Computed Tomography Vs Magnetic Resonance Imaging for Identifying Acute Lesions in Pediatric Traumatic Brain Injury

**authors**

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**key words**

pediatrics, acute brain injuries, magnetic resonance imaging, child abuse

**abbr eviations**

AHT: abusive head trauma
CT: computed tomography
EDH: epidural hematoma
GCS: Glasgow Coma Scale
IQR: interquartile range
SAH: subarachnoid hemorrhage
SDH: subdural hematoma
TAI: traumatic axonal injury
TBI: traumatic brain injury

**abstract**

**BACKGROUND AND OBJECTIVE:** Pediatric traumatic brain injury (TBI) is a leading cause of morbidity and mortality in children. Computed tomography (CT) is the modality of choice to screen for brain injuries. MRI may provide more clinically relevant information. The purpose of this study was to compare lesion detection between CT and MRI after TBI.

**METHODS:** Retrospective cohort of children (0–21 years) with TBI between 2008 and 2010 at a Level 1 pediatric trauma center with a head CT scan on day of injury and a brain MRI scan within 2 weeks of injury. Agreement between CT and MRI was determined by κ statistic and stratified by injury mechanism.

**RESULTS:** One hundred five children were studied. Of these, 78% had mild TBI. The MRI scan was obtained a median of 1 day (interquartile range, 1–2) after CT. Overall, CT and MRI demonstrated poor agreement (κ = −0.083; P = .18). MRI detected a greater number of intraparenchymal lesions (n = 36; 34%) compared with CT (n = 16; 15%) (P < .001). Among patients with abusive head trauma, MRI detected intraparenchymal lesions in 16 (43%), compared with only 4 (11%) lesions with CT (P = .03). Of 8 subjects with a normal CT scan, 6 out of 8 had abnormal lesions on MRI.

**CONCLUSIONS:** Compared with CT, MRI identified significantly more intraparenchymal lesions in pediatric TBI, particularly in children with abusive head trauma. The prognostic value of identification of intraparenchymal lesions by MRI is unknown but warrants additional inquiry. Risks and benefits from early MRI (including sedation, time, and lack of radiation exposure) compared with CT should be weighed by clinicians.

Traumatic brain injury (TBI) is responsible for almost half a million emergency department visits each year in children 0 to 14 years old1 and is the leading cause of injury-related mortality in infants and children.2 One factor that contributes to morbidity is the degree of focal intraparenchymal brain injury or presence of diffuse injury. These intraparenchymal injuries may include contusions, traumatic axonal injury (TAI), and ischemia. In adults, the presence of these focal lesions is an important predictor of poor functional outcome.3,4

Computed tomography (CT) imaging has been the preferred modality for the acute evaluation of TBI in the emergency department because it can be completed quickly, is readily available in most centers, and does not require sedation. CT is effective at accurately identifying lesions such as fracture, acute hemorrhage, and mass effect, all of which may warrant emergent neurosurgical intervention.5,6 However, recent literature suggests that the exposure to radiation associated with...
CT may outweigh the potential benefits in some children with presumed minor injuries. MRI offers the advantage of greater anatomic detail of brain parenchyma and monitoring injury over time, without radiation exposure, but often requires sedation. Existing research in imaging for pediatric TBI has been limited to selected subgroups. Analysis of this type has not previously been reported in such a diverse group of severities and etiologies of pediatric TBI. Overall, the literature is inadequate to yield a level 1 or level 2 recommendation for the specific type of imaging for evaluation of acute brain injury in the guidelines for treating these children.

We sought to compare the findings for early CT and MRI modalities in children regardless of severity or mechanism to assess the agreement of the modalities in the acute period.

METHODS

Study Design

All children (0–21 years old) with a diagnosis of TBI admitted to a freestanding children’s hospital (level I trauma center) during a 3-year time period (2008–2010) were retrospectively studied. Severity of TBI was determined by Glasgow Coma Scale (GCS) at time of presentation to the emergency department. Patients with a head CT scan obtained on the day of injury and an MRI scan of the brain within 14 days of the injury made up the study sample. The timing of neuroimaging is similar to that previously reported in adults. Patients were excluded if the neuroimaging studies were unavailable or the MRI was obtained >2 weeks after the injury. The use of MRI is not protocolized at the institution but follows general standard of care for treatment of patients with TBI. At the discretion of the attending physician, follow-up MRI is obtained for patients with lesions or symptoms that warrant additional imaging. The study was conducted in accordance with protocols approved by the institutional review board at Phoenix Children’s Hospital.

