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PAEDIATRIC NEURORADIOLOGY

Multiplanar reconstructed CT images increased depiction of intracranial hemorrhages in pediatric head trauma

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Abstract
Introduction The benefits of multiplanar reconstructed images (MPR) of unenhanced axial head computed tomography (CT) data have not been established in trauma patients younger than 3 years old, a population in which a reliable history and physical examination may be most difficult. We retrospectively evaluated unenhanced head CTs in pediatric trauma patients to investigate the various benefits of MPR in this age group.
Methods A total of 221 unenhanced head CTs performed for any case of head trauma (HT) on children younger than 3 years old were independently reviewed by two radiologists. Studies were reviewed first in the standard axial plane alone and then with the addition of MPR. Reviewers were asked to determine if the MPR affected the ability to make findings of hemorrhage, incidental findings, and artifacts.
Results MPR improved the detection of hemorrhage in 14 cases (6.5 %, p-value<0.01) and incidental findings in five cases (2.3 %, p-value<0.05) as well as helped prove artifacts in five cases (2.3 %, p-value<0.05).
Conclusion Routine use of MPR in HT patients younger than 3 years old has the potential to increase the detection of acute and incidental imaging findings.

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Keywords Craniocerebral trauma · Brain hemorrhage, traumatic · Abusive head trauma · Pediatrics

Introduction

Pediatric head trauma (HT) results in hundreds of thousands of emergency department (ED) visits each year, and rates are increasing in patients younger than 3 years old [1]. Computed tomography (CT) is sometimes utilized in the evaluation of these patients. Multiplanar reconstructed images (MPR) of unenhanced axial head CT data have been shown to improve the detection of intracranial hemorrhage (ICH) [2] and other subtle findings [3] in patients 3 years old to adulthood. To our knowledge, the benefits of MPR have not been established in HT patients younger than 3 years old, a population in which a reliable history and physical examination may be most difficult.

Coronal and sagittal MPR are routinely obtained on trauma patients in this age group at our institution, and prior literature regarding this topic in the adult population [2, 3] led us to hypothesize that these images do significantly improve the detection of ICH. It was also felt that MPR assists in differentiating small ICH from motion artifact, a common problem in this age group. Also, while incidental findings are common in head CT evaluation of pediatric trauma patients [4], it was hypothesized that detection of incidental findings was increased with routine MPR acquisition. Therefore, we retrospectively evaluated unenhanced head CTs in pediatric HT patients to investigate the potential benefits of MPR in this age group. Specifically, we examined how

MPR affected the detection of hemorrhages, incidental findings, and artifacts.

Materials and methods

Patient selection

As this scanning and reconstruction procedure has been the standard protocol at our institution for nearly 3 years, we retrospectively reviewed cases from the previous 2 years. A total of 1849 unenhanced head CTs were performed on children under 3 years old in the ED at Children's Hospital of Pittsburgh over this 2-year period. Of those, 356 consecutive cases were reviewed for exam indication and patient history, and 221 cases were identified as having been performed for HT. Of those, six were excluded due to lack of soft tissue algorithm MPR. Analysis was performed on the remaining 215 reviewed studies. The mean age of the study population was 15.4 months at the time of imaging (standard deviation 12.5 months) with 59 % being male. This study design was approved by the Institutional Review Board (IRB).

Scanning procedure

All patients were scanned per routine institutional protocol for head CT evaluation of trauma patients younger than 3 years old. CT images were acquired on a GE Lightspeed VCT 64 slice CT scanner (GE Healthcare, Milwaukee, WI, USA) by using axial acquisition from the skull base to just above the vertex. Scanning was performed with a kVp of 120 and mAs of 130. Dose reduction techniques were achieved utilizing adaptive statistical iterative reconstruction, as previously described [5]. In our patients, a head CT resulted in an average dose length product (DLP) of 250 mGy cm.

Images were reconstructed into contiguous 5- and 0.625-mm axial datasets by using a soft tissue algorithm, and 1.25- and 0.625-mm axial datasets were reconstructed using bone algorithm. Coronal and sagittal MPR were routinely created from axial source data using soft tissue algorithm at 5-mm slice thickness. The imaging protocol also typically included coronal and sagittal MPR in bone algorithm at 1.2-mm slice thickness as well as 3D surface-rendered reconstructed images of the skull created from the 0.625-mm axial images in soft tissue algorithm; however, bone algorithm images and 3D reconstructions were not specifically reviewed as part of this study, so their absence did not result in study exclusion.

