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Comparison of intracranial computed tomographic (CT) findings in pediatric abusive and accidental head trauma

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Abstract *Background.* Child abuse specialists rely heavily on diagnostic neuroimaging.
Objectives. Study objectives were: (1) to compare the frequencies of six specific intracranial CT abnormalities in accidental and non-accidental pediatric head trauma, and (2) to assess interobserver agreement regarding these CT findings.
Materials and methods. Three pediatric radiologists blindly and independently reviewed cranial CT scans of pediatric patients who sustained closed head trauma between 1991 and 1994. All patients were less than 4 years of age. Study cases included thirty-nine (50 %) with non-accidental head trauma and thirty-nine (50 %) with accidental head trauma. Each scan was evaluated for the presence or absence of the following six intracranial findings: (1) interhemispheric falx hemorrhage, (2) subdural hemorrhage, (3) large (non-acute) extra-axial fluid, (4) basal ganglia edema, (5) posterior fossa hemorrhage, and (6) frontal-parietal shearing tear(s). Interobserver agreement was calculated as the percentage of total cases in which all reviewers agreed a specific CT finding was present or absent. Diagnosis required independent agreement by all three pediatric radiologists. The frequencies of these six intracranial CT abnormalities were compared between the two study groups by Chi-square analysis and Fisher's exact test.
Results. Interobserver agreement between radiologists was greater than 80 % for all lesions evaluated, with the exception of frontal-parietal shearing tear(s). Interhemispheric falx hemorrhage, subdural hemorrhage, large (non-acute) extra-axial fluid, and basal ganglia edema were discovered significantly more frequently in non-accidental trauma ($P \leq .05$).
Conclusion. Although not specific for child abuse, discovery of these intracranial CT abnormalities in young patients should prompt careful evaluation of family and injury circumstances for indicators of non-accidental trauma.

Introduction

Intracranial injuries represent the most devastating sequelae of child abuse. Differentiation between accidental and inflicted pediatric head trauma can be difficult. Experienced child abuse and radiology professionals generally agree there are no pediatric intracranial injuries which are independently diagnostic of child abuse [1]. Nevertheless, child abuse specialists rely heavily on diagnostic neuroimaging.

Although not specific, subdural hemorrhage is a frequent finding in abusive pediatric head trauma [1–10]. The frequency of other intracranial computed tomographic (CT) findings in non-accidental trauma is less well described. The objectives of this retrospective study were twofold: (1) to compare the frequencies of interhemispheric falx hemorrhage, subdural hemorrhage, large (non-acute) extra-axial fluid, basal ganglia edema, posterior fossa hemorrhage, and frontal-parietal shearing tear(s) in non-accidental and accidental pediatric head trauma, and (2) to assess pediatric radiologist interobserver agreement for these six specific intracranial CT findings.

Table 1 Interobserver agreement (see Materials and methods)

CT finding	Interobserver agreement
Interhemispheric falx hemorrhage	63 of 78 (81 %)
Subdural hemorrhage	66 of 78 (85 %)
Large (non-acute) extra-axial fluid	64 of 78 (82 %)
Basal ganglia edema	69 of 78 (88 %)
Posterior fossa hemorrhage	67 of 78 (86 %)
Frontal-parietal shearing tear(s)	53 of 78 (68 %)

Materials and methods

A group of 39 patients who sustained abusive head trauma as determined by an experienced multidisciplinary child abuse team constituted the non-accidental trauma (NAT) group. A control group included the 39 youngest patients imaged by CT following accidental head injury during the same 1991–1994 time frame. Unlike abusive head trauma, accidental head trauma requiring CT evaluation occurred infrequently in very young pediatric patients during the 4-year study period. For this reason, comparison groups could not be matched specifically with respect to age.

The CT scans of the 78 study patients were reviewed independently by three board-certified pediatric radiologists who were blinded with respect to patient demographics, history and group assignment. For each patient and potential CT finding, the reviewers independently assigned a diagnostic confidence score (scale 0 to 100). A score of 0 was defined as total confidence that a particular CT finding was absent. A score of 100 was defined as total confidence that a particular CT finding was present. An average diagnostic confidence score was computed (from the three independent diagnostic confidence scores) for each intracranial CT finding in all study patients.

Interobserver agreement for each listed CT finding was calculated as the percentage of total cases ($n = 78$) in which all three reviewers independently agreed that a specific finding was more likely present (i. e., all three independent diagnostic confidence scores were ≥ 51) or absent (i. e., all three independent diagnostic confidence scores were ≤ 50). Diagnosis of a specific intracranial CT abnormality required reviewer consensus (i. e., all three reviewers independently rated the specific CT finding with a diagnostic confidence score ≥ 51). The frequencies of each CT abnormality were compared between accidental and non-accidental groups using Chi-square analysis and Fisher's exact test.

Results

An age difference was noted between the two comparison groups. Whereas the mean age for the (39 youngest) accidental closed head trauma patients in our study period was 1 year 4.5 months (range 1 month to 1 year 11.5 months), the mean age for our randomly selected study patients with non-accidental head trauma (NAT) was 8 months (range 2 weeks to 3 years 8.5 months).

Interobserver diagnostic agreement was greater than 80 % (Table 1) for the specific intracranial CT findings of interhemispheric falx hemorrhage, subdural hemorrhage, large (non-acute) extra-axial fluid, basal ganglia edema, and posterior fossa hemorrhage. There was less interobserver agreement for the CT diagnosis of frontal-parietal shearing tear(s) (68 %).

The primary purpose of this study was to compare the frequencies of six specific intracranial CT abnormalities in accidental and non-accidental pediatric head trauma (Table 2). Twenty patients (51 %) in the NAT group demonstrated a total of 51 intracranial CT abnormalities. In the accidental group, five patients (13 %) demonstrated a total of seven intracranial CT abnormalities. For all CT abnormalities diagnosed by reviewer consensus ($n = 58$), the average diagnostic confidence scores were high (mean 94, range 67–100).

Seventeen of 19 interhemispheric falx hemorrhages were identified among non-accidental head trauma patients ($\chi^2 = .00008$). Sixteen of 20 subdural hematomas diagnosed in our study population occurred in the

Table 2 CT abnormalities[a] in non-accidental trauma *(NAT)* vs accidental pediatric closed head trauma

CT abnormality	NAT	Accidental	*P* value[b]
Interhemispheric falx hemorrhage	17 of 39 (44 %)	2 of 39 (5 %)	0.00008
Subdural hemorrhage	16 of 39 (41 %)	4 of 39 (10 %)	0.002
Large (non-acute) extra-axial fluid	8 of 39 (21 %)	0 of 39 (0 %)	0.005
Basal ganglia edema	5 of 39 (13 %)	0 of 39 (0 %)	0.05
Posterior fossa hemorrhage	4 of 39 (10 %)	0 of 39 (0 %)	0.12
Frontal-parietal shearing tear(s)	1 of 39 (3 %)	1 of 39 (3 %)	1.0

[a] Diagnosis of a specific CT abnormality required independent consensus by three pediatric radiologists

[b] χ^2 analysis was used to compare the frequencies of subdural hemorrhage and interhemispheric falx hemorrhage between study groups. Because the other listed CT abnormalities were diagnosed infrequently in our study population, the Fisher's exact test (two tail) was used for the remaining group comparisons

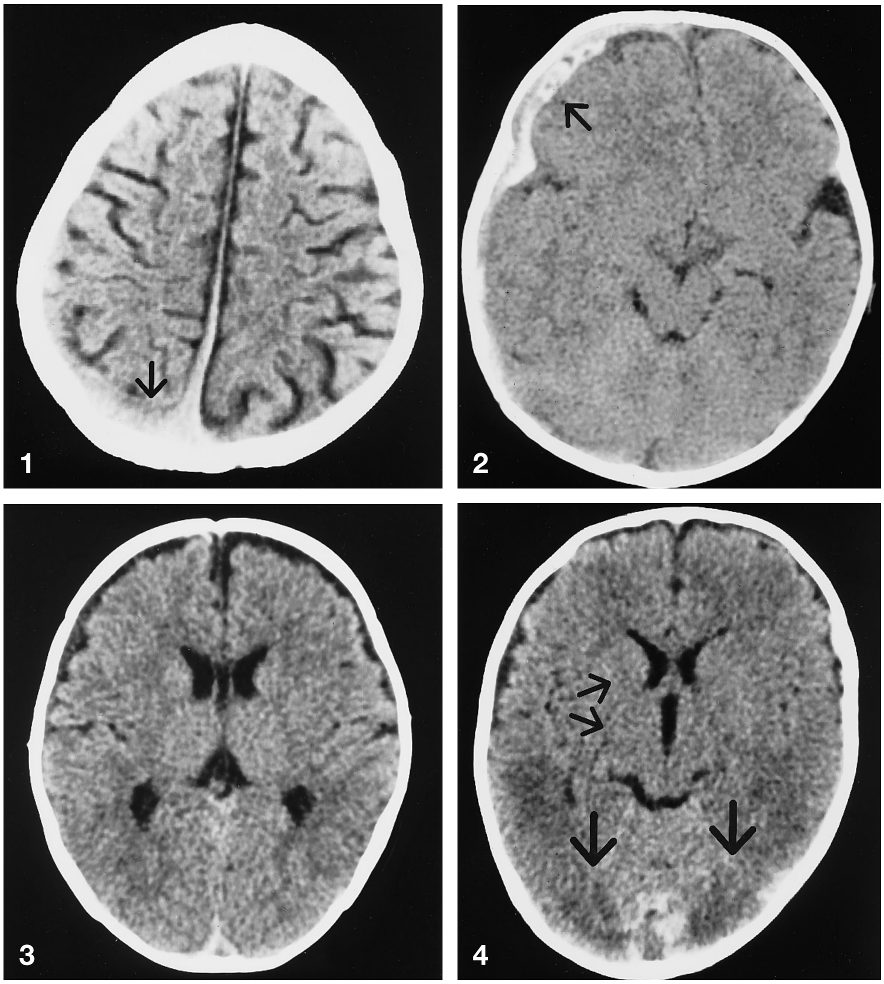


Fig. 1 Interhemispheric subdural hematoma. Axial CT image demonstrates interhemispheric subdural hemorrhage extending posteriorly and around the right parietal lobe (*arrow*). The thickness of the hemorrhage without invagination into the sulci confirms subdural location

Fig. 2 Subdural hematoma. Axial CT slice shows hyperdense right frontal and parietal fluid in the subdural compartment (*arrow*). The more peripheral hypodense fluid could suggest a separate, older subdural hemorrhage. Right cerebral edema with mass effect is also present with contralateral displacement of midline structures

Fig. 3 Non-acute extra-axial fluid collection. Axial CT slice shows hypodense fluid around the frontal lobes with extension into the parietal regions. This finding does not confirm traumatic intracranial injury

Fig. 4 Basal ganglia edema. Axial CT slice to the level of the frontal horns and third ventricle shows absence of clear definition of the anterior and posterior limbs of the internal capsules bilaterally (*short arrows*). This can represent early basal ganglia edema. Hypodense areas in the occipital lobes (and high posterior temporal lobes) represent areas of evolving brain edema and infarct (*long arrows*)

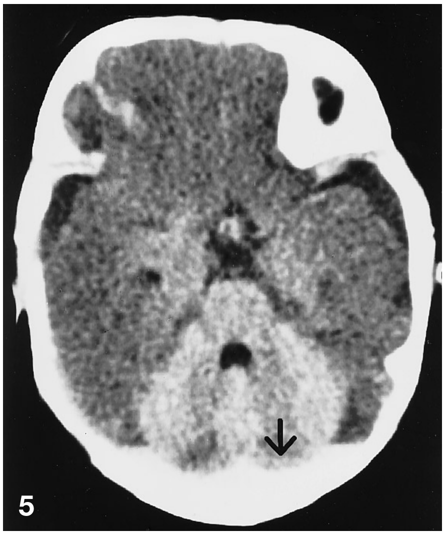
NAT patient group $\chi^2 = .002$). Large (non-acute) extra-axial fluid (Fisher's exact test $P = .005$), basal ganglia edema (Fisher's exact test $P = .05$), and posterior fossa hemorrhage (Fisher's exact test $P = .12$; not significant) were diagnosed exclusively in the NAT patient group.

Discussion

Most acute, post-traumatic central nervous system pathology which requires intervention can be readily diagnosed by CT imaging. Computed tomography has become the initial neuroimaging modality of choice for the evaluation of acute pediatric head trauma, including child abuse [11–13]. Medical professionals asked to review initial CT scans of patients with closed head trauma must be familiar with patterns of intracranial injury which occur more frequently in child abuse.

In 1979, Zimmerman et al. first described the frequent discovery of interhemispheric falx hemorrhage in abused children [14]. Parietal-occipital acute interhemispheric subdural hematoma was the most frequent CT diagnosis in that series and was demonstrated in 56% of 26 abused children. Differentiation between interhemispheric subdural and subarachnoid hemorrhage may be difficult [15, 16]. In our study, 17 of 19 interhemispheric falx hemorrhages (Fig. 1) occurred in the NAT group ($\chi^2 = .00008$).

Duhaime et al. prospectively screened 100 children (≤ 2 years of age) hospitalized with closed head trauma for indicators of child abuse [6]. This prospective study confirmed several earlier reports that non-accidental pediatric head trauma frequently results in subdural hemorrhage [1–5, 7–9]. In our study, subdural hematomas were discovered in 16 of 39 infants and young children with NAT (Fig. 2). Only four patients in the accidental group had subdural hematomas ($\chi^2 = .002$).



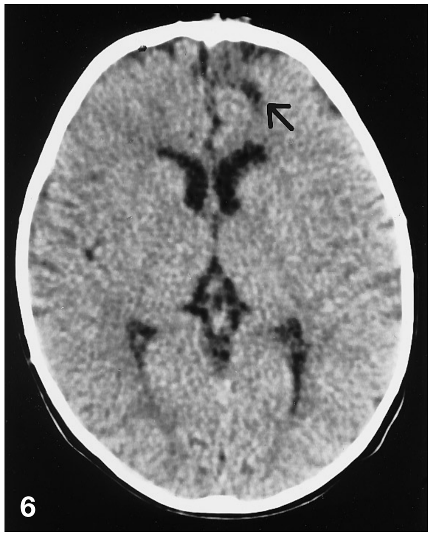


Fig. 5 Posterior fossa hemorrhage. Axial CT examination shows marked linear hyperdense fluid in the posterior fossa consistent with acute hemorrhage (*arrow*). The temporal and frontal lobes are hypodense from evolving cerebral edema

Fig. 6 Shear injury. Axial CT slice at the level of the frontal horns shows a hypodense linear shear injury in the left frontal lobe at the gray/white matter junction (*arrow*)

These findings support previous conclusions that subdural hemorrhage is a frequent finding in NAT.

Compared to CT, MRI is a preferable modality for detecting small extra-axial fluid collections, for differentiating between aging hematoma and cerebrospinal fluid, and for estimating the age of subdural bleeding [4, 5, 11, 17–25]. For this study, fluid not dense enough to confirm hemorrhage was termed non-acute. A large, non-acute extra-axial fluid collection in a young infant or child may represent a post-traumatic, chronic subdural hemorrhage. Birth trauma, as well as accidental or abusive trauma, are the primary etiologic considerations. Chronic subdural hematomas have been reported as late sequelae of child abuse [2, 14, 26, 27]. In our study, all eight large, non-acute extra-axial fluid collections (Fig. 3) were diagnosed in the NAT patient group (Fisher's exact test $P = .005$).

All five cases of basal ganglia edema in our study population (Fig. 4) occurred in patients with NAT (Fisher's exact test $P = .05$). It has been hypothesized that such deeper brain structures are the least vulnerable part of the brain and that closed head injury to deeper parenchymal locations is always associated with significant injury to more peripheral parts of the brain [28]. In the setting of diffuse cerebral edema, basal ganglia edema may represent a secondary diffuse hypoxic-ischemic phenomenon. In isolation, brain edema should not be considered specific for a traumatic etiology. However, trauma-induced apnea may precipitate secondary hypoxic-ischemic parenchymal injury [29].

Posterior fossa hemorrhage has been reported occasionally to be a complication of non-accidental pediatric head trauma [4, 17]. In newborn infants, birth trauma must also be considered. Differentiation between subdural and subarachnoid bleeding in this region is difficult with CT imaging. Magnetic resonance neuroimaging is more sensitive than CT scanning for the detection of posterior fossa lesions, which may be missed on CT [30]. All four posterior fossa hemorrhages in our study population (Fig. 5) occurred in children with NAT (Fisher's exact $P = .12$; not significant).

Parenchymal shearing tear(s) have also been reported to be a potential complication of pediatric non-accidental head trauma [5, 17, 31]. They are often seen at gray-white matter interfaces or within large white matter tracts. Traumatic parenchymal shearing tear(s) occur predominantly in infants less than 5 months of age [32, 33]. Only two frontal-parietal shearing tear(s) were confirmed in our study (Fig. 6) – one in each patient group (χ^2 analysis and Fisher's exact test $P = 1.0$, not significant).

Cerebral parenchymal lacerations unassociated with skull fracture or acute hemorrhage can be difficult to identify with CT scanning. Magnetic resonance imaging (MRI) is a more sensitive modality for the detection of subtle brain parenchymal lesions [5, 17, 18–22, 34]. An equivocal CT diagnosis of frontal-parietal shearing tear(s) may require confirmation by MRI.

Child abuse experts are frequently queried in court regarding the mechanisms of accidental trauma which may produce significant intracranial injury. The five study patients in the accidental (control) group who revealed intracranial CT abnormalities all underwent an extensive, multidisciplinary NAT evaluation. A clear history regarding the accidental injury mechanism was lacking in two, although medical records revealed no suspicion of abusive head injury. The other three infants (ages 13 days, 7 months, and 7.5 months) each sustained accidental skull fracture with a small underlying subdural hemorrhage at the site of direct cranial impact in a fall onto a firm surface.

We conclude that interobserver agreement between radiologists is high for CT evaluation of pediatric closed head trauma. Frontal-parietal shearing tear(s) are the most subtle CT finding considered in this study and show the most interobserver variability. Pediatric victims of non-accidental head trauma reveal more frequent intracranial injuries at the time of clinical presentation than those whose injuries are accidental. Although intracranial CT abnormalities in infants and young children should not be considered independently diagnostic of NAT, their discovery should prompt careful evaluation of the family and injury circumstances for indicators of abuse.

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References

1. Merten DF, Carpenter BLM (1990) Radiologic imaging of abusive injury in the child abuse syndrome. Pediatr Clin North Am 37: 815–837
2. Merten DF, Osborne DRS, Radowski MA, Leonidas JC (1984) Craniocerebral trauma in the child abuse syndrome: radiological observations. Pediatr Radiol 14: 272–277
3. Cohen RA, Kaufman RA, Myers PA, Towbin RB (1986) Cranial computed tomography in the abused child with head injury. AJR 146: 97–102
4. Alexander RC, Schor DP, Smith WL (1986) Magnetic resonance imaging of intracranial injuries from child abuse. J Pediatr 109: 975–979
5. Sato Y, Yuh WTC, Smith WL, Alexander RC, Kao SCS, Ellerbroek CJ (1989) Head injury in child abuse: evaluation with MR imaging. Radiology 173: 653–657
6. Duhaime AC, Alario AJ, Lewander WJ, et al (1992) Head injury in very young children: mechanisms, injury types, and opthalmologic findings in 100 hospitalized patients younger than 2 years of age. Pediatrics 90: 179–185
7. Aoki N, Masuzawa H (1986) Subdural hematomas in abused children: report of six cases from Japan. Neurosurgery 18: 475–477
8. Bruce DA, Zimmerman RA (1989) Shaken impact syndrome. Pediatr Ann 18: 482–494
9. Tsai FY, Zee CS, Apthorp JS, Dixon GH (1980) Computed tomography in child abuse head trauma. J Comput Tomogr 4: 277–286
10. Cheah IG, Kasim MS, Shafie HM, Khoo TH (1994) Intracranial haemorrhage and child abuse. Ann Trop Paediatr 14: 325–328
11. Snow RB, Zimmerman RA, Gandy SE, Deck MDF (1986) Comparison of magnetic resonance imaging and computed tomography in the evaluation of head injury. Neurosurgery 18: 45–52
12. Haller JO, Kleinman PK, Merten DF, et al (1991) Diagnostic imaging of child abuse. Pediatrics 87: 262–264
13. Krugman RD, Bays JA, Chadwick DL, Kanda MB, Levitt CJ, McHugh MT (1993) Shaken baby syndrome: abusive cerebral trauma. Pediatrics 92: 872–875
14. Zimmerman RA, Bilaniuk LT, Bruce D, Schut L, Uzzell B, Goldberg HI (1979) Computed tomography of craniocerebral injury in the abused child. Radiology 130: 687–690
15. Zimmerman RA, Russell EJ, Yurberg E, Leeds N (1982) Falx and interhemispheric fissure on axial CT: II. Recognition and differentiation of interhemispheric subarachnoid and subdural hemorrhage. AJNR 3: 635–642
16. Osborn AG, Anderson RE, Wing SD (1980) The false falx sign. Radiology 134: 421–425
17. Harwood-Nash DC (1992) Abuse to the pediatric central nervous system. AJNR 13: 569–575
18. Ball WS (1989) Nonaccidental craniocerebral trauma (child abuse): MR imaging. Radiology 173: 609–610
19. Han JS, Kaufman B, Alfidi RJ, et al (1984) Head trauma evaluated by magnetic resonance and computed tomography: a comparison. Radiology 150: 71–77
20. Gentry LR, Godersky JC, Thompson B, Dunn VD (1988) Prospective comparative study of intermediate-field MR and CT in the evaluation of closed head trauma. AJNR 9: 91–100
21. Zimmerman RA, Bilaniuk LT, Hackney DB, Goldberg HI, Grossman RI (1986) Head injury: early results of comparing CT and high-field MR. AJR 147: 1215–1222
22. Kelley AB, Zimmerman RD, Snow RB, Gandy SE, Heier LA, Deck MDF (1988) Head trauma: comparison of MR and CT – experience in 100 patients. AJNR 9: 699–708
23. Langfitt TW, Obrist WD, Alavi A, et al (1986) Computed tomography, magnetic resonance imaging, and positron emission tomography in the study of brain trauma. J Neurosurg 64: 760–767
24. Gomori JM, Grossman RI, Goldberg HI, Zimmerman RA, Bilaniuk LT (1985) Intracranial hematomas: imaging by high-field MR. Radiology 157: 87–93
25. Fobben ES, Grossman RI, Atlas SW, et al (1989) MR characteristics of subdural hematomas and hygromas at 1.5 T. AJR Am J Roentgenol 153: 589–595
26. Feldman KW, Brewer DK, Shaw DW (1995) Evolution of the cranial computed tomography scan in child abuse. Child Abuse Neglect 19: 307–313
27. Sinal SH, Ball MR (1987) Head trauma due to child abuse: serial computed tomography in diagnosis and management. South Med J 80: 1505–1512
28. Ommaya AK, Gennarelli TA (1974) Cerebral concussion and traumatic unconsciousness. Brain 97: 633–654
29. Johnson DL, Boal D, Baule R (1995) Role of apnea in nonaccidental head injury. Pediatr Neurosurg 23: 305–310
30. Packer RJ, Zimmerman RA, Bilanuik LT, et al (1985) Magnetic resonance imaging of lesions of the posterior fossa and upper cervical cord in childhood. Pediatrics 76: 84–90
31. Jaspan T, Narborough G, Punt JAG, Lowe J (1992) Cerebral contusional tear(s) as a marker of child abuse – detection by cranial sonography. Pediatr Radiol 22: 237–245
32. Calder JM, Hill I, Scholtz CL (1984) Primary brain trauma in non-accidental injury. J Clin Pathol 37: 1095–1100
33. Lindenberg R, Freytag E (1969) Morphology of brain lesions from blunt trauma in early infancy. Arch Pathol 87: 298–305
34. Gentry LR, Godersky JC, Thompson B (1988) MR imaging of head trauma: review of the distribution and radiopathologic features of traumatic lesions. AJNR 9: 101–110