INTRODUCTION

Traumatic head injury is a common cause of mortality and acquired neurological impairment in children (1). Several studies from different countries have established that many (19–33%) (2–7) head injuries in young children are inflicted. The highest proportion is found in infants (2–7). Subdural haemorrhage (SDH) is the most common type of injury after an inflicted trauma (2,3,8,9). SDH and subarachnoid haemorrhage, along with retinal haemorrhage and metaphysal fractures, occur when a small child is violently shaken and a forceful rotation and acceleration of the head and extremities is caused. This mechanism of shaking alone or along with an impact confounds the Shaken Baby Syndrome (SBS) (10). Parenchymal brain injuries often occur together with SDH after inflicted trauma. The acceleration–deceleration of the brain creates shearing forces which can cause diffuse axonal injuries and the impact of the brain against the inner surface of the skull can cause contusions and cerebral oedema. Hypoxic–ischaemic injury may result from the tendency of apnoea and respiratory depression these babies have following the trauma (11,12).

Inflicted head injuries have a poor prognosis with a mortality rate from 10% to 27% (3,4,6,11,13). They also have a high morbidity rate that include long hospital stays, and often the need for intensive care (1,3,4). Neurological sequelae are recorded in 45–70% at the time of discharge (13). Nearly 70% have late neurological and cognitive sequelae, of which at least 40% have severe neurological disabilities (14).

Symptoms of inflicted head trauma are often non-specific (13,15,16), making it difficult to recognize that these children have been exposed to head trauma. To evaluate whether or not the trauma is inflicted can be difficult (15,17). Neglect must also be considered in children with both an accidental and inflicted traumatic injury (2). Children who are not properly looked after will be susceptible to accidents, and there is co-occurrence of abuse and neglect.

Although the knowledge of inflicted head injuries has improved, this is still a controversial area. In courtrooms and the media, both new and old cases are disputed. The objective of the present study was to assess how to distinguish inflicted injuries from accidents, and to describe head trauma characteristics in young children.

METHODS

Subjects and settings

Enrolled in this study were children younger than 36 months who were admitted to Ullevål University Hospital, UUH, with a traumatic head injury from 1 January 1995 through December 31 December 2005. UUH is a tertiary teaching hospital and the largest trauma centre in Norway, serving a population of 2.5 million people. UUS is also a primary hospital for all children in the city of Oslo.

Children with a traumatic head injury were identified from the registered Internation Classification of Disease (ICD) diagnostic code in administrative discharge lists and from the Trauma Registry, Ullevaal University Hospital. The following...
diagnoses were included in this study: (i) Fracture(s) of the skull and fracture of the base of the skull, excluding fracture of the facial bones, (ii) traumatic intracranial haemorrhage and (iii) intracerebral haemorrhage and cerebral parenchymal injuries. Concussions were not included, because there was too little information available in the medical records.

This review identified 114 subjects. Twenty-three cases were excluded. The registered ICD code was inaccurate in 16 cases; 11 cases were concussion and five cases had fracture of facial bone, and wrong in one case. One patient had osteogenesis imperfecta, one had haemophilia A, and in five cases the medical records could not be found. The study was approved by the Regional Committee for Medical Research Ethics.

Classifications

The cases were categorized into four groups according to the type of head injury described in the radiological reports: skull fractures, epidural haemorrhage (EDH), SDH and parenchymal brain injury including intracerebral haemorrhage. All patients had a CT-scan. MRI was performed in 21 patients.

The injuries were also classified as ‘inflicted injury’, ‘accident’ or ‘indeterminate’. To insure interrater reliability and to minimize the impact of socio-demographic factors on this classification, all cases were also classified by an external collaborator, who was only presented with the age of the patient, anamnestic information regarding the cause of the head injury and copies of the radiological reports.

