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ORIGINAL ARTICLE

Implementation of a brain injury screen MRI for infants at risk for abusive head trauma

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Abstract

Background Head computed tomography (CT) is the current standard of care for evaluating infants at high risk of abusive head trauma.

Objective To both assess the feasibility of using a previously developed magnetic resonance imaging (MRI) brain injury screen (MRBRscreen) in the acute care setting in place of head CT to identify intracranial hemorrhage in high-risk infants and to compare the accuracy of a rapid imaging pulse sequence (single-shot T2 fast spin echo [ssT2FSE]) to a conventional pulse sequence (conventional T2 fast spin echo [conT2FSE]).

Materials and methods This was a quality improvement initiative to evaluate infants <12 months of age who were screened for intracranial hemorrhage using an MRBRscreen as part of clinical care. The MRBRscreen included axial conT2FSE, axial gradient recalled echo, coronal T1-weighted inversion recovery, axial diffusion-weighted image and an axial ssT2FSE. A comparison of ssT2FSE to conT2FSE with respect to lesion detection was also performed.

Results Of 158 subjects, the MRBRscreen was able to be completed in 155 (98%); 9% (14/155) were abnormal. Ninety-four percent (137/145) of subjects underwent only an MRBRscreen and avoided both radiation from head CT and sedation from MRI. The axial ssT2FSE and conT2FSE results were congruent 99% of the time.

Conclusion An MRBRscreen in place of a head CT is feasible and potentially could decrease head CT use by more than 90% in this population. Using a rapid ssT2FSE in place of a conT2FSE can reduce total scan time without losing lesion detection. If an MRBRscreen is readily available, physicians' threshold to perform neuroimaging may be lowered and lead to earlier detection of abusive head trauma.

Keywords Abusive head trauma · Brain · Child abuse · Computed tomography · Infants · Magnetic resonance imaging · Screening

Introduction

Abusive head trauma (AHT) is the leading cause of death from child abuse and an important cause of traumatic brain injury in infants. Early and accurate diagnosis of AHT can be difficult because infants often have no external signs of injury and present without a history of trauma and with nonspecific symptoms, such as vomiting and/or fussiness [1–5]. In two large studies of missed abusive head trauma conducted 15 years apart, the rate of missed abuse was the same at 31% (54/173) [5] and 31% (73/232) [6] despite the time interval and the ongoing attempts at provider education that occurred after the earlier study.

Head computed tomography (CT) is the standard of care test to screen for intracranial hemorrhage in infants at high risk of AHT [7]. It can be completed quickly, therefore avoiding sedation, and is available at all hours in the vast majority of emergency departments throughout the United States [8]. Most importantly, it accurately detects subdural hemorrhage, the type of intracranial hemorrhage seen in almost all cases of AHT [9, 10]. But the performance of head CT requires exposure of the brain to ionizing radiation – this is particularly problematic in infants who may be more vulnerable to the effects of radiation and who have a longer life span during which to develop cancer [11, 12]. These risks are

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among the reasons why limiting head CT has been recommended in well-appearing children in whom there is no concern for abuse [13, 14]. One explanation for why the diagnosis of AHT continues to be missed may be related to provider concerns about radiation risk and misunderstanding about whether there should be concern for abuse in a given infant.

Conventional brain magnetic resonance imaging (MRI) is used as an adjunct to head CT in children with suspected AHT. MRI is better able to identify ischemia, diffuse axonal injury, cerebellar injury and subtle, parenchymal injury and to differentiate benign extra-axial fluid from chronic subdural hemorrhage [7, 15]. Conventional brain MRI is not the standard of care of identification of intracranial hemorrhage in high-risk infants; the need for sedation or general anesthesia after a period of no oral intake is not practical in an emergency department setting. There are also concerns about whether anesthesia may have long-term effects on the developing brain [16]. While some providers have used head ultrasound (US) due to concern about radiation from head CT and sedation from MRI, it is not sensitive enough for intracranial hemorrhage to be used as a screening tool. Its use can result in missed cases of AHT [7, 17].

