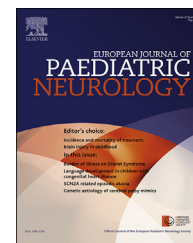




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Original article

Incidence and mortality of moderate and severe traumatic brain injury in children: A ten year population-based cohort study in Norway



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ABSTRACT

Objective: In this study we wanted to estimate population-based rates of incidence and mortality of moderate and severe traumatic brain injury (TBI) in children in one specific region in Norway.

Methods: In the region there are seven acute care hospitals (ACHs) in addition to a Level 1 trauma centre. Of 702 869 inhabitants (2014), 145 395 were children aged 0–16 years. Data were collected during ten years (2004–2014). All children aged 0–16 years with moderate (Glasgow Coma Scale [GCS] score 9–13) or severe (GCS score $\leq$ 8) TBI admitted to the Level 1 trauma centre were prospectively included. Children treated outside the Level 1 trauma centre were retrospectively included from the ACHs. Children who died from TBI pre-hospitally were included from the National Cause of Death Registry. Poisson regression was used to estimate incidence rate ratios (with a 95% confidence interval) comparing age, sex, and time periods.

Results: A total of 71 children with moderate or severe TBI were identified. Crude incidence rates were 2.4 (95% CI 1.7–3.3) for moderate and 2.5 (95% CI 1.8–3.4) for severe TBI per 100

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Mortality	000 person-years (py). Mortality rate from TBI was 1.2 (95% CI 0.7–1.9) per 100 000 py, and
Epidemiology	88% were prehospital deaths.
Epidemiological study	Conclusion: The incidence rates and mortality of moderate and severe TBI were low
Population	compared to international reports. Most likely explained by successful national prevention
Child	of TBI.
Children	© 2019 The Authors. Published by Elsevier Ltd on behalf of European Paediatric Neurology
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1. Introduction

Traumatic brain injury (TBI) in children is a growing global health concern and a major cause of death and disability in children.^{1–4} Mild TBI is the most common type of TBI, and moderate and severe TBI constitute less than 10% of all TBI in children.⁴ Moderate and severe TBI is nonetheless associated with a much higher risk of death or disability and knowledge of their epidemiological characteristics is therefore needed.^{1,5} Despite the large impact that moderate and severe TBI induce in children, the existing reports of incidence and mortality, exclusively of moderate and severe TBI in children, is insufficient. Few studies have reported incidence rates of paediatric moderate and severe TBI separated from mild TBI, and consequently estimates from many studies are heavily influenced by the high frequency of mild TBI.⁴ Furthermore, few studies of incidence have included prehospital deaths in their estimates,^{6–8} which is important as the majority of deaths from TBI in children have been observed to occur pre-hospitally.^{9,10} Currently, both the reported incidence rates and the reported mortalities of moderate and severe TBI in children vary widely - also in studies from high-income countries. Previous reported incidence rates have ranged from 5.9–159 per 100 000 person-years (py)^{6,11–14} for moderate TBI and from 0.8–36 per 100 000 py^{6,11–15} for severe TBI. Methodological differences between the studies may explain some of the wide range, nevertheless there is most likely a true difference in the risk of sustaining a moderate, severe or fatal TBI for children across the world, and across high-income countries. Rigorous epidemiological studies can inform policymakers and contribute with information to reduce the occurrence of TBI in children.

The main aim of this study was to estimate population-based rates of incidence and mortality of moderate and severe TBI in children aged 0–16 years residing in Mid-Norway.

2. Method

2.1. Study region

Mid-Norway consists of both urban and rural areas with seven acute care hospitals (ACHs) in addition to a Level 1 trauma centre; St. Olavs Hospital, Trondheim University Hospital, the only neurosurgical service in the region.¹⁶ Of 702 869 inhabitants (2014), 145 395 (21%) were children aged 0–16 years. The Level 1 trauma centre also serves as the ACH for 306 197

inhabitants (2014), with 62 174 (20%) children aged 0–16 years. All children sustaining a moderate TBI (GCS score 9–13) shall be admitted to hospital, in accordance with the Scandinavian guidelines for initial management of moderate TBI in children.¹⁷ Children sustaining a severe TBI shall according to guidelines, be admitted directly to the Level 1 trauma centre.¹⁶

2.2. Patients

Children aged 0–16 years, residing in Mid-Norway at the time of injury, with moderate (Glasgow Coma Scale [GCS] score 9–13) or severe (GCS score ≤ 8) TBI, were included. We defined paediatric patients as children from birth up to 17.0 years of age, as this is considered the general definition of paediatric patients in Mid-Norway.