Criteria for classification as inflicted injury (2):
1. Documented presumptive abuse in the medical record, and referral to child protective services.
2. Injuries where the medical history could not explain the injury (18).
   - No history of trauma
   - A low impact insult (height of fall < 1.0 m)
   - Changes in the history given by the caregivers
   - History incompatible with the child’s developmental level
3. Injuries where additional findings indicate child abuse.
   - Retinal haemorrhages
   - Additional injuries which were incompatible with the given mechanism of the injury
   - Older injuries without explanation

Criteria for classification as accident (3):
1. Motor vehicle accident.
2. Witnessed accident by people other than the caretaker(s).
3. Isolated or unique injury mechanism with consistent and detailed description evaluated as accidental in the medical record.

For cases with skull fracture(s) and EDH, the interrater agreement was low (kappa 0.13). Therefore, these cases had to meet the first or third criteria above in order to be classified as inflicted. For cases with SDH or parenchymal brain injuries, the intrerrater agreement was good (kappa 0.85). These cases were classified as inflicted if agreement between the interraters was found and one of the above criteria was present. All cases were classified as accident if they met one of the above criteria for accidents. The remaining cases were classified as indeterminate.

Statistics

SPSS 12.01 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Continuous data are presented as mean with 95% confidence interval (CI), except when the distribution is far from normal. In such cases, median and interquartile range (IQR) were used. When comparing continuous variables, the t-test was used if the distribution of the variable was sufficiently close to the normal distribution, otherwise the Mann–Whitney test was used. A chi-square test was used when analyzing categorical data. Pearson’s correlation coefficient was used to measure associations between two continuous variables. All tests were two-sided, and p-values equal to or less than 0.05 were considered significant.

RESULTS

Ninety-one children with a traumatic head injury were enrolled in the study, of which 51 were boys. The median age was 10 months. In 73% of the cases, both parents were Norwegian or from Western Europe. Forty-seven (52%) children were from Oslo. The head injury was the only injury found in 90% of the cases.

The types of injuries are listed in Table S1.

Isolated skull fractures

Isolated skull fractures were found in 39 patients. Most of the fractures were simple linear (74%). Domestic falls were the most commonly reported causes of skull fractures (63%). Height of falls varied between < 0.5 and 8.0 m (mean 1.5 m). In 13% of the cases, there was no trauma in the medical history (Table S2). There was a positive correlation between age and height of fall, r = 0.60, p = 0.003. A period of unconsciousness after the trauma was common (77%), but most of the children (69%) had only minor symptoms when examined in the hospital. Median length of hospital stay was 1 day (IQR = 1–3). Except for growing fractures, which developed in two patients, there were few complications and the children were all well when discharged.

Epidural haemorrhage

EDH was found in 12 patients. The dominant reported causes of injury were falls (92%). The height of the falls varied between 0.7 m and 4.0 m (mean 1.5 m). All EDHs were associated with a skull fracture. Ten out of 12 fractures were simple linear fractures. Signs of increased intracranial pressure (ICP) were found in five patients, four of them deteriorated rapidly and required urgent surgical evacuation of the haematoma. Seven patients did not develop severe symptoms, and recovered spontaneously. Except for one focal contusion, no parenchymal injuries or cerebral oedema...
were found in the children with EDH. One of the children had seizures during the hospital stay, and minor neurological impairment at discharge was described in one child.

Subdural haemorrhage
SDH was found in 27 patients. Falls were the cause of injury in 45%, of which 2/3 were reported from heights less than 0.80 m. There was no history of trauma in 26% of the cases with SDH (Table S2). As opposed to EDH, a relatively large proportion of the SDH occurred without a skull fracture (SDH 37% vs. EDH 0%, p = 0.017). (Table S1). Cerebral parenchymal injuries and/or oedema were present in 52% of the patients. There was a decreased level of consciousness at admittance to the hospital in 22 patients (81%). Apnoea or hypoventilation was reported in 14 patients (52%) and seizures in nine (33%). There were 82% referrals to the paediatric intensive care unit (PICU) with a median length of stay of 2 days (IQR 2–8). Surgery was performed in seven patients. Two patients with SDH died. Neurological impairment was recorded in 48% of those who survived.

Parenchymal brain injury
Parenchymal brain injury was found in 13 patients. The reported mechanisms of injury differed from the other injury groups in that no low impact fall was reported, and the largest proportion of motor vehicle accidents (31%) was found in this category.