Image analysis

Each study was independently reviewed by two radiologists. Cases of discrepancy were reviewed by a third radiologist. Studies were reviewed first in the standard axial plane alone and then with the addition of coronal and sagittal MPR. Reviewers were asked to determine if the MPR affected the ability to identify hemorrhages, incidental findings, and artifacts. The negative, null, or positive effect of MPR was recorded on an evaluation sheet as −1, 0, or +1, respectively. −1 was answered if MPR actually affected the ability to identify a finding, 0 if MPR neither helped nor affected the ability to identify a finding, and +1 if MPR improved the diagnostic capability.

Statistical analysis

The total number of −1, 0, and 1 responses were recorded for each category: hemorrhages, incidental findings, and artifacts. A chi-square contingency was used in each category to assess the significance of our results. Using the Bonferroni method to correct for multiple comparisons in these three categories, a p-value of <0.0167 (0.05/3) was considered statistically significant.

Results

Reviewer responses are summarized in Table 1. In 14 of 215 cases (6.5 %), ICH which was not initially detected on axial images was subsequently discovered on coronal and/or sagittal MPR (Figs. 1, 2, 3, 4, and 5), and this benefit was considered statistically significant (p-value 0.000142). In one case, two different foci of hemorrhage were better identified on MPR (Fig. 4). All 14 cases of hemorrhage better identified on MPR were extra-axial and included six cases of subdural hemorrhage (SDH), six cases of epidural hemorrhage (EDH), and two cases of subarachnoid hemorrhage (SAH). ICH was ultimately present in a total of 26 of 215 cases (12.1 %), so the 14 additional hemorrhages identified on MPR made up more than half of the total ICH cases.

In four of 14 cases, hemorrhages were located at the vertex along the falx cerebri (Fig. 4b). In two of 14 cases, hemorrhages were identified along the tentorium extending into the posterior fossa (Fig. 4a). A third case of posterior fossa hemorrhage was identified separate from the tentorium. In seven of 14 cases, hemorrhages were supratentorial but separate from both the falx and tentorium (Fig. 2). In one of 14 cases, hemorrhage was located in the middle cranial fossa (Fig. 1b). In 12 of the 14 cases, axial images were still considered abnormal due to fracture, scalp swelling/hematoma, or concomitant intracranial hemorrhage (ICH). In two of the 14 cases, axial images were considered completely normal before discovering hemorrhage on MPR.

Coronal and/or sagittal MPR revealed incidental findings in five cases that were not detected on axial images (Fig. 6). These included Chiari 1 malformation (2 cases), vermian hypoplasia, a small infratentorial fluid collection, and an orbital foreign body not appreciated on axial images but seen on

Table 1 Effect of additional coronal and sagittal MPR in evaluating unenhanced head CT images on trauma patients younger than 3 years old compared to axial alone (n=215). The negative, null, or positive effect of MPR was recorded as −1, 0, or +1, respectively, for evaluation of hemorrhages, incidental findings, and artifacts

Reviewer response	Hemorrhages	Incidental findings	Artifacts
+1	14 (6.5 %)	5 (2.3 %)	5 (2.3 %)
	p-value 0.000142	p-value 0.0245	p-value 0.0242
0	201	210	209
−1	0	0	1 (0.5 %)

MPR. These benefits were considered marginally significant (p-value >0.02). In another five cases, questionable findings on axial images proved to represent artifact after a review of MPR (Fig. 7). Motion artifact accounted for two of the five cases, while slice selection, beam hardening artifact, and volume averaging accounted for the others. These benefits were also considered marginally significant (p-value >0.02).

The presence or absence of concern for abusive head trauma (AHT) was discussed in the electronic medical records of all 14 cases in which MPR improved the detection of hemorrhage. Nine of the 14 cases involved a Child Advocacy Center consult, and four cases were evaluated by a social worker. Four of the 14 cases were ultimately deemed AHT after extensive evaluation and further investigation (Figs. 1 and 4). Among the four AHT patients, all four demonstrated multiple extra-axial hemorrhages, three demonstrated convexity hemorrhage, and two demonstrated interhemispheric hemorrhage. While undocumented suspicion of AHT may have existed in all of these cases, of these four cases, only one specifically listed concern for AHT as an indication for the exam, and the other three listed HT as the indication for CT. All four of these patients ultimately had other findings of non-accidental trauma including fractures, retinal hemorrhages, and/or suspicious bruising.

Greater than 90 % of cases were not affected by the addition of MPR compared to axial images alone. This resulted in many "0" responses. In one of 215 cases (0.5 %), both reviewers agreed that an area of probable artifact was exaggerated on MPR compared to axial images alone, and this was the only example of negative effect of the additional MPR.