2.3. Inclusion procedures

Data were collected from 1st October 2004 to 30th September 2014 from three different sources: 1) The Level 1 trauma centre, 2) The ACHs and 3) The National Cause of Death Registry. To yield accurate population-based incidence rates for Mid-Norway, children residing outside Mid-Norway were excluded.

2.3.1. Inclusion from the Level 1 trauma centre

All children who were treated at the Level 1 trauma centre with moderate or severe TBI were consecutively registered on admission and subsequently enrolled. To ensure that no patients were missed, the hospital trauma registry at the Level 1 trauma centre was continuously checked for TBI patients.

2.3.2. Inclusion from the acute care hospitals

To provide population-based data, we supplemented the hospital-based data from the Level 1 trauma centre with data from the ACHs. Medical records of all children admitted to one of the seven ACHs with ICD-10 codes S06.1 to S09.9 were retrospectively reviewed by MO and TS. All children with moderate or severe TBI, not already prospectively included from the Level 1 trauma centre, were thereby included.

2.3.3. National Cause of Death Registry

We retrieved information from the nation-wide Cause of Death Registry on all TBI related deaths in children residing in Mid-Norway. Deaths of children residing in Mid-Norway, who died outside the region, were also recorded. The search used the following ICD-10 codes to define TBI: S00 to S09 and T00.0, T01.0, T02.0, T03.0, T04.0 and T06.0. Medical records were

checked to ensure that only children with TBI as the primary cause of death were included. Prehospital deaths included children who died at the scene of injury and during transport to the hospital, and all were registered as severe TBI.

2.4. Study variables

Injury severity was measured by GCS score at admission. In patients who deteriorated, the lowest GCS score was registered. In case of prehospital intubation, GCS score was registered by prehospital physician before intubation. All patients in this study had a GCS score ≤ 13 that could not be better explained by extracranial injuries. External cause of TBI were categorized as road traffic accident (RTA), fall, violence, gunshot, self-harm and other. To determine the probability of physical abuse as the external cause of TBI, all medical records in children aged 0–2 years were retrospectively checked by the first author (MO). Cases where clinicians reported possible abuse to the child welfare authorities were separately marked in Table 1.

2.5. Ethics

The study was approved by the Regional Committee for Medical Research Ethics (reference 2010/2022b and 2009/2328). Regarding data from the Level 1 trauma centre, written informed consent had been obtained from the parents. Data from the ACHs and the National Cause of Death Registry were collected without consent.

2.6. Statistical analysis

We calculated crude and adjusted incidence rates of moderate and severe TBI per 100 000 person-years (py), as well as crude and adjusted mortality from TBI per 100 000 py. All rates are figures per 100 000 py with the population aged 0–16 years residing in Mid-Norway, as the denominator. Adjusted rates were standardized according to the age-distribution of the world standard population.¹⁸ All rates were estimated for the overall observation period, as well as stratified into defined age groups (0–4, 5–9, 10–14, 15–16 years), sex, and time periods (2004–2009, 2010–2014). For moderate and severe TBI, population-based incidence rates were presented for the 10-year period (2004–2014). For severe TBI, prehospital deaths were included. Poisson regression was used to estimate incidence rate ratios (IRRs) comparing age, sex, and time periods. Precision of the estimated rates and ratios was given by a 95% confidence interval (95% CI). In additional analyses, we estimated the incidence rate of hospitalized severe TBI (excluding prehospital deaths). Data were analysed using Stata/SE 12.1 for Windows (Copyright 1985–2011 StataCorp LP).

2.7. Role of the founding source

The funding source, St. Olavs Hospital, Trondheim University Hospital and the Liaison Committee between the Central Norway Regional Health Authority and the Norwegian University of Science and Technology, had no influence on the scientific work with this study.