Image Technique

Contiguous axial CT images of the head were obtained at 3-mm intervals. Brain MRI was performed with a 1.5-Tesla magnet under our TBI protocol for pediatric imaging with sagittal T1, axial T1/T2/Fluid attenuated inversion recovery/diffusion weighted imaging/gradient echo, and coronal T2 sequences. Limited MRI included sagittal, axial, and coronal turbo spin echo T2 and axial and coronal gradient echo sequences. One pediatric radiologist and 1 pediatric neuroradiologist, blinded to clinical information, reviewed CT and MRI scans to identify abnormalities by consensus ($\kappa = 0.79$).

Data Collection and Analysis

Abstracted medical record data included age at time of injury, gender, mechanism of injury, first documented GCS, and symptoms. For calculating the age of injury for abusive head trauma (AHT) cases, we imputed the date of injury with the date of presentation. Findings on CT and MRI scans were characterized as extraparenchymal lesions (basal cistern compression, midline shift, extraaxial collections) and intraparenchymal lesions (TAI, contusions, and ischemia). Classification of contusions was based on T2 hyperintensity with corresponding susceptibility and ischemia on presence of diffusion restriction. Mechanism of injury was dichotomized as either abusive or accidental. Abuse was based on determination by the institution’s child forensic team investigation of caregiver interviews and clinical findings (ophthalmologic examination, radiographic imaging [skeletal survey, abdominal CT] as indicated).

Data were analyzed to describe the presence and type of abnormality identified on CT or MRI and mechanism of injury (abusive versus accidental). Continuous data are presented with the median and interquartile range (IQR). The agreement between CT and MRI was measured and classified using the $\kappa$ statistic. The agreement was also examined in terms of accidental or abusive injury mechanism.

RESULTS

There were 203 patients who presented with TBI from 2008 to 2010. Of these, 98 were excluded because imaging was unavailable ($n = 1$ [severe]), not performed ($n = 27$ [all mild]), or no brain MRI within 2 weeks of injury ($n = 70$ [64% mild]). In the remaining sample of 105 patients, 78% ($n = 82$ out of 105) were diagnosed with mild TBI (GCS 13–15). Table 1 presents the demographics of the study cohort. Subjects classified with AHT were younger (5 months; IQR 3–9) than those with an accidental injury (62 months; IQR 11–137) ($P < .001$). AHT was ultimately diagnosed in 35% ($n = 37$) of cases, of which 68% were mild TBI.

CT and MRI Findings

Overall, findings on early CT and MRI within 2 weeks of injury demonstrated poor agreement ($\kappa = -0.083; P = .18$). The median interval between imaging modalities was 1 day (IQR, 1–2). Restricting the analysis to MRI performed within 1 day of injury did...
There was substantial agreement in the identification of extraaxial collections \((\kappa = 0.65, P < .001)\) and midline shift \((\kappa = 0.64, P < .001)\). The presence of extraaxial hemorrhage on CT as compared with MRI was discordant in 19 subjects; 6 had no hemorrhage present on CT but had a subdural hematoma (SDH) on MRI, an epidural hematoma (EDH) on CT was classified as SDH on MRI \((n = 1)\), an SDH on CT was classified as EDH on MRI \((n = 1)\), 1 had an SDH on CT and an additional finding of EDH on MRI, 2 had an SDH on CT classified as subarachnoid hemorrhage (SAH) on MRI, and 8 with an SDH \((n = 6)\) or EDH \((n = 2)\) on CT had no hemorrhage present on MRI. Two subjects with a basal cistern abnormality (1 compressed and 1 absent) had no abnormality detected on MRI \((92\%\) agreement).

There was moderate agreement for the detection of intraparenchymal lesions \((\kappa = 0.42, P < .001)\), with a greater number detected using MRI \((n = 36, 34\%)\) compared with CT \((n = 16, 15\%)\) \((P < .001)\). The higher prevalence of lesions on MRI included TAI in 8 subjects that was not seen on CT. There was moderate agreement for contusions \((\kappa = 0.48, P < .001)\) and ischemia \((\kappa = 0.43, P < .001)\). MRI detected contusions in 13 subjects and ischemia in 6 subjects that were not visualized on CT.

