LOS of 6 days, regardless of injury severity. Even children with mild TBI, estimated by GCS at admission, but with confirmed ICI (complicated mild TBI), had more prolonged hospital stays compared to those with mild TBI with normal neuroimaging (uncomplicated mild TBI) ($p < 0.001$). The median LOS was 4 days (IQR 2.5-7.5) for the patients with pathology and 1 day (IQR 1.0-1.0) for the ones without pathology (Figure 2).

The majority of the patients, 155 (89%), were discharged to their homes. Nine patients (5%) were transferred to a specialized rehabilitation unit with services for children. Due to additional orthopedic injuries or familial considerations, seven patients (4%) were transferred to their local hospital. (Table 3).

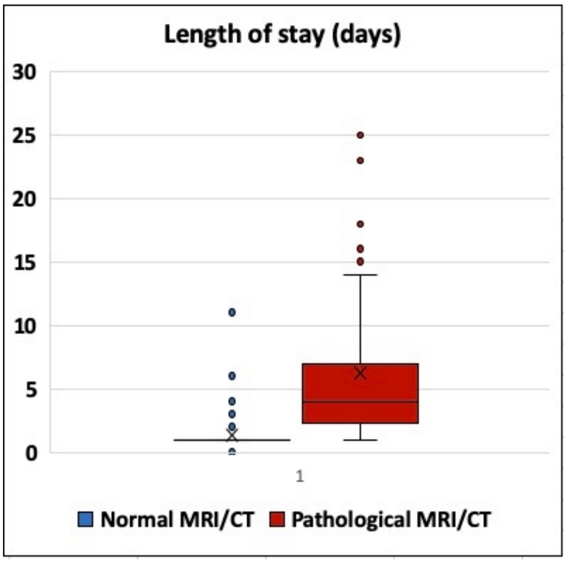


Fig. 2. Length of stay by intracranial injury in mild pTBI.

Mann-Whitney U test was used to compare the length of hospital stay in days for mild pTBI with or without MRI/CT pathology. A horizontal line represents the Median. The Mean is represented by x. MRI = magnetic resonance imaging, CT = computerized tomography.

3.4 Difference between the youngest and eldest group

The proportion of moderate and severe TBI (AIS ≥ 3) in the youngest group was 53% compared to 28% in the oldest group (Table 3). In all age groups, up to 13 years, boys were more exposed to head injuries regardless of injury mechanisms. However, in the adolescent group (14-15 years of age), there was no difference between the genders (Table 1).

4 Discussion

4.1 Incidence

The incidence of pTBI in Oslo was comparable with other Scandinavian studies [2,18,26]. Our results may reflect that the Scandinavian focus on road safety and the use of safety equipment has resulted in lower incidences than other parts of the world [2]. Still, known preventable mechanism of injury contributed to severe pTBI.

4.2 Boy: girl ratio

A large body of studies has described a male predominance for pTBI. The European study of TBI patients 0-18 years old included patients from Norway, found a boy: girl ratio of 1,7:1[13]. Finland reported a male predomination of 1.5:1 in 2012 in patients under 18 years of age [26]. We found that the boy-girl ratio in our sample was 1.9:1. In 2005-2006, male predomination was 1.2:1 among children residing in Oslo, and the difference between the genders was most prominent in the young teenage group (10-14 years of age) [14].

In our sample 10 years later, the pattern is different and indicates that young teenage girls might be catching up with the boys in exposure to TBI. The injury mechanisms may suggest that young adolescent girls were engaged in high energy activities more in line with teenage boys in our study. The teenage girls had more falls and got more head injuries in a contact sport, the latter in line with a recently published review by Arambra et al. [10]. However, they were less involved in transport accidents (notably bicycle) than adolescent boys. Only girls acquired their head injury by horseback riding, and only teenage boys were involved in violent episodes. This gender difference in injury mechanism resembles Collin et al.´s findings, but the changes in risk-taking behavior in young teenaged girls indicate that we need to change focus on adolescent groups at risk of TBI [11].