Table 1 – Demographic and injury characteristics in children with moderate and severe traumatic brain injury.

	Total TBI (n = 71)	Fatal TBI (n = 17)	Nonfatal TBI	
			Moderate (n = 35)	Severe (n = 19)
Mean age in years (SD)	9.6 (5.6)	8.7 (6.8)	9.6 (5.3)	10.5 (5.2)
Boys	51 (72%)	13 (76%)	23 (66%)	15 (79%)
Inclusion sources				
Level 1 trauma centre	52 (73%)			
Acute care hospitals	4 (6%)			
National Cause of Death Registry	15 (21%)			
GCS score				
13	10 (14%)		10 (29%)	0
9–12	24 (34%)		24 (69%)	0
5–8	16 (23%)	1 (6%)	0	15 (79%)
3–4	5 (7%)	2 (12%)	0	3 (16%)
unknown	16 ^a (23%)	14 (82%)	1 (3%)	1 (5%)
External cause				
RTA	26 (37%)	9 (53%)	8 (23%)	9 (47%)
Fall	29 (41%) ^b	2 (12%)	18 (51%)	9 (47%)
Gunshot	2 (3%)	2 (12%)	0	0
Violence	1 (1%)	0	1 (3%)	0
Self-harm	1 (1%)	1 (6%)	0	0
Other	12 (17%)	3 (18%)	8 (23%)	1 (5%)

GCS score = Glasgow coma scale score.

RTA = Road traffic accident.

TBI = Traumatic brain injury.

^a 14 of the children who died before reaching the hospital had no registered GCS score and 2 admitted children had no registered GCS score.

^b Two children registered as fall had injuries of presumptive physical abuse.

3. Results

A total of 71 children with moderate and severe TBI were included from the three sources: 1) 52 children treated at the Level 1 trauma centre, 2) Four children treated only at an ACH, and 3) 15 children who died prehospitally from the National Cause of Death Registry (Table 1). Among hospitalized children 95% of children (20/21) with severe TBI and 91% (32/35) of children with moderate TBI were treated at the Level 1 trauma centre.

Fall was the most frequent cause of injury in children with moderate TBI (51%), while RTA was most frequent in fatal TBI (53%) (Table 1). Two children admitted to hospital had missing GCS score, but could be classified as one severe TBI and one moderate TBI from clinical information in the medical record.

3.1. Incidence

Crude incidence rate of moderate TBI was 2.4 (CI 1.7–3.3) per 100 000 py and adjusted incidence rate of moderate TBI was 2.4 (CI 1.6–3.2) per 100 000 py (Table 2).

Crude incidence rate of severe TBI was 2.5 (CI 1.8–3.4) per 100 000 py and adjusted incidence rate of severe TBI was 2.9 (CI 1.9–3.9) per 100 000 py (Table 2). Adjusted incidence rate of hospitalized severe TBI was 1.4 (CI 0.9–2.3) per 100.000 py (not shown in the tables).

Crude incidence rate of moderate and severe TBI combined was 4.8 (CI 3.8–6.1) per 100 000 py (Table 2).

Highest age specific incidence rate ratio was found in children aged 15–16 years (Table 3). Boys had higher incidence rate than girls (Table 3). No difference was found in incidence rates between the two five-years periods (2004–2009 and 2010–2014).

3.2. Mortality

The crude overall mortality rate from TBI was 1.2 (CI 0.7–1.9) per 100 000 py and adjusted mortality rate from TBI was 1.5 (CI 0.7–2.2) (Table 4). A total of 17 deaths were recorded, and 15 of these (88%) were prehospital deaths. Only two of the 20

children with severe TBI who were admitted alive to the hospital, died after hospital admittance during the 10 years. As with incidence, children aged 15–16 years had the highest mortality from TBI, with a crude mortality rate of 3.3 (CI 1.5–7.3). Boys had higher mortality rate than girls (Table 4).

4. Discussion

4.1. Main findings

In this Norwegian population-based study in children, we found low incidence and mortality of moderate and severe TBI. Another important finding of our study was that nearly all deaths from TBI in our region occurred before hospital admission.