### AHT Versus Accidental TBI

The CT and MRI findings stratified by AHT versus accidental TBI are summarized in Table 2. In the subset of patients with AHT, agreement between CT and MRI was lower compared with that of accidental TBI for extraparenchymal \((\kappa = 0.23 [P = .060] vs \kappa = 0.71 [P < .001])\) and intraparenchymal \((\kappa = 0.27 [P = .008] vs \kappa = 0.52 [P < .001])\) lesions. Disagreement was greatest for intraparenchymal lesions; there was a 3-fold difference in detection rate for AHT compared with 1.5-fold for accidental (Table 2). An example of TAI seen only on MRI in a patient with AHT is depicted in Fig 1.

### DISCUSSION

Neuroimaging modalities including CT and MRI are important for diagnosis and guiding therapeutic management in infants and children with TBI. The purpose of this study was to compare the findings between CT and MRI modalities in a representative sample of pediatric patients with TBI.

There was poor agreement between early CT and MRI within 2 weeks of injury. Time interval from early CT to MRI may affect the agreement.

### TABLE 1 Characteristics of Study Sample

<table>
<thead>
<tr>
<th>Age, mo</th>
<th>(n)</th>
<th>(%)</th>
</tr>
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<tbody>
<tr>
<td>(\leq 12)</td>
<td>49</td>
<td>(66.7)</td>
</tr>
<tr>
<td>12–23</td>
<td>9</td>
<td>(6.6)</td>
</tr>
<tr>
<td>24–59</td>
<td>11</td>
<td>(10.5)</td>
</tr>
<tr>
<td>60+</td>
<td>36</td>
<td>(43.3)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>TBI severity</th>
<th>(n)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild (GCS 13–15)</td>
<td>82</td>
<td>(78.1)</td>
</tr>
<tr>
<td>Moderate (GCS 9–12)</td>
<td>10</td>
<td>(9.5)</td>
</tr>
<tr>
<td>Severe (GCS &lt;8)</td>
<td>13</td>
<td>(12.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanism of injury</th>
<th>(n)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>47</td>
<td>(44.8)</td>
</tr>
<tr>
<td>Motor vehicle accident</td>
<td>6</td>
<td>(5.7)</td>
</tr>
<tr>
<td>Abuse</td>
<td>1</td>
<td>(1.0)</td>
</tr>
<tr>
<td>Recreational</td>
<td>4</td>
<td>(3.8)</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>(5.7)</td>
</tr>
<tr>
<td>Unknown</td>
<td>4</td>
<td>(3.8)</td>
</tr>
<tr>
<td>ICP monitor</td>
<td>7</td>
<td>(7)</td>
</tr>
<tr>
<td>Mortality</td>
<td>1</td>
<td>(1)</td>
</tr>
</tbody>
</table>

There were 8 subjects with an early CT classified as normal, and 7 of these 8 (87.5%) had a mild TBI. Three (37.5%) of these had an abusive etiology, of which 1 was a severe TBI (GCS 5). Among subjects with a normal early CT, MRI (median 2.5 [IQR, 0.5–3.5] days) identified abnormalities in 75% \((n = 6)\), including SDH in 2 subjects, contusion in 2, and ischemia in 3. Two of the 8 subjects had normal MRI scans (both accidental etiology).

### TABLE 2 Abnormalities on Early CT and Subsequent MRI in Pediatric Patients With an Accidental TBI or AHT

<table>
<thead>
<tr>
<th>Accidental ((n = 68))</th>
<th>(%)</th>
<th>MRI</th>
<th>(%)</th>
<th>CT</th>
<th>(%)</th>
<th>AHT ((n = 37))</th>
<th>(%)</th>
<th>MRI</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraparenchymal(^a)</td>
<td>47</td>
<td>(69.1%)</td>
<td>42</td>
<td>(61.8%)</td>
<td>32</td>
<td>(86.5%)</td>
<td>35</td>
<td>(94.6%)</td>
<td></td>
</tr>
<tr>
<td>Basal cisterns</td>
<td>1</td>
<td>(2.7%)</td>
<td>0</td>
<td>(0%)</td>
<td>1</td>
<td>(2.7%)</td>
<td>0</td>
<td>(0%)</td>
<td></td>
</tr>
<tr>
<td>Compressed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Absent</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midline shift, mm</td>
<td>4</td>
<td>(5.9%)</td>
<td>5</td>
<td>(7.3%)</td>
<td>6</td>
<td>(16.2%)</td>
<td>3</td>
<td>(8.1%)</td>
<td></td>
</tr>
<tr>
<td>1–5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6–10</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extraxial</td>
<td>47</td>
<td>(77.2%)</td>
<td>42</td>
<td>(61.8%)</td>
<td>32</td>
<td>(86.5%)</td>
<td>35</td>
<td>(94.6%)</td>
<td></td>
</tr>
<tr>
<td>EDH</td>
<td>15</td>
<td>13</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDH</td>
<td>30</td>
<td>24</td>
<td>29</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAH</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1+</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraparenchymal(^b)</td>
<td>12</td>
<td>(17.6%)</td>
<td>20</td>
<td>(29.4%)</td>
<td>4</td>
<td>(10.8%)</td>
<td>16</td>
<td>(43.2%)</td>
<td></td>
</tr>
<tr>
<td>TAI</td>
<td>0</td>
<td>(0%)</td>
<td>2</td>
<td>(2.9%)</td>
<td>0</td>
<td>(0%)</td>
<td>6</td>
<td>(16.2%)</td>
<td></td>
</tr>
<tr>
<td>Contusion</td>
<td>12</td>
<td>(17.6%)</td>
<td>17</td>
<td>(25.0%)</td>
<td>2</td>
<td>(5.4%)</td>
<td>10</td>
<td>(29.7%)</td>
<td></td>
</tr>
<tr>
<td>Ischemia</td>
<td>0</td>
<td>(0%)</td>
<td>2</td>
<td>(2.9%)</td>
<td>2</td>
<td>(5.4%)</td>
<td>6</td>
<td>(16.2%)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Frequency estimates are not mutually exclusive.

\(^b\) >1 extraxial hemorrhage present.
The median interval was 1 day in our cohort. Among the 13 subjects with a contusion, 7 underwent MRI within 1 day of injury. Similarly, MRI was performed within 1 day of injury in 4 of the 6 subjects with ischemia. Given the inherent differences between CT and MRI modalities, it is not unexpected that MRI identified contusions and ischemia more readily than CT.

Compared with CT, MRI detected nearly 3 times as many intraparenchymal lesions (15% CT vs 44% MRI), including TAI. This discordance in detection of intraparenchymal lesions is worse than that reported by Lee et al for adults with mild TBI (GCS 13–15) (50% CT vs 75% MRI). More recently, the same group presented research findings confirming the greater sensitivity of MRI for focal lesions in a larger cohort of adults with mild TBI.15 Although our cohort showed overall lower rates of intraparenchymal lesions than adults, the discrepancy between CT and MRI findings in pediatric TBI is notable.

Similar investigations in a pediatric population have been less comprehensive. In a 2009 literature review, Kemp et al found that MRI was useful in identifying additional or evolving injury in 25% of patients with abnormal early CT scans. Only 13 patients (out of the 367 in the meta-analysis) had a normal early CT examination, 8 of whom had new findings on a later MRI scan. This same year, in a cohort of 47 patients with AHT and both an early CT and subsequent MRI examination, Foerster et al provided additional evidence of injury for risk stratification for poor outcomes. Only 1 of the subjects in this cohort had a normal early CT scan. In both studies, additional pathology included SDH, SAH, TAI or shearing injury, and ischemia or infarction. Foerster et al showed that ischemia or TAI was of adverse neurologic outcomes in the population with AHT.

Although substantial agreement between CT and MRI was noted for the identification of extraxial lesions, there was disagreement in 19 subjects. Seven of these subjects had negative CT scans but had a lesion (6 SDH) on MRI. Of the 6 subjects with SDH, the MRI was obtained within 1 day of injury for 4 patients and 3 and 4 days, respectively, after injury for the remaining 2 patients. The SDH presumably accumulated after the CT scan was obtained because CT is very sensitive for detecting acute hemorrhage.17 There were 10 subjects with extraxial hemorrhages on CT (2 EDH, 8 SDH) but not on MRI. Misclassification for 6 of these involved small hematomas not visualized on the follow-up MRI (limited series). In the remaining 4 subjects, 1 had a significant SDH with mass effect necessitating surgical evacuation. MRI, performed postoperatively, showed resolution of the SDH. Excluding this patient from the analysis had a negligible effect on the agreement (κ = 0.67 vs κ = 0.65). Two subjects with SDH on CT were identified as having SAH on MRI. Although the location may be clinically insignificant, this difference highlights the greater sensitivity of MRI compared with CT. One of the patients had a questionable small SDH on CT that was subsequently deemed artifact on follow-up MRI.

AHT, an entity unique to the pediatric population, has been on the rise in the past 5 years, with recent incidence rates ranging from 13.7 in young children (<5 years) to 28.9 per 100 000 infants. These patients often present with incomplete information about the mechanism of injury, timing of injury, and injuries of varied ages. We found that agreement between CT and MRI findings was worse for patients with AHT than for those with accidental TBI. In patients with AHT, MRI detected nearly 4 times as many intraparenchymal lesions (43%) as compared with CT (11%). Our study found a higher discordance between CT and MRI than previous reports. Foerster et al reported MRI findings of TAI and ischemia in 13% of patients with AHT that were not detected on CT, and Kemp et al estimated MRI would identify new lesions in 25% of patients with AHT. The degree of discordance compared with accidental etiology may reflect the greater likelihood of delayed presentation of these patients.
Moreover, the time delay may be complicated by a secondary hypoxic ischemic insult and provide additional time for contusions to develop.

A study by Sigmund et al\textsuperscript{10} reported a group of 10 children with poor outcomes after TBI, of whom 4 had a normal early CT. In our study, 6 out of 8 children with a normal early CT scan were found to have intraparenchymal abnormalities on MRI. This finding again highlights the diagnostic limitations of CT imaging. In both children and adults, intraparenchymal lesions identified on MRI such as TAI, contusion, and ischemia have been shown to correlate with worse clinical outcome.\textsuperscript{9,11,22–26}

The benefits of early CT imaging can be attributed largely to convenience. CT is available on site in 97% of emergency departments in the United States,\textsuperscript{27} and the rapidity of image acquisition (seconds) does not require additional patient sedation. However, the ionizing radiation exposure from CT is not insignificant. CT of the head is associated with a lifetime leukemia risk of 1.9 cases per 10 000 CT scans in children <5 years of age.\textsuperscript{16}

MRI is also associated with benefits and risks. The numerous MRI sequences confer greater anatomic detail without the risk of exposure to ionizing radiation. However, MRI is less readily available than CT, with only 66% of US emergency departments having access to an on-site MRI and even fewer (13%) having continuous on-site technologist availability.\textsuperscript{28} MRI is contraindicated in patients with indwelling magnetic foreign bodies. Image acquisition takes much longer for MRI and therefore usually requires sedation or anesthesia. There is evidence that anesthesia and surgery may increase the risk of adverse behavioral and developmental outcomes\textsuperscript{29} and negatively affect academic achievement.\textsuperscript{30} More recent advances that allow short sequences of only 3 minutes increase the potential value of MRI in the acute period, although it is still necessary to use nonmagnetic materials in trauma management so diagnostic images can be obtained.

The appropriate imaging technique to assess injury after pediatric TBI should maximize clinical yield with the fewest number of studies, in consideration of the associated benefits and risks. In the absence of contraindications, MRI is optimal for broader identification of lesions without exposure to ionizing radiation. In patients with AHT, there are both clinical (worse outcomes) and potential legal ramifications.

To our knowledge, this is the largest cohort to compare CT and MRI findings after pediatric TBI regardless of etiology and severity of injury. One strength of our study was the short duration between CT and MRI, with MRI performed within a median interval of 1 day after injury. This implies that lesions identified on MRI were less likely to reflect evolution over multiple days or delayed secondary insults; rather, MRI was simply more effective in identifying specific traumatic lesions. A longer delay would decrease detection of basal cistern compression and midline shift seen on CT but potentially increase identification of contusions that can evolve after TBI.

Our study has several limitations, including the retrospective nature of the study design. The study cohort was restricted to patients who underwent MRI, either limited ($n = 48$) or full. This may explain the high prevalence of AHT because this subgroup is more likely to have both CT and MRI scans. The exclusion of patients with accidental injury is probably nondifferential, resulting in negative bias or underestimation. Moreover, the smaller number of sequences in a limited rather than full MRI may have underestimated the prevalence of intraparenchymal lesions and negatively affected agreement statistics. Our analysis did not stratify the agreement on limited versus full MRI. Interventions related to noted lesions on MRI and CT were not evaluated, nor was the outcome of patients assessed.

CONCLUSIONS

MRI identified more lesions in children with pediatric TBI than CT, particularly in children who had sustained AHT. The prognostic value of early identification of intraparenchymal lesions with MRI is unknown but warrants additional inquiry. Clinicians should weigh the risks and benefits from early MRI (eg, potential need for sedation, time for image processing, lack of exposure to radiation) compared with CT. Assessment of necessary interventions and outcomes from lesions identified by MRI should also be evaluated.

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