Ninety-two percent had skull fractures. A cerebral oedema was described in more than half of the patients. Decreased level of consciousness at the time of admittance was recorded in eight patients (61%). Seventy-seven percent of these patients were admitted to the PICU, with a median length of stay of 5 days (IQR 0.5–12). Four needed surgery. One of the children died, and neurological impairment was recorded in 1/5 of those who survived.

Inflicted injuries and accidents
Seventeen cases met the criteria for inflicted injury (19%), 35 cases met the criteria for accident (39%), and the remaining 39 (43%) were regarded as indeterminate.

Fourteen of the cases in the inflicted injury group were presumed inflicted at discharge. Five of the cases were recognized as abuse before admittance to the university hospital; two prior to hospital admission and three at the local hospital. The child protecting services was investigating one of the families after a report on neglect. To our knowledge, none of the cases had a history of previous abuse.

All cases classified as inflicted had SDHs, accounting for 63% of the cases with SDH. There was no history of trauma in seven cases, and a low impact fall was reported in 10 cases. Within the inflicted group additional injuries were present in 65% of the children; six patients had SDH of different ages, three patients had a combination of SDH of different ages and old fractures, and one had only old fractures. One patient had a new fracture. Retinal haemorrhages were found in seven out of 10 examined patients. The classification criteria which lead to inclusion in the inflicted injury group in each case are shown in Table S3.

The accident group included 37% motor vehicle accidents, 43% witnessed falls and 20% isolated or unique accidents (sledging, skating, hit by a tree branch, hit by tractor wheel, penetrating injury with screwdriver and penetrating injury by chandelier).

Comparison between the accident group and the inflicted group (Table S4)
The children in the inflicted group were younger. There was a non-significant predominance of boys (71%) in the inflicted group. The biological fathers in the inflicted group were younger than in the accident group. Otherwise, there were no significant differences in the demographic variables. In the inflicted group, fathers were younger than mothers, opposite of the case in the accident group and in the general population. A significantly larger proportion of the inflicted group were previously hospitalized, p = 0.031. Then, no significant difference regarding level of consciousness or respiratory depression was found. Neurological impairment was present at discharge in 10 (59%) of the children with an inflicted injury.

Indeterminate group
Median age was 7.0 months. Twenty-six percent of these children had been hospitalized earlier. This was comparable with the inflicted group, but significantly more than in the accident group. Skull fractures were the most common injury (58%), followed by EDH (23%), SDH (10%) and parenchymal brain injuries (10%). Most of the injuries (46%) were caused by falls from 0.8 to 1.2 m. Falls less than 0.8 m accounted for 18% of the cases. There was no history of trauma in 15% of the cases. The indeterminate group was characterized by low morbidity, with few symptom described when admitted to the hospital, a short hospital stay and few referrals to the PICU (Table S5).

DISCUSSION
Previous research has demonstrated that severe abuse should be suspected when SDH is found in young children without documented major trauma. The results in our study are in line with these findings, with 65% of the cases with SDH classified as inflicted. This proportion is consistent with other studies (4,9). The interrater agreement was good for cases with SDH or parenchymal brain injuries. Inflicted injury accounted for 19% of all cases in this study. This was in the lower range of what is reported in other comparable studies (2–4).

Unlike other studies, demographic characteristics of the inflicted group did not differ significantly from the accident
group. This finding may be due to a more homogeneous population in Norway than in UK and USA with regards to socio-demographic parameters. In our study, information with regards to socio-economic parameters such as finance, employment and education were incomplete and did not allow analysis.

This study did not allow comparison with the general population, as the referral routines and the catchment areas were not absolute.

Compared to the accident group, the children in the inflicted group were significantly more likely to have been hospitalized earlier despite being considerably younger. There were no significant patterns in the causes of hospitalization, and only one child had been admitted because of injuries.

As reported in previous studies (9,20,21), inflicted head injuries were more frequently followed by seizures than accidental injuries. In addition, an instance of SDH without a skull fracture took place more frequently when the injury was inflicted. This has also been demonstrated in previous studies (4,9). Both of these findings have clinical implications. Doctors should have the possibility of an inflicted head injury in mind when evaluating children with seizures even when there are no or few external signs of trauma.