4.2. Strengths and limitations

An apparent strength of our study is inclusion from all hospitals in the Mid-Norway region and the inclusion of all pre-hospital deaths, which make the data population-based and complete. Another strength of our study is the case ascertainment with the majority of hospitalized patients (93%) included prospectively and a thorough review of all medical journals of patients included retrospectively. All children residing in Mid-Norway who died from TBI were registered (in-hospital deaths and prehospital deaths). This means that also the children declared dead from TBI outside hospitals, at the scene of injury or during transport, were registered. Children who died from TBI residing in Mid-Norway, were also included if they were injured in other countries and other parts of Norway. A limitation was that children with non-fatal TBI residing in Mid-Norway, but injured outside the region, were not included. Nevertheless, we believe to have captured close to all children with severe TBI. Regarding children with moderate TBI, the retrospective review of the ACH admissions, did not include ICD-10 code S06.0; concussion, which might be used in children with GCS score 13 and normal CT.

Table 2 – Crude and adjusted incidence rates of moderate, severe, and total traumatic brain injury per 100 000 py from 10-year period^b, according to age, sex, and time period.

Variable	Moderate TBI		Severe TBI		Total TBI	
	Crude	Adjusted ^a	Crude	Adjusted ^a	Crude	Adjusted ^a
Overall	2.4 (1.7–3.3)	2.4 (1.6–3.2)	2.5 (1.8–3.4)	2.9 (1.9–3.9)	4.8 (3.8–6.1)	5.3 (4.0–6.6)
Age, years						
0–4	2.2 (1.1–4.2)	NA	2.2 (1.1–4.2)	NA	4.4 (2.8–7.0)	NA
5–9	2.1 (1.1–4.0)	NA	2.3 (1.3–4.3)	NA	4.4 (2.8–7.0)	NA
10–14	2.7 (1.5–4.7)	NA	1.3 (0.6–3.0)	NA	4.0 (2.5–6.4)	NA
15–16	2.7 (1.1–6.6)	NA	6.0 (3.3–10.8)	NA	8.7 (5.4–14.3)	NA
Sex						
Girls	1.8 (1.1–3.1)	1.9 (0.8–2.9)	1.1 (0.6–2.2)	1.0 (0.3–1.7)	2.9 (1.9–4.5)	2.9 (1.6–4.1)
Boys	2.9 (1.9–4.4)	2.9 (1.6–4.2)	3.7 (2.6–5.4)	4.7 (2.8–6.5)	6.6 (5.0–8.8)	7.6 (5.4–9.9)
Period, years						
2004–2009	2.2 (1.4–3.6)	2.2 (1.1–3.3)	2.9 (1.9–4.4)	3.3 (1.9–4.8)	5.1 (3.7–7.0)	5.5 (3.7–7.4)
2010–2014	2.6 (1.6–4.1)	2.6 (1.3–3.9)	2.0 (1.2–3.4)	2.4 (1.1–3.8)	4.5 (3.2–6.4)	5.0 (3.2–6.8)

^a Standardized according to the world standard population.

^b From 1st of October 2004 to 30st of September 2014. NA = Not applicable. Py = Person-years. TBI = Traumatic brain injury

Table 3 – Incidence rate ratios of traumatic brain injury according to age, sex, and time period.

	Moderate TBI		Severe TBI		Total TBI	
	IRR	CI	IRR	CI	IRR	CI
Age, years						
0–4	1.0	(Reference)	1.0	(Reference)	1.0	(Reference)
5–9	1.0	(0.4–2.4)	1.1	(0.4–2.6)	1.0	(0.5–1.9)
10–14	1.2	(0.5–2.9)	0.6	(0.2–1.7)	0.9	(0.5–1.8)
15–16	1.2	(0.4–3.7)	2.7	(1.1–6.6)	2.0	(1.0–3.9)
Sex						
Girls	1.0	(Reference)	1.0	(Reference)	1.0	(Reference)
Boys	1.6	(0.8–3.2)	3.3	(1.5–7.3)	2.3	(1.4–3.8)
Period, years						
2004–2009	1.0	(Reference)	1.0	(Reference)	1.0	(Reference)
2010–2014	1.2	(0.6–2.2)	0.7	(0.4–1.4)	0.9	(0.6–1.4)

CI = 95% confidence interval. IRR = Incidence Rate Ratio. TBI = Traumatic brain injury.