Rapid MRI — generally a fast T2-weighted sequence acquired with single-shot technique (single-shot T2 fast spin echo [ssT2FSE]) — is commonly used to evaluate for shunt malfunction in children with hydrocephalus [18, 19]. A shunt rapid MRI, however, cannot reliably be used to identify intracranial hemorrhage because ssT2FSE is not a blood-sensitive sequence [20]. A study by Young and colleagues [21] evaluated the sensitivity of ssT2FSE plus a susceptibility-weighted image (SWI) in 30 children younger than 7 years; they showed that head CT and the MRI with the added SWI identified intracranial hemorrhage with equal sensitivity. As expected, MRI had a lower sensitivity for skull fracture. A similar study by Ryan and colleagues [22] evaluated the sensitivity of ssT2FSE plus gradient recalled echo (GRE) sequences to detect intracranial hemorrhage in 61 children. They demonstrated a lower sensitivity of MRI for intracranial hemorrhage with the most significant difference being the poorer sensitivity of MRI for subarachnoid hemorrhage and for very small hemorrhages. The reduced tissue contrast of ssT2FSE compared with conventional T2 fast spin echo (conT2FSE) images is a potential limitation of using ssT2FSE for abnormalities other than hydrocephalus. The fact that the intracranial hemorrhage in AHT is typically a subdural hemorrhage rather than subarachnoid hemorrhage increases the likelihood that this limitation will not be significant when screening for AHT.

We previously derived and validated an MRI brain injury screen — referred to herein as an MRBRscreen — specifically to screen for intracranial hemorrhage in infants at high risk for AHT [23]. The MRBRscreen included three conventional pulse sequences: axial T2, GRE and a coronal T1-weighted inversion recovery. In the derivation cohort, these three sequences were 100% sensitive for intracranial hemorrhage; they were 100% sensitive and 83% specific in the validation cohort. The time to complete these sequences was approximately 6 min. One limitation of the initial study was that all subjects were sedated for the MRI; if the MRBRscreen were used in clinical practice, infants would not be sedated. If the MRBRscreen were to suggest an intracranial hemorrhage, the infant would likely need to either undergo head CT or a full MRI with sedation. Another limitation of the initial study was that a rapid imaging sequence like ssT2FSE was not employed, leaving the unanswered question of whether a fast T2 image can replace con T2FSE in the setting of screening for brain injury in infants at risk for AHT.

The current study objectives were, therefore, to prospectively evaluate the feasibility of using an MRBRscreen in clinical practice both in terms of fitting these cases into a busy MRI schedule and assessing the ability of infants to hold still for approximately 6 min to obtain images with a high enough quality to be interpreted. We also retrospectively compared the diagnostic accuracy of ssT2FSE and conT2FSE with respect to lesion detection.

Materials and methods

This quality improvement project was approved by the University of Pittsburgh Medical Center Quality Improvement Committee.

Patient preparation for scanning

Infants were positioned in the coil to minimize head tilting. A standard feed and bundle technique was used to swaddle the infants using standard warm blankets. Infants wore earplugs (Quiet Earplugs; Sperian Hearing Protection, San Diego, CA) and infant ear muffs (MiniMuffs; Natus, San Carlos, CA). An MR-compatible vital signs monitoring system (Veris; MEDRAD, Inc., Indianola, PA) was used. Scans were performed using a multichannel head coil (8–15 channels).

Imaging protocol (Table 1)

The MRBRscreen protocol included the three sequences that were included as part of our original study – axial conT2FSE, axial GRE and coronal T1-weighted inversion recovery – plus an axial diffusion-weighted image (DWI) and an axial ssT2FSE. The axial DWI was added to the original protocol because the other sequences are not sensitive to acute cytotoxic edema; the DWI sequence can depict acute hypoxic-ischemic/hypoperfusion, brain parenchymal injury and/or acute focal stroke.