As in other studies, there were significantly more neurological sequelae in the inflicted group compared with the accident group. This was not surprising as the injuries recognized as inflicted were all severe. This poor outcome can also be seen in association with the young age of these children, as there is evidence of greater vulnerability after brain injuries in the youngest (22). Neurological sequelae at discharge were described in 58% of the cases with inflicted injuries. This was lower than most other studies, and unlike other studies, there were no deaths after an inflicted injury. This may have been due to the small numbers, as there was no statistically significant difference between the groups, but may also be a characteristic of the population. In such case, it seems to be because of less severe injuries and not because of differences in treatment, as life threatening events were not described after the initial stabilization, and none were discharged in a vegetative state.

For skull fractures, the correlation found between height of fall and age reflects the fact that older children are able to climb and that the skull of the youngest children may be more fragile. To our knowledge, this phenomenon has not been described previously. Consistent with other studies, EDHs followed the pattern of skull fractures with regards to the mechanism of injury and an equal mean height of fall was found. The presence of an EDH did not indicate abuse (19). EDHs are important to detect because of the potential danger of rapid deterioration and the need for urgent surgery.

The low interrater agreement in cases with skull fractures and EDH can partly be explained by the limited information available. However, it is also demonstrated that the biomechanics of skull fractures in infants is difficult to evaluate and that more research is needed. In our sample, a low fall was observed in a newborn baby by objective witnesses causing a skull fracture. In this study, there was no case of an isolated skull fracture or EDH where other signs of inflicted injuries were present, and no case where a conclusion of presumptive abuse was made.

In many cases, the caretakers could have protected their child from the accidents, and embarrassment and guilt might have been the reasons why some caretakers did not say what had really happened. This called for cautiousness when classifying cases where the only recorded sign of abuse was a possible discrepancy between the reported history and the injury. In such cases, it is important to evaluate the child’s situation even if the injury was concluded to be unintentional, as they may be at risk of further neglect and new injuries.

An important finding in our study was that the indeterminate group shared some characteristics with the inflicted injury group. They were young, more of them than expected, had previously been hospitalized and there were cases with no history of trauma, changing history or just a low impact fall described as injury mechanism. This could indicate that more children were abused or neglected.

In this study, the information available was limited, something which set restrictions on both the classification and the analysis. The largest group turned out to be indeterminate. This reflects the difficulties found in the everyday clinical judgment of children with injuries, but the proportion could have been smaller if more information had been recorded. Standardized measures were not regularly used in the records and that made comparison of injury severity and outcome with other studies difficult. Such measures would also have been preferable for comparison between groups within the study.

Our study demonstrated both the progress made and the problems still existing in the field of traumatic head injuries in the youngest children. For SDH and parenchymal brain injuries, the existing knowledge made it possible to recognize inflicted injuries. For skull fractures and EDH, our study demonstrated how difficult it is to be conclusive if there are no other signs of child maltreatment. The likelihood for cases of abuse and neglect being overseen was demonstrated, and our results highlight the importance of a thorough evaluation every time a doctor sees a young child with a head trauma.