Our study had a slightly higher male predominance for the children under 13 years of age than reported in other European studies. Many studies report a bimodal distribution of pTBI in different age groups, with the most significant injury occurring in the very young and teenage groups [2,10]. In our study, the distribution is steadily increasing in frequency of pTBI from 2 years old to the teenagers, mainly contributed to boys with TBI from falls and traffic accidents.

4.3 Severity grades:

Our results are in line with existing literature, with 80% mild TBI assessed by GCS [2]. The occurrence of complicated mild TBI and skull fractures was slightly higher than referred by Hansen et al. [5]. The proportion of severe injuries was slightly higher since OUH is a trauma referral center; thus, more severe TBI patients were transferred to OUH from other hospitals in the region.

Severity distribution was somewhat different if assessed by AIS head, characterizing 61% as mild TBI (AIS head 1-2). The severe TBI assessment was similar using GCS and AIS head (11.4% v.s. 10%), confirming that these instruments provide more similar results for severe brain injuries [6].

Thirty-three (19%) of the patients had multi-trauma injuries (ISS $\geq$ 16), probably impacting the length of hospital stay, especially on the most extensive admissions. The proportion of multi-trauma is relatively lower than stated in other studies [24,27].

4.4 Differences between the youngest and eldest group

The severity grade estimated by the AIS head in the current sample was significantly different between the youngest group (0-7 years) and the oldest group (8-15 years), with a higher rate of moderate and severe ICI in the youngest group. These findings indicate that younger children are prone to more severe structural injuries by trauma to the head. This result points to a particular need for radiological follow-up for this group.

The children under 7 years of age were injured primarily by falls from heights, the group under four years, mainly at home and indoors. The more independent mobile group (5-7 years) were roadside pedestrians or passengers in road accidents, coinciding with findings in other studies [3,13,28]. Fall in sport or leisure activities is only occurring in the older group (Table 3), with alpine accidents being a significant contributor.

4.5 Which TBI patients require admission, and who need follow-up?

Pediatric patients with severe TBI are all admitted for observation and treatment, but only some of them have established rehabilitation plans at discharge. One-fifth (20%) of our sample was classified as moderate and severe TBI at admission. Of these, only a minority were transferred to a rehabilitation unit for children. Of the group of mild TBI classified by GCS at admission, 27% had ICI confirmed during admission, for some changing the severity grade assessment. One in this group was considered to need specialized neurorehabilitation.

In Norway, neurorehabilitation in health care for children is less developed than in the adult population, especially for children under 6 years of age, which is probably a contributing factor in the current discharge practices. Besides, there might be less attention to a possible need for follow-up or rehabilitation for pediatric patients, especially for the youngest age group. There is a need for future studies surveying uncovered rehabilitation needs for the pediatric TBI group so that the healthcare services can be adjusted accordingly.

The Scandinavian guidelines for mild and moderate pTBI [29] recommend that children with mild TBI, but high-risk trauma, should be admitted for observation regardless of a normal head CT. Children under 1 year of age should be admitted after head injury regardless of symptoms [29]. A large number of pTBI patients observed in the hospital will, therefore, have mild and moderate TBIs. The challenge is to decide, based on the right criteria, which patients would benefit from follow-up after discharge.

4.5.1. Assessment of need for follow-up

There has been a discussion regarding the use of CT scans for the age group 0-4 years, as they are more sensitive to radiation-induced malignancies [30]. As a result, there has been a focus on limiting CT scans for the youngest patients. Instead, we are observing them as an in-patient [29]. In this sample, a group of patients with no CT scan at admission had later findings of moderate to severe ICI on MRI, including 30% of the patients in the 1-4 year age group, compared to 7% for the children > 9 years old. This probably indicates a more restrictive approach in the use of CT scans for the toddlers in line with the Scandinavian guidelines. Consequently, this may lead to overlooking intracranial injuries of significance. Of note, among the toddlers exposed to child abuse, the majority had high GCS scores at admission but moderate and severe ICI on neuroradiology.