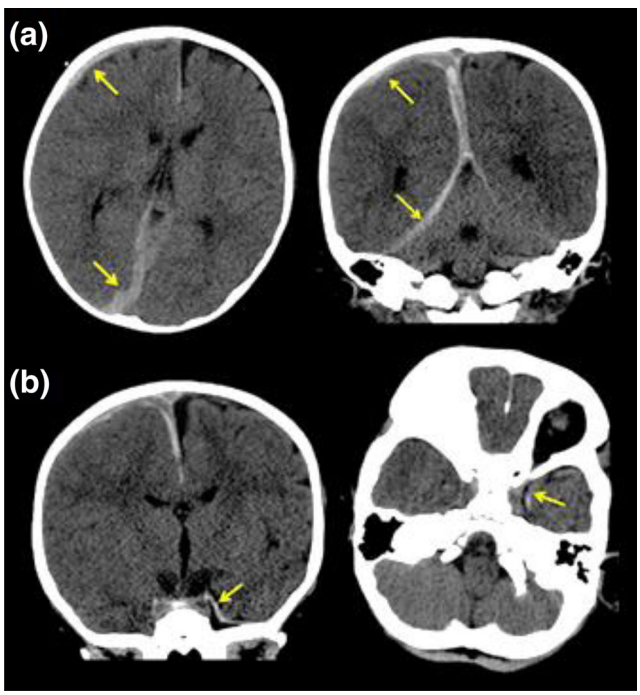

Fig. 1 A 16-month-old who reportedly fell down ten steps. A right subdural hematoma is easily seen on both axial and coronal images (**a**). A second small left subdural was not appreciated on axial imaging but stood out on coronal MPR (**b**). This was seen retrospectively on a single axial image. Bilateral hemorrhages raised suspicion for abusive head trauma, which was later confirmed after further investigation and discovery of additional injuries

Discussion

The results from this study demonstrated significantly improved detection of ICH in the setting of trauma in patients

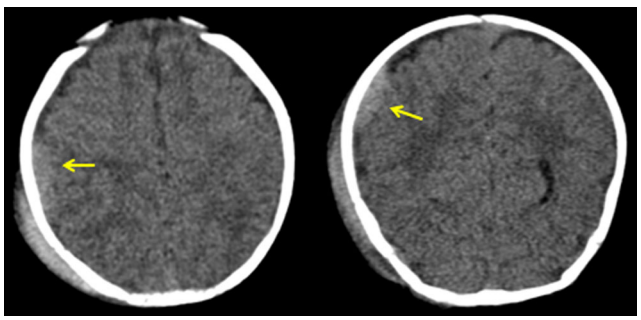

Fig. 2 Reportedly, a 3-month-old who fell from dad's arms to a carpeted floor. An epidural hematoma adjacent to a skull fracture is much better seen on coronal (*right*) images than axial (*left*) images at the same window and level

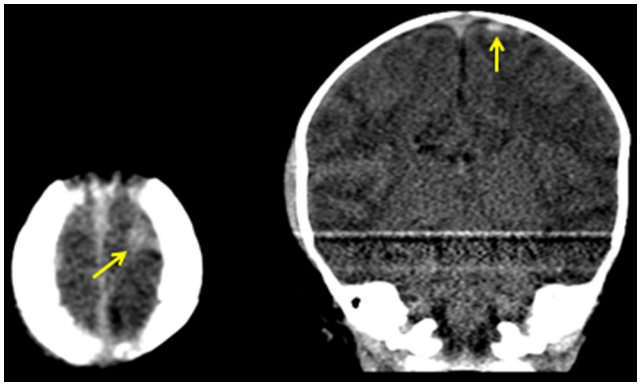

Fig. 3 A 20-day-old who fell out of a bouncy chair while mom was carrying it. Hemorrhage present at the vertex was seen much better on coronal images (*right*) than axial images (*left*)

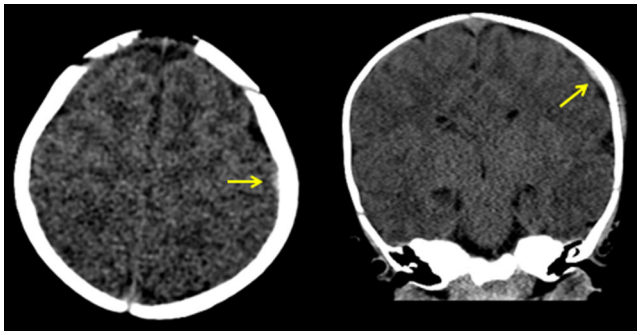

Fig. 5 A 1-month-old dropped by the father onto a hardwood floor after he slipped on the stairs. A small epidural hematoma was not detected on axial images (*left*) but was depicted on coronal MPR (*right*)