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References
1. Parslow RC, Morris KP, Tasker RC, Forsyth RJ, Hawley CA, on behalf of the UK, Paediatric Traumatic, Brain Injury, Study Steering, Group and the Paediatric, Intensive Care, Society Study Group. Epidemiology of traumatic brain injury in children receiving intensive care in the UK. Arch Dis Child 2005; 90: 1182–7.
2. Duhaime AC, Alarjo AJ, Lewander WJ, Schut L, Sutton LN, Seidl TS, et al. Head injury in very young children: mechanisms, injury types, and ophthalmologic findings in 100 hospitalized patients younger than 2 years of age. Pediatrics 1992; 90: 179–85.
3. Reece RM, Sege R. Childhood head injuries. Accidental of inflicted? Arch Pediatr Adolesc Med 2000; 154: 11–5.
4. Ettario L, Berger RP, Songer T. Abusive head trauma in young children: characteristics and medical charges in a hospitalized population. Child Abuse Neglect 2004; 28: 1099–111.
5. Keenan HT, Runyan DK, Marshall SW, Nocera AM, Merten DF, Sinal SH. A population-based study of inflicted traumatic brain injury in young children. JAMA 2003; 290: 621–6.
6. Jayawant S, Rawlinson A, Gibbons F, Price J, Sharples P, Sibert JR, et al. Subdural haemorrhages in infants: population based study. BMJ 1998; 317: 1558–61.
7. Barlow KM, Minns RA. Annual incidence of shaken impact syndrome in young children. Lancet 2000; 356: 1571–2.
8. Feldman KW, Bethel R, Shugerman RP, Grossman DC, Grady MS, Ellenbogen RG. The cause of infant and toddler subdural hemorrhage: a prospective study. Pediatrics 2001; 108: 636–46.
9. Ewing-Cobbs L, Prasad M, Kramer L, Louis PT, Baumgartner J, Fletcher JM, et al. Acute neuroradiologic findings in young children with inflicted or noninflicted traumatic brain injury. Child's Nerv Syst 2000; 16: 25–34.
10. Duhaime AC, Christian CW, Rorke LB, Zimmerman RA. Nonaccidental head injury in infants – the “Shaken-Baby Syndrome”. New Engl J Med 1998; 338: 1822–9.
11. Kemp AM, Stoodley N, Cobley C, Kemp KW. Apnoea and brain swelling in non-accidental head injury. Arch Dis Child 2003; 88: 472–6.
12. Geddes JF, Vowles GH, Hackshaw AK, Nickols CD, Scott IS, Whitwell HL. Neuropathology of inflicted head injury in children. Brain 2001; 124: 1299–306.
13. King WJ, MacKay M, Sirnick A. Shaken baby syndrome in Canada: clinical characteristics and outcome of hospital cases. CMAJ 2003; 168: 155–9.
14. Barlow KM, Thomson E, Johnson D, Minns RA. Late neurologic and cognitive sequelae of inflicted traumatic brain injury in infancy. Pediatrics 2005; 116: 174–85.
15. Jenny C, Hymel KP, Ritzen A, Reinert SE, Hay TC. Analysis of missed cases of abusive head trauma. JAMA 1999; 281: 621–6.
16. Grahrman A, Bhasin V, Chaseling R, Andrews B, Lang EW. Nonaccidental head injuries in children: a Sydney experience. J Neurosurg (Pediatrics 3) 2005; 103: 213–8.
17. Trokel M, Wadimmba A, Griffith J, Sege R. Variation in the diagnosis of child abuse in severely injured infants. Pediatrics 2006; 117: 722–8.
18. Hettler J, Greences DS. Can the initial history predict whether a child with a head injury has been abused? Pediatrics 2003; 111: 602–7.
19. Shugerman RP, Paez A, Grossman DC, Feldman KW, Grady S. Epidural haemorrhage: is it abuse? Pediatrics 1996; 97: 664–8.
20. Bechtel K, Stoessell K, Leventhal J, Ogle E, Teague B, Lavites S, et al. Characteristics that distinguish accidental from abusive injury in hospitalized young children with head trauma. Pediatrics 2004; 114: 165–8.
21. Vinchon M, Defoort-Dhellemmes S, Desurmont M, Dhellemmes P. Accidental and nonaccidental head injuries in infants: a prospective study. J Neurosurg (Pediatrics 4) 2005; 102: 380–4.
22. Anderson V, Catroppa C, Morse S, Haritou F, Rosenfeld J. Functional plasticity or vulnerability after early brain injury? Pediatrics 2005; 116: 1374–82.

Supplementary material
The following supplementary material is available for this article:

Table S1. Type of injury, evaluated by radiological reports.
Table S2. Reported cause of injury in relation to type of injury.
Table S3. Classification criteria for the cases in the inflicted injury group.
Table S4. Comparison between the inflicted and the accident group.
Table S5. Characteristics of the indeterminate cases.

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