The MRI technicians were instructed to perform the sequences in the order listed above axial conT2FSE with periodically rotated overlapping parallel lines with enhanced

Table 1 Imaging protocol

Sequence	Time to complete	TR	TE	NEX	Slice thickness	Echo train length (ETL)	Receiver bandwidth	Matrix	FOV
Axial conventional T2 FSE (con T2FSE)	1 m 45 s	7.5 s	92 ms	2	5 mm 1.5-mm gap	24	50.0 KHz	256×256 reconstructed at 256×256	20 cm
Axial gradient recalled Echo (GRE)	1 m, 45 s	7.5 s	92 ms	1	5 mm 1.5-mm gap	24	50.0 KHz	256×256 reconstructed at 256×256	20 cm
Coronal T1-weighted inversion recovery[a]	1 m, 19 s	2,500 s	Minimum full	1	5 mm 1-mm gap	7	31.25 KHz	288×224 reconstructed at 256×256	22 cm
Axial diffusion (DWI)[b]	50 s	10,000 s	Minimum	2	5 mm 0-mm gap	N/A	N/A	128×128 reconstructed at 256×256	26 cm
Rapid sequence single shot T2 fast spin echo (ssT2FSE)	37 s	Minimum	90 ms	2	4 mm with 0 gap	N/A	62.0 KHz	256×256 reconstructed at 256×256	20 cm
	Total: ~6 m 15 s								

[a] TI=automatic

[b] echo planar technique (three diffusion directions) and b=1,000

DWI diffusion-weighted imaging, *FOV* field of view, *FSE* fast spin echo, *ms* millisecond, *m* minute, *N/A* not applicable, *NEX* number of excitations, *s* second, *TE* echo time, *TR* repetition time

reconstruction (PROPELLER), axial GRE coronal T1-weighted inversion recovery, axial DWI, and axial ssT2FSE with the total time of the protocol approximately 6 m 15 s. If the infant was moving, repeat imaging of selected sequence(s) was performed as part of routine clinical care; the technician performing the MRI assesses the sequences in real-time and decides whether repeats are needed. If the infant was not moving, and the original protocol was of high enough quality to be diagnostic, the MR technician added additional optional sequences from a standard brain MRI protocol (axial proton density, axial fluid attenuated inversion recovery [FLAIR], axial SWI) for this age group. We also added sagittal and coronal ssT2FSE in a small subset of the cases after the addition of the optional standard brain MRI protocol, if the infant was still asleep.

The study was performed with either 3-T (GE Signa HDX [Waukesha, WI] or Siemens Skyra [Erlangen, Germany]) or 1.5-T (GE Signa HDX) scanners with harmonized comparable protocols used on each magnet. For example, PROPELLER on the GE scanner was performed using BLADE on the Siemens scanner; ssT2FSE on the GE scanner is a HASTE (half-Fourier acquired single-shot turbo spin echo) on the Siemens scanner.

Interpretation of the MRBRscreens

All MRIs were interpreted by an attending pediatric neuroradiologist as part of clinical care. At a later date, each study was reviewed by one of the authors (L.L.F. with 33 years of experience or A.D.F. with 7 years of experience) who assessed whether the sequences were performed in the correct order and whether the study was normal, normal except for incidental findings consistent with birth, abnormal due to a traumatic abnormality or abnormal due to an atraumatic abnormality. The plan a priori was that any disagreement between the clinical interpretation and the interpretation by L.L.F. or A.D.F. would be resolved by consensus. The data about the order of the sequences were used to provide ongoing feedback to the technicians.

Study cohort

Infants who underwent a MRBRscreen from January 1, 2016, to June 30, 2017, were eligible. To identify these patients, we first queried our electronic health record for all children younger than 1 year who underwent brain MRI during this time. Children who received sedation for the MRI were excluded first (since these patients underwent a full MRI and not an MRBRscreen). The remaining subjects were reviewed by hand; subjects with a MRBRscreen (versus a standard MRI) could be identified by the fact that the single-shot turbo spin echo (SSTSE) sequence was completed; the MRBRscreen protocol is the only MRI protocol in our institution (other than the shunt protocol) that includes this sequence. Finally, subjects were excluded if they had had prior abnormal neuroimaging (e.g., infant with a shunt) or if the MRBRscreen was performed after a CT. Performing the MRBRscreen after a CT was common when clarity was needed about whether a finding on CT represented chronic subdural hemorrhage or benign extra-axial fluid.