This study's results indicate that GCS at admission alone does not point to which patient requires prolonged observation or follow-up. The course and duration of head injury-related symptoms, such as headaches, fatigue, light and sound sensitivity, or post-traumatic amnesia symptoms during the hospital stay, should also be considered. pTBI of all severity grades with pathology on MRI stayed for 2 days or more. This may suggest that patients categorized with GCS 13-15 at admission with symptoms lasting more than 48 hours may need neuroimaging to assess a potential ICI.

The findings also suggest that the youngest age group was more prone to more severe ICI by head trauma. Several studies show that a proportion of patients with mild TBI do not recover without long-term problems [8] and may benefit from follow-up and plans for a stepwise return to school and sports. Furthermore, a recent study showed that early psychoeducation might be beneficial for children with mTBI [31]

Therefore, it might be advisable to have a continuous rehabilitation pathway for pediatric patients with TBI adjusted to provide individualized treatment and follow-up for all pediatric patients with ICI or prolonged symptoms following TBI of all severity grades.

4.6 Strengths and limitations

We consider using the Trauma Registry (TR-OUS) data to be a strength of this study. TR-OUS is the most systematic and consistent source of information on patients with TBI, systematizing information from medical records, and neuroimaging prospectively. We chose AIS head as selection criteria since ICD10 codes, in clinical care and especially emergency departments, is considered to be an inaccurate way of defining TBI severity [3]. This inclusion strategy, including AIS head ≥ 1, has made it likely that almost all pTBI admitted to the hospital were included. Thus, we believe we have a representative sample regarding all severity levels of pTBI from Oslo. OUS is the only trauma referral hospital with neurosurgical services in the region for over 50 % of the Norwegian population, and our findings of severe injuries may, therefore, be representative of the most populated part of Norway.

Moreover, at OUH, the admission criteria, triage, and treatment level for pTBI had remained unchanged since the early 2000s, before Andelic et al. conducted their study on a comparable population in 2005-2006 at the OUH. We, therefore, had the opportunity to compare the incidence of pTBI and the male: female ratio with historical data.

A limitation is that we did not have access to information regarding patients age 16-18 years.This made a comparison with other studies for the oldest teenagers difficult. We did not have a register including all patients with mild and possibly also moderate TBI who were admitted at other hospitals in the South-Eastern region of Norway and, therefore, could not indicate the incidence for the whole region. A retrospective design is a limitation, but we find that the Trauma Registry's stringent and unchanged inclusion criteria limit these disadvantages.

5 Conclusion

The incidence of hospital-treated pTBI was low compared to most regions globally, but still, many of the TBIs in childhood may be preventable. We found that the boy: girl ratio has been altered over the past ten years in the South-Eastern region of Norway, suggesting that young teenage girls might be catching up with the boys in TBI exposure. This novel finding highlights that we need to monitor changes in incidences and risk-taking behavior to tailor preventive measures to new social trends.

Children aged seven years old or younger seem to get more severe ICI from trauma to the head and might need a particular focus regarding prevention measures and follow-up. There may also be a reason to maintain and emphasize the discussion on prevention measures for the youngest group. Counseling parents on fall accidents in the newly ambulating small toddlers and road safety may increase awareness of this problem. The severe consequences of abusive head injuries in the youngest also emphasize the importance of preventing child abuse and neglect [32].

The severity of the injury, assessed by GCS and AIS/neuroimaging, combined with the duration of symptoms, must be considered when evaluating which patients need follow-up and rehabilitation. It might be advisable to provide individualized treatment and follow-up for all pediatric patients with ICI or prolonged symptoms following TBI of all severity grades. However, neurorehabilitation healthcare for children is less developed than for the adult population, and sequelae may be overlooked. There is a need for future studies surveying uncovered rehabilitation needs for the pTBI group to adjust the health services as needed.

Highlights:

- Monitoring changes in risk-seeking behavior is significant regarding preventing TBI
- Children under eight years old suffer more severe intracranial injuries (ICI) from TBI
- Follow up is needed for ICI or prolonged symptoms after TBI of all severity grades

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