younger than 3 years old with the use of coronal and sagittal MPR during unenhanced head CT examination. In 6.5 % of cases, ICH not detected on standard axial images alone was discovered on coronal and/or sagittal MPR, and these cases made up more than half of the total cases in which ICH was diagnosed. Features of ICH detected on MPR but not axial images included small size, location near the vertex or along tentorium, and isodensity to brain parenchyma, similar to findings in studies of older age groups [2, 3]. In one study of older age groups [2], hemorrhages detected on MPR but not axial images were more likely to be parenchymal and/or located at the floor of the anterior or middle cranial fossae than in our study population, in which all missed hemorrhages were extra-axial and most commonly at the vertex or along the tentorium. This difference in hemorrhage location in children younger than 3 years old may reflect the differences in skull, membranous sutures, and brain deformation patterns in response to trauma compared to adults [6]. The region just below the vertex may be more subject to volume averaging artifact on axial images due to the convex morphology of the calvarium, which may not allow clear depiction of blood.

Interestingly, four of the 14 cases that benefitted from addition of MPR in detecting ICH were in cases of AHT. In these cases, MPR became an important component of the diagnostic evaluation. Children younger than 3 years old are at greatest risk for AHT [7]. In one study, AHT was found to be the cause of the majority of subdural ICH in children younger than 3 years old [7]. The shear modulus for infant brain tissue model is lower compared to adults, resulting in an increased brain susceptibility to traumatic brain injury [8]. Among the four AHT patients in our study that benefitted from MPR, all four demonstrated multiple extra-axial hemorrhages, three demonstrated convexity hemorrhage, and two demonstrated inter-hemispheric hemorrhage. This further supports the use of MPR since Kemp et al. in a review of the literature showed

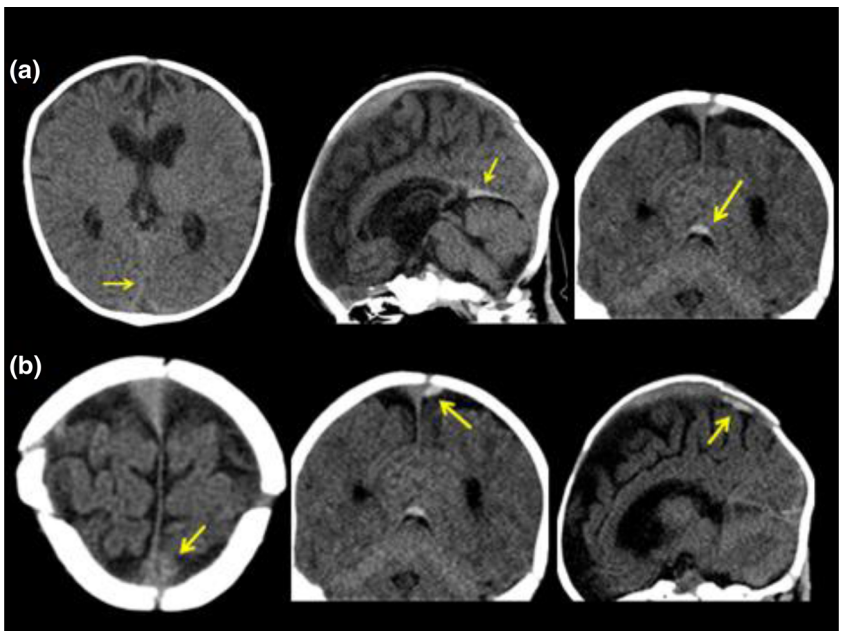

Fig. 4 A 2-month-old with concern for abusive head trauma. Skull fractures were easily detected in all planes, but acute blood along the tentorium was appreciated only on MPR (**a**). Acute blood adjacent to the falx cerebri at the vertex was visualized on both coronal and sagittal MPR after being inconclusive on axial images (**b**). Multiple additional injuries and further investigation later confirmed abusive head trauma