To compare the ability of the conT2FSE and the ssT2FSE to identify abnormalities, each conT2FSE was compared with the ssT2FSE by one of three pediatric neuradiologists (A.P. with 21 years of experience, L.L.F., A.D.F.). Each axial image was independently assessed as normal or abnormal; the proportion which were congruent was calculated to assess the congruence between the conT2FSE and the ssT2FSE.

Data collection

The following data were collected for each subject: age (in months), gender, race (white or not white), reason for ordering the MRBRscreen, date of the MRI, time of the MRI, location where the MRI was completed (emergency department, inpatient, outpatient), which sequences were performed, results of the MRI, whether the physician interpreting the MRI noted that there was concern for motion, and whether follow-up neuroimaging was performed in the subsequent 6 months and, if so, what type of imaging and the result. There were seven possible indications for ordering the MRBRscreen: symptom of head injury (e.g., vomiting, irritability, fussiness), a history of trauma, follow-up to an US, increased head circumference or macrocephaly, head swelling or bulging fontanel, a noncranial injury suspicious for physical abuse (e.g., fracture, bruise) or other. MRI results were classified as normal, normal except for incidental findings consistent with birth (e.g., germinal matrix hemorrhage), abnormal with a traumatic abnormality, abnormal with an atraumatic abnormality and not successful (too much motion artifact to be interpreted).

Statistical analysis

We used descriptive statistics to describe the cohort. A $P<0.05$ was considered statistically significant. All statistics were performed using SPSS 23.0 (IBM Corporation, Armonk, NY).

Results

Patient characteristics

One hundred fifty-eight infants underwent the MRBRscreen during the 18-month study. The mean (standard deviation [SD]) age was 3.4 (2.7) months; 54% of the subjects were male. The most common indication for the MRI was a symptom of head injury (45%). Other indications included a history of trauma (18%), increased head circumference (12%), a noncranial injury suspicious for physical abuse (17%) and other (8%). The “other” category primarily included infants who were either siblings of physically abused children or infants involved in a domestic dispute.

The number of MRIs completed increased during each 6-month period, although the increase was not statistically significant: 37 in the first 6 months, 53 in the second 6 months and 68 in the last 6 months. The time of day when the MRIs were performed was equally distributed over the 24-h period. Eighty percent of the MRIs were performed in the emergency department, 16% were inpatients and 4% were outpatients.

Feasibility of a non-sedated MRBRscreen

In 27% (n=42) of cases, there was concern for patient motion; in 3 of the 158 (2%) cases, the radiologist did not interpret the MRI due to severe motion artifact. In two of these three cases, a head CT was then performed, which was normal. In the other case, that of an 11-month-old with a femur fracture due to suspected abuse, no follow-up imaging was performed.

Results of MRBRscreen

Nine pediatric neuroradiologists evaluated the MRBRscreens as part of clinical care. The median interquartile (IQR) number of years in practice for these neuroradiologists was 11.0 (5, 26.5). Of the 155 MRBRscreens that were successfully completed, 76% (n=120) were interpreted as entirely normal and an additional 13% (n=21) were normal except for incidental findings consistent with a normal birth. Nine percent (n=14) were abnormal or were possibly abnormal because of a traumatic (n=13) or atraumatic (n=1) abnormality (Table 2). There were no cases in which there was disagreement between the clinical interpretation of the MRI and the interpretation by one of the study authors (A.D.F. or L.L.F.).

Comparing axial conT2FSE to axial ssT2FSE

In 132 cases, both the ssT2FSE and conT2FSE were normal and in 14 cases they were both abnormal (Fig. 1). In four cases, they were both nondiagnostic due to motion and in seven cases the ssT2FSE was normal, but the conT2FSE was either nondiagnostic due to movement or not done. In one case (Fig. 2), the intracranial hemorrhage was clearly seen on the conT2FSE and was believed to be possible, but not definite, on the ssT2FSE. Importantly, the other non-T2 sequences were clearly abnormal in this case so the lack of clarity on the ssT2FSE would not have altered the overall result of the MRBRscreen (Fig. 2). There were no cases in which the ssT2FSE was considered abnormal and then determined to be an artifact on review of the conT2FSE. Therefore, there was agreement between the ssT2FSE and conT2FSE in 99% (146/147) of cases.

Follow-up imaging

In addition to the subjects with abnormal neuroimaging described above, eight additional subjects had additional imaging (CT [n=5] or full MRI [n=3]) within 1 day of the MRBRscreen to follow up on severe motion artifact on the

Table 2 Description of all subjects with abnormal MRBRscreen

Patient number	Age (in months)	Indication for ordering the MRBRscreen	Details of indication	Result of MRBRscreen	Imaging performed to follow up on MRI and result	Notes
1	3.0	Symptom of head injury	Fussiness, vomiting without diarrhea, also with macrocephaly	Bilateral large frontal subarachnoid spaces with possible small left frontal SDH	Head CT: No subdural hemorrhage	
2	1.6	Symptom of head injury	Fussiness. Infant with known birth-related hypoxic ischemic encephalopathy	Diffuse severe cerebral encephalomalacia. Large bilateral subdural fluid collections. Restricted diffusion in the cerebral white matter and right thalamus. Hypoplastic pons	None	Patient died 7 days later
3	4.0	Bulging fontanel	Infant with complex congenital heart disease and a history of recent anticoagulation	Acute subdural hemorrhage along left parieto-occipital region. Possible restricted diffusion in left occipital parenchyma, multiple punctate foci of susceptibility likely chronic microhemorrhages	Head CT: confirmed acute SDH	CPT consulted; SDH believed to be consistent with recent anticoagulation and not due to abuse
4	6.9	History of trauma	Status post fall from a countertop	Bilateral cerebellar tonsil signal intensity alterations consistent with infarct and hemorrhage.	Full-brain MRI 6 weeks later showed resolution of hemorrhage with trace residual hemosiderin	CPT notified; abnormalities believed to be consistent with fall and not related to abuse
5	3.7	Macrocephaly	Epistaxis	Significantly motion limited exam: 5-mm extra-axial subdural collection over left frontoparietal convexity	Head CT: chronic left subdural hemorrhage	CPT consulted: Diagnosis of AHT
6	1.4	Symptom of head injury	Seizures	Vasogenic edema posterior parietal white matter	None	Abnormality believed to be related to the seizures
7	0.25	Symptom of head injury	Fussiness	Restricted diffusion 2.5-mm area right pericallosal near corpus callosum	Full MR: resolution of the area of restricted diffusion	Full MRI performed 2 days later; CPT not consulted
8	3.0	Macrocephaly	Abnormal head ultrasound. Failure to thrive	Bilateral chronic SDH, diffuse parenchymal loss	Head CT performed after placement of subdural drains (done based on MRBRscreen results)	CPT consulted: possible abuse, SDH may be related to volume loss
9	11.0	History of trauma	Dropped by father	Right acute frontal-parietal subdural hemorrhage	Head CT: confirmed subdural hemorrhage, right parietal skull fracture	CPT not consulted
10	2.0	Symptom of head injury	Fussiness	Small 5-mm focus on abnormal susceptibility effect in the right posterior parietal region, small SAH	CT: confirmed the SAH	CPT consulted: did not believe SAH was due to abuse
11	2.0	Symptom of head injury	Vomiting and acute weight loss	Bilateral acute frontal subdural hemorrhages, rupture of bridging veins, possible retinal hemorrhages	Full MRI: previously recognized SDH, left frontal SAH, probable retinal hemorrhages and SDH of cervical spine	CPT involved: diagnosis of AHT
12	2.0	Macrocephaly	Abnormal head ultrasound	Chronic bilateral frontal SDH	None	CPT consulted: diagnosis of probable AHT
13	2.0	Symptom of head injury	Vomiting	SDH of multiple ages bilateral fronto-parietal area and within the 4th and possible posterior 3rd ventricles	Head CT: consistent with MRBRscreen	CPT consulted: diagