ORIGINAL ARTICLE

Non-accidental brain trauma in infants: diffusion imaging, contributions to understanding the injury process

Traumatismes non accidentels du nourrisson : imagerie de diffusion, contributions dans la compréhension des mécanismes

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KEYWORDS
Non-accidental trauma;
Imaging;
Child abuse;
MRI;
MRI diffusion imaging;
Traumatic

Abstract Analysis of MRI diffusion images from 33 infants suffering from non-accidental trauma reveals five patterns of injury. These are diffuse supratentorial hypoxic ischemic, watershed hypoxic ischemic, venous infarction, diffuse axonal injury and contusion.
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MOTS CLÉS
Traumatisme non
accidental ;
Imagerie ;
Sévices ;
IRM ;
Imagerie de diffusion ;
Traumatisme

Résumé L'analyse de l'IRM de diffusion chez 33 enfants atteints de traumatisme non acciden-tel met en évidence cinq différents types d'atteinte cérébrale. Ils incluent des lésions hypoxo-ischémiques diffuses supratentorielles, des lésions hypoxo-ischémiques des territoires vascu-laires jonctionnels, des infarctus veineux, des lésions axonales diffuses et des contusions.
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Introduction

Since the introduction of diffusion-weighted imaging (DWI) in the mid-1990s as a tool in the identification of acute cytotoxic cell edema, the technique's major clinical application has been to evaluate adult stroke [9,10] and neonatal hypoxic ischemic brain injury [1,12]. To a lesser extent, DWI has made contributions in the characterization of central nervous system (CNS) metabolic disorders [8], certain pediatric brain tumors [4] and cerebral traumatic lesions [7].

This paper looks at the patterns of DWI abnormalities in non-accidental trauma (NAT) in infants and young children who have been the victims of abuse. This is a subject that has received relatively little attention in the literature [2, 11].

Materials and methods

Thirty-three infants and young children, 22 males and 11 females, ranging from 3 weeks to 4 years of age, were evaluated with MRI and DWI over a 4-year period of time. Twenty-five of 33 (76%) were 6 months or younger.

All of the patients selected for this study had an acute brain injury with a positive DWI (restricted motion of water). The 33 patients had a total of 57 CT and 40 MRI examinations during the acute phase of hospitalization following trauma. In all cases a CT preceded the MRI evaluation.

CT examinations utilized a single slice Siemens Somatom CT scanner with a slice thickness of 5 mm, 120 kV and a 1-s scan time with images displayed in brain, subdural and bone windows. MRI scans were performed on one of three Siemens 1.5 Tesla MRI units, sagittal and axial 5 mm spin echo T1WI images were performed with TR = 1000 ms, TE = 11 ms; axial and coronal TSE 5 mm T2WI with TR = 6000, TE = 99 ms, an axial 5 mm T2 gradient echo susceptibility scan with a TR = 636 ms, TE = 12 ms and an axial single shot DWI with a TR = 4300 ms and a TE = 85 ms. The DWI is performed with B0, B500 and B1000 set of images, from which an apparent diffusion coefficient (ADC) is calculated.

Results

Five imaging patterns were found with DWI in the 33 patients with NAT. One type consisted of diffuse supratentorial brain swelling (infarction) involving the cortex and white matter of all cerebral lobes bilaterally. This was present in 13/33 (39%) (Fig. 1). The second pattern showed watershed infarction involving the parasagittal region between the anterior and middle cerebral arteries anteriorly and the posterior middle cerebral arteries posteriorly. In some cases there was also involvement of the inferior temporal lobes between middle and posterior cerebral arteries and the cerebellar hemispheres between the three vascular territories supplying the cerebellum (Figs. 2 and 3). Supratentorial watershed infarctions were found in 12/33 (36%), while two of these 12 also had cerebellar watershed infarctions 2/33 (6%). The third pattern of DWI consisted of venous infarction occurring in the parieto-occipital region unilaterally at the site of venous disruption of bridging veins, 4/33 (12%) (Fig. 4). The fourth pattern was that of diffuse axonal injury (DAI), found in only 2/33 (6%) (Fig. 5). The fifth pattern of injury was that of the contusion, a focal superficial injury at the point of the brain impact on adjacent bony surface of the skull, 2/33 (6%) (Fig. 6).
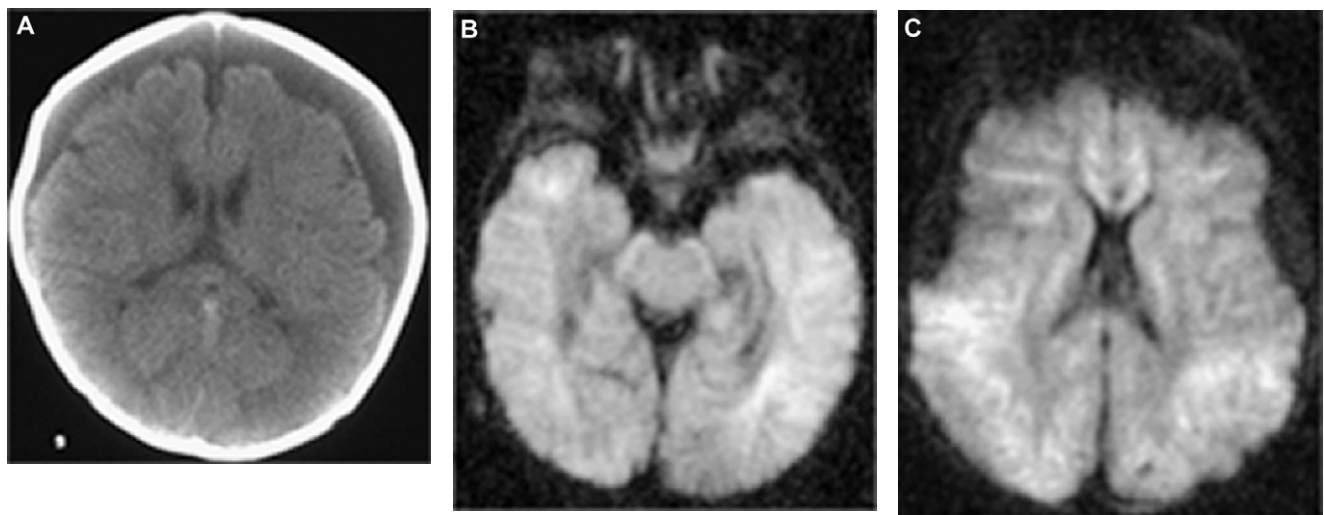

Figure 1 Diffuse supratentorial hypoxic ischemic injury. Eight-week-old male with new onset of seizures, blown left pupil and bulging anterior fontanelle. A: CT on admission to ER, shows bilateral chronic subdural collection; B and C: MRI axial diffusion study, B1000 image, performed 16 hours after CT, shows diffusely restricted motion of water in the supratentorial brain.
Figure 1 Lésions hypoxo-ischémiques diffuses supratentorielles. Nourrisson de huit semaines avec convulsions, mydriase gauche, et bombement de la fontanelle antérieure. A : TDM à l'admission aux urgences : collection sousdurale chronique bilatérale ; B, C : Images axiales en pondération de diffusion (B 1000), réalisées 16 heures après le scanner : restriction de la diffusion au niveau supratentoriel.
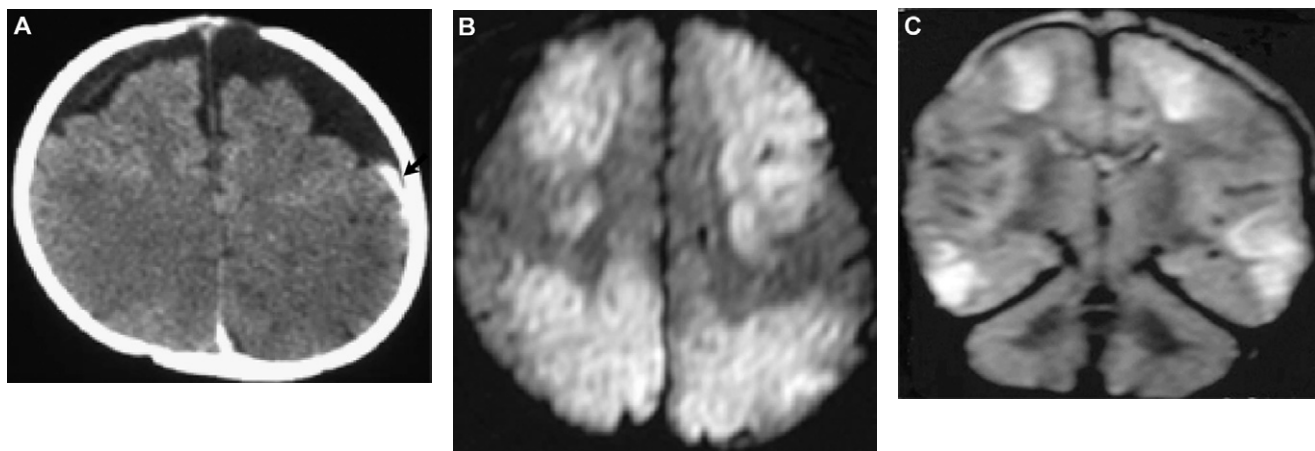
Figure 2 Watershed pattern of supratentorial hypoxic ischemic injury. Four-month-old male with acute mental status change and seizures. A: CT on admission to ER shows bilateral chronic subdural collections with evidence of acute bleed on the left (arrow). Loss of gray white matter discrimination because of cortical edema is present bilaterally; B: MRI axial diffusion, B1000, shows bilateral watershed areas of restricted diffusion in watershed distribution. C. MRI coronal diffusion, B1000, shows bilateral watershed areas of restricted diffusion.

Figure 2 Lésions hypoxo-ischémiques des zones jonctionnelles. Nourrisson de quatre mois avec trouble du comportement aigu et convulsions. A : TDM à l'admission aux urgences : collections soudurales bilatérales chroniques avec saignement aigu du côté gauche (flèche). Perte de la differentiation entre le cortex et la substance blanche due à un œdème cortical bilatéral ; B : Image axiale en pondération de diffusion (B 1000) : restriction de la diffusion dans les zones jonctionnelles ; C : Image coronale en pondération de diffusion : atteinte bilatérale de zones jonctionnelles.
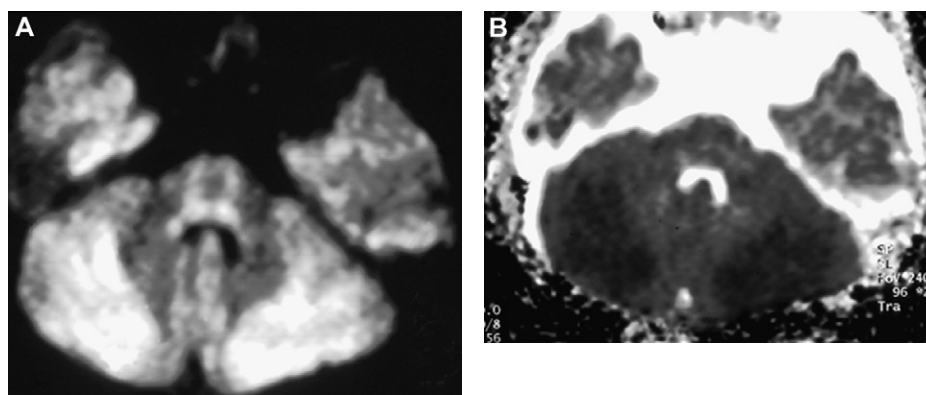

Figure 3 Watershed pattern of infratentorial hypoxic ischemic injury. Seven-month-old male with physical evidence of multiple trauma. CT on admission to ER had shown evidence of bilateral chronic subdural hematomas with fresh bleeding. MRI was performed 48 hours after admission. In addition to supratentorial watershed injuries the posterior fossa was also abnormal. A: MRI, axial B1000 diffusion, shows extensive bilateral cerebellar watershed infarcts; B: MRI, axial ADC map shows abnormal low intensity in the watershed patterns, confirming diffusion abnormalities.

Figure 3 Lésions hypoxo-ischémiques des régions jonctionnelles de la fosse postérieure. Nourrisson de sept mois avec trauma-tismes multiples externes. La TDM à l'admission aux urgences a mis en évidence des hématomes sous duraux chroniques avec du sang frais. L'IRM est réalisée 48 heures après l'admission. La fosse postérieure est anormale associée à des lésions supratentor-ielles des aires jonctionnelles. A : Image axiale en pondération de diffusion (B 1000) : infarctus cérébelleux bilatéral au niveau des zones jonctionnelles ; B : Image axiale de la cartographie ADC : aspect hypo-intense des infarctus jonctionnels.

Discussion

The neuroimaging evaluation of non-accidental brain trauma in infants and young children has evolved dramatically over the last four decades from plain skull films and invasive cerebral arteriography to computed tomography (CT) and MRI. Plain films and CT continue to play an important role in identifying skull fracture as evidence of direct calvarial trauma [3]. CT and conventional MRI with T1, T2, and FLAIR, are the modalities most often utilized for the evaluation of both subdural hematomas and parenchymal brain injury [3,13]. However, while both are sensitive to the detection of blood products and both are good at identifying well-established parenchymal brain abnormalities, neither is that successful in demonstrating early manifestations of cytotoxic edema from infarction/hypoxic ischemia or direct physical trauma.
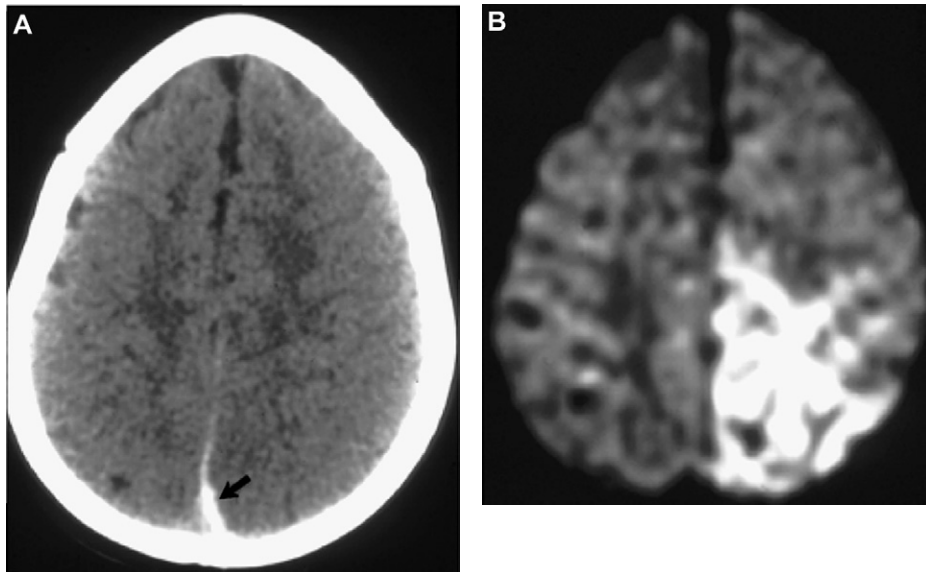
Figure 4   Venous infarction. Five-month-old female with new onset of seizures and lethargy. A: CT on admission to ER, shows acute left-sided subdural bleed along posterior aspect of the superior sagittal sinus (arrow); B: MRI, axial B1000 diffusion, shows focal left parietal infarction.

Figure 4   Infarctus veineux. Nourrisson de cinq mois avec convulsions et léthargie. A : TDM à l'admission : hématome sous-dural aigu gauche le long de la partie postérieure du sinus longitudinal postérieur (flèche) ; B : image axiale en pondération de diffusion (B 1000) : infarctus pariétal gauche focal.
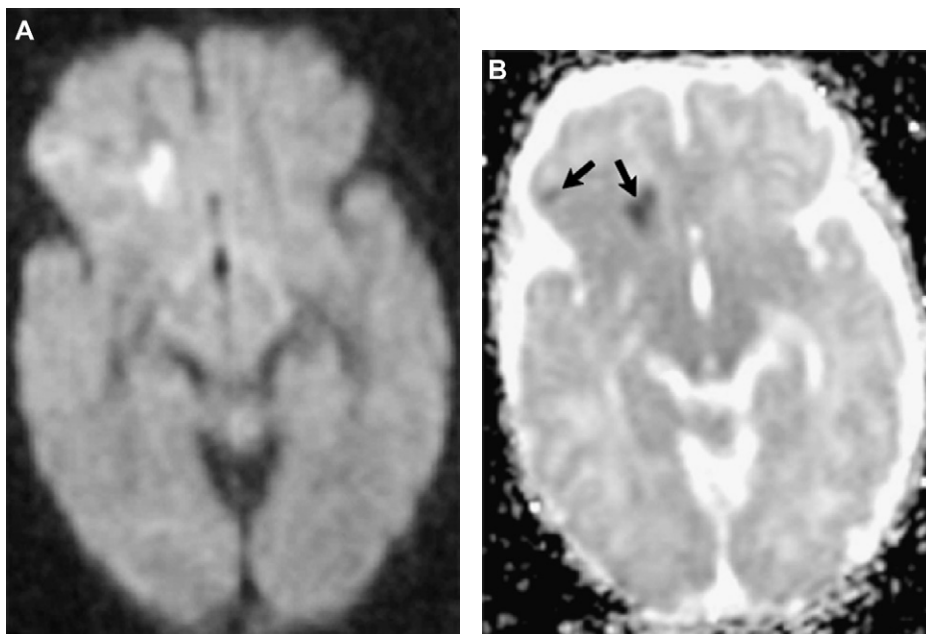

Figure 5   DAI. One-month-old male with fracture of the right femur. CT was negative on admission. MRI was performed 3 days later. A: MRI, axial B1000 diffusion, shows focal white matter areas of restricted diffusion; B: MRI, axial ADC maps, confirms two areas of diffusion abnormalities (arrows). Multiple others were also present at the different levels in the brain.

Figure 5   Lésions axonales diffuses. Nouveau-né d'un mois avec fracture du fémur. La TDM était normale à l'admission. L'IRM est realisée trois jours après. A : Image axiale en pondération de diffusion (B 1000) : lésions focales de la substance blanche avec restriction de la diffusion. B. Image axiale de la cartographie ADC : confirme les anomalies de diffusion (flèche). Des lésions multiples étaient présentes.
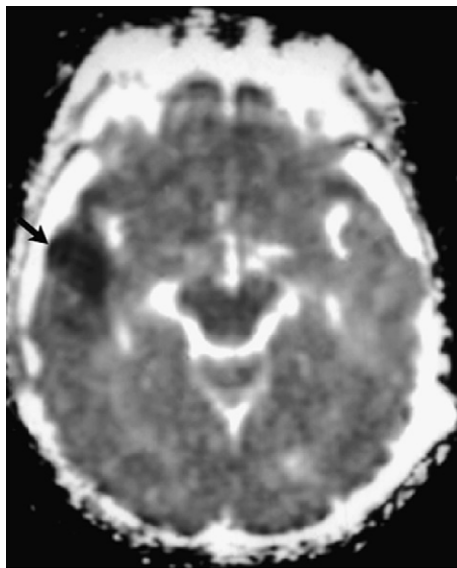
Figure 6   Contusion. Six-month-old male who "fell down." CT on admission showed right-sided subarachnoid hemorrhage. MRI was performed 48 hours later. MRI, axial B1000 ADC, shows right anterior temporal lobe contusion (arrow).

Figure 6   Contusion. Nourrisson de six mois "qui est tombé". La TDM à l'admission a mis en évidence une hémorragie sous-arachnoïdienne droite. L'IRM est réalisée 48 heures plus tard. Image axiale de la cartographie ADC : contusion temporale antérieure droite (flèche).

Diffusion-weighted MR imaging has revolutionized the demonstration of acute cytotoxic cell edema in adult stroke patients with acute cerebral infarction, by showing restriction of the motion of water as high signal intensity on DWI and on the corresponding ADC maps as an area of low signal intensity. In adult stroke and in neonatal HIE these findings are most often associated with irreversible damage to the tissues if the ADC measurements show a numerical reduction of greater than 15% below normal values [5].

Thus, it has been no surprise that in adult and pediatric patients with traumatic brain injury, that DWI MRI would be of value in the early evaluation of these patients [7]. There are already several reports of the utility of DWI in NAT [2, 11], but these papers, while indicating its utility and sensitivity, do not analyze the pattern of injury relative to the potential different mechanisms of injury.

In the 33 patients with non-accidental brain trauma in this series, the patterns of brain injury on DWI indicate one major type of injury having two different levels of magnitude and several other less frequent forms of injury. The first and overwhelming predominant forms of injury are the two related to hypoxic ischemic injury patterns. The more severe form is that of bilateral total supratentorial diffuse cortical and subcortical swelling. This, we believe, represents only a more severe form of the watershed pattern of injury, a more prolonged and perhaps more severe hypoxic ischemic brain injury. Together they account for 75% of patients in this series. The etiology of this injury is most likely the respiratory depression that accompanies injury

to the respiratory centers in the medullae of the brain stem. Dr. Geddes has described pathologically, DAI as a frequent finding in NAT [6]. The DAI to the respiratory centers of the medulla is thought to result from forces exerted on these structures that accompany violent shaking of the head, when the neck muscles offer little physical support.

Two other forms of injury demonstrated on DWI are those that have been associated with trauma in older patients, e.g. contusions and DAI. Both of these are not surprising in that they occur, but are surprising in that they are relatively infrequent in this series, only 6% each. Regarding the low incidence of contusions in this series, it reflects the fact that these were not infants who were hit by blunt objects or were struck onto hard surfaces. On the other hand, DAI which was once thought to be a likely mechanism for the more diffuse brain injuries, both in this series of DWI studies and in the pathological studies of Dr. Geddes et al. [6] reflect that they are infrequent in the supratentorial brain. The fifth form of injury, venous infarction from impairment of venous drainage by rupture of bridging veins, comes as no surprise, as rupture of veins is the common mechanism for the production of acute subdural hemorrhage in this patient population. It should be noted, however, that this study is limited to the patterns of diffusion abnormality and that one or more types of injury pattern could be present, but the larger area of abnormal diffusion could obscure a smaller one arising from a contusion or DAI. Finally, a future study should address the correlation between diffusion MRI and post-mortem examination in order to answer this question.

Conclusion

DWI, besides being sensitive to acute brain injury in non-accidental brain trauma, has been found to have patterns of injury that indicate different mechanisms by which the brain is injured.

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