Therefore, we have likely missed a few children with moderate TBI as defined by the GCS score, yet coded as concussion.

Finally, the low incidence of moderate and severe TBI in children led to a small sample size and therefore a nationwide study with inclusion from all hospitals in Norway would be preferable. We tried to compensate for the low frequency by having a long time period for inclusion; ie. ten years of inclusion.

4.3. Incidence

In line with the literature, we found higher incidence rate in boys than in girls and highest incidence rates in children age 15–16 years.⁴ We observed no clear change in incidence rates during the ten year study period, however, the precision of the estimated differences was low due to few cases of TBI.

4.3.1. Incidence of moderate TBI

In the current study, estimated incidence of moderate TBI was 2.4 per 100 000 py. Previous reported incidence rates of moderate TBI have ranged from 5.9–159 per 100 000 py.^{6,11–14}

Lowest previous incidence of moderate TBI was found in a study from the Netherlands (2007–2008) with incidence of 5.9 for moderate TBI in children aged 0–14 years, defining moderate TBI as GCS score 9–12.¹² In our study we included children with GCS score of 13 in our moderate group, a definition which will yield higher estimates than when moderate TBI is defined by GCS score 9–12, and yet we found lower incidence rate compared to the Dutch study.¹² The four other studies reporting incidence rates of moderate TBI have found higher incidence rates than we did.^{6,11,13,14} All these four studies did however apply wider criteria for defining moderate TBI, which will yield higher estimates. Indeed, some of these cases might in other studies be classified as complicated mild TBI. Hence, we consider our estimated incidence of moderate TBI, as defined by GCS score 9–13, to be the lowest ever reported.

4.3.2. Incidence of severe TBI

In the current study, estimated incidence of severe TBI was 2.5 per 100 000 py. Previous reported incidence rates of severe TBI have ranged from 0.8–36 per 100 000 py.^{6,11–15} Importantly, studies reporting the lowest estimates did, however, not include prehospital deaths.^{11–15} With regards to severe TBI, the high proportion of prehospital deaths also found in other studies^{9,10} underscores how important it is to include prehospital deaths in the estimates, and in the current study children who died prehospitally were included in the severe group. Only one previous study have included prehospital deaths when reporting incidence rates of severe TBI exclusively, and this study from Estonia (2001–2005) reported an incidence rate of severe TBI of 36 per 100 000 py in children aged 0–14 years.⁶ The study defined severe TBI by GCS score ≤ 8 and duration of loss of consciousness > 24 h. Again, the estimated incidence rate in the current study is the lowest ever reported.

4.3.3. Incidence of moderate and severe TBI combined

In the current study, estimated incidence of moderate and severe TBI combined was 4.8 per 100 000 py. Three previous studies, reporting incidence of moderate and severe TBI combined, comprised also prehospital deaths^{7,8,11}: (1) A study from the US (2007–2008) reported an incidence rate of moderate and severe TBI of 7.6 per 100 000 py.¹¹ (2) A study from Iceland (1992–1993) reported an incidence rate of moderate and severe TBI of 26 per 100 000 py in children and adolescents

Table 4 – Mortality of traumatic brain injury per 100 000 py according to age, sex, and time period during 10-year period.^b

Variable	Mortality from TBI	
	Crude	Adjusted ^a
Overall	1.2 (0.7–1.9)	1.5 (0.7–2.2)
Age, years		
0–4	1.5 (0.7–3.3)	NA
5–9	0.9 (0.4–2.5)	NA
10–14	0.2 (0.0–1.6)	NA
15–16	3.3 (1.5–7.3)	NA
Sex		
Girls	0.6 (0.2–1.5)	0.5 (0.0–1.1)
Boys	1.7 (1.0–3.0)	2.3 (1.0–3.7)
Period, years		
2004–2009	1.2 (0.6–2.3)	1.5 (0.5–2.5)
2010–2014	1.1 (0.6–2.3)	1.4 (0.4–2.5)

NA = Not applicable. Py = Person-years. TBI = Traumatic brain injury.

^a Standardized according to the world standard population.