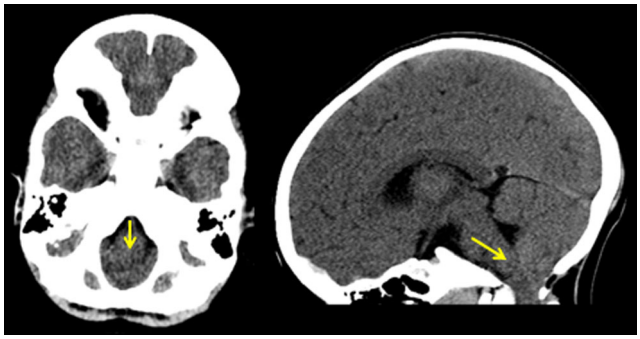

Fig. 6 A 30-month-old who hit the back of head on a bathtub. No traumatic intracranial abnormality was found, but incidental findings of Chiari 1 malformation including ventral medullary kinking and herniation of the cerebellar tonsils greater than 5 mm below the foramen magnum were better seen on sagittal MPR (*right*)

that inter-hemispheric hemorrhages, convexity hemorrhages, multiple extra-axial hemorrhages, and posterior fossa hemorrhages were significantly associated with AHT [9]. Furthermore, wall thickness of the bridging veins is significantly decreased where they penetrate the dura mater (10 μm) compared to the subarachnoid segments of the bridging veins (50–200 μm). This suggests increased vulnerability of the bridging veins to shearing injury in the subdural space compared to the subarachnoid space [10]. Because a history of trauma is not always offered in cases of AHT, routine creation of MPR in unenhanced CT evaluation in this age group without history of trauma could potentially increase the detection of ICH particularly in AHT at no additional radiation or cost, and more investigation into these associations as well as into the additional role of brain magnetic resonance imaging (MRI) in cases of suspected AHT is needed.

Five cases benefitted from MPR in the visualization of incidental findings, including Chiari 1 malformation, vermian hypoplasia, a small infratentorial fluid collection, and an orbital foreign body. These results were considered marginally statistically significant. Four of these cases underwent no further imaging at our institution, and the infratentorial fluid collection was considered normal on CT and MRI performed 8 months later. Midline malformations including callosal anomalies, vermian dysplasia, and vermian ectopia may be better depicted on MPR due to the increased visualization of the anatomical contours of the midline structures. Although pediatric Chiari 1 malformations may change over time, only a minority result in neurosurgical intervention, and the clinical significance of incidental detection is unclear [11].

In five cases, questionable abnormalities seen on axial images proved to represent artifacts after addition of MPR. Motion was not uncommon in this age group and was the artifact encountered in two of the five artifact cases, while slice selection, beam hardening artifact, and volume averaging accounted for the others. While these results were considered marginally statistically significant, they do highlight the value of MPR in characterizing CT-related artifacts, which in the setting of head trauma in children younger than 3 years old may have the potential to decrease the need for follow-up CT evaluations, likely decreasing the long-term effects of radiation exposure during childhood [12, 13].

More than 90 % of cases in our study were not affected by the addition of MPR compared to axial images alone. Many of these cases were considered normal in all three planes. Others had findings easily seen on all planes, including axial images alone. Technically, MPR are easily and quickly created from source axial images with no additional radiation exposure to the patient. In only one of 215 cases did both reviewers agree that the MPR negatively affected the interpretation of the study. This case contained an area of probable artifact that was exaggerated on MPR.

In summary, pediatric HT requiring CT evaluation is very common, including children younger than 3 years old, a population in which a reliable history and physical examination may be most difficult. This study suggests that routine creation of MPR during unenhanced head CT examination significantly increases the detection of hemorrhages in HT patients younger than 3 years old, which may have beneficial implications in the setting of accidental HT and AHT. Visualization of incidental findings and artifacts may also be improved but is less certain. MPR are easily and quickly created and interpreted and should be a routine part of CT protocols in this age group.

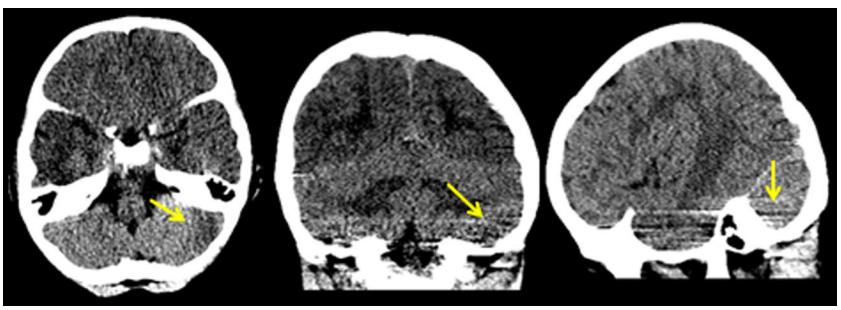

Fig. 7 A 14-month-old who fell down ten carpeted stairs. While there was no ICH or fracture detected, a focal hypodensity in the left cerebellar hemisphere was initially concerning for edema on axial images (*left*). This was shown to be artifact on coronal (*center*) and sagittal (*right*) MPR

Ethical standards and patient consent We declare that all human and animal studies have been approved by the UPMC Institutional Review Board and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

Conflict of interest We declare that we have no conflict of interest.

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