^b From 1st of October 2004 to 30st of September 2014.

aged 0–19 years.⁷ However, this study included all cases with any diagnosis code indicating intracranial traumatic lesions, hence likely comprising many cases of complicated mild TBI according to a GCS score based classification. (3) A study from New Zealand (2010–2011), estimated incidence rate of moderate and severe TBI of 38 per 100 000 py in children aged 0–4 and 8 per 100 000 py in children aged 5–14.⁸ In summary, all these three studies^{7,8,11} comprising prehospital deaths found higher incidence than our estimate. Again, methods for classification of injury severity, the upper age limit and the years which the study was conducted will all affect incidence rates. First, it is known that including the oldest teenagers will increase incidence rates^{8,19} and second, incidence has decreased between 1980 and 2005 in high-income countries.¹⁹ Taking such methodological differences into account, we still consider our estimated incidence rates of moderate and severe TBI to be the lowest incidence rates ever reported.

4.4. Mortality

In our study, nearly all deaths from TBI (88%) occurred prior to hospital admission, whereas the proportion of prehospital deaths from TBI in two previous studies was 66% and 67%, respectively.^{9,10} Accordingly, we have only compared the observed mortality with mortality found in ten studies comprising prehospital deaths. The overall mortality rate from TBI in our study was low, 1.2 per 100 000 py. Previous reported mortalities have ranged from 1.8–9.3 per 100 000 py.^{6,7,9,10,20–25} Unfortunately, most of the previous studies are old, which makes comparison less relevant since the mortality from TBI has decreased dramatically in the last decades in high-income countries.^{20,23–25} This reduction in TBI related mortality was demonstrated in the study by Majdan et al. showing a decrease in mortality rate from TBI in Austria from 16.9 per 100 000 py in 1980 to 1.8 in 2012.²⁰ In the latter study, Majdan et al. included children aged 0–19. As with incidence, mortality is higher when including the oldest teenagers.^{13,19,20} Hence, we regard the mortality rate of 1.8 per 100 000 py reported from Austria to be fairly similar to our finding of 1.2 per 100 000 py in children aged 0–16.

4.5. Prevention of injuries

Mid-Norway is a region in Norway which is similar to Norway as a whole regarding demographic information such as age, sex, distribution of urban and rural areas, level of education, average income, distribution between goods producing and service industry and the number of immigrants.²⁶ There might be differences that do not show in the general statistic information about Norway, nevertheless we consider our findings to be a result of national environmental and preventive measures which yield for Norway as a whole and not measures special for Mid-Norway as a region.

In line with the literature we found RTAs and falls as the two leading external causes of TBI,^{4,12} with RTA as the leading cause of fatal TBI.¹⁰ Numbers of RTAs in general are decreasing in high-income countries and increasing in low-income countries,^{27,28} and a similar trend therefore likely exists for TBI.²⁹ The main explanation of the low incidence may be a strong focus on prevention of injuries in children, in

particular prevention of injuries sustained in RTAs. Norway has one of the lowest frequency of deaths from RTAs in the world,³⁰ and the annual number of road traffic deaths in children has decreased from 94 in 1970 to five in 2014.³¹ Several factors have contributed to this decrease such as; strict use of child car seats and/or seat belts in all cars, improved vehicle standard, improved road standards, strict regulations regarding drinking and driving, speed limit laws, helmet use in motorbikes and scooters, and play areas clearly separated from cars.

Furthermore, we believe that children in Norway are well protected against injuries from falls. Numbers from the Norwegian Council for Road Safety shows that in Norway a total of 77% of children 12 years or younger uses a helmet when bicycling.³² In Norway there are also building rules for fences, soft floor in outdoor play ground areas and child protections on windows. Likely, these safety measures contribute to a high level of child safety for Norwegian children.

5. Conclusion

Low incidence and mortality rates of moderate and severe paediatric TBI found in the present study, are most likely explained by successful national prevention of RTAs and safety regulations protecting children from falling injuries. Nearly all deaths occurred before hospital admission; hence, to obtain an additional reduction of deaths from TBI in Norway, further prevention of injuries is needed and further research might explore whether also prehospital treatment can be improved.

Conflicts of interest

No conflicts of interest exist.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ejpn.2019.01.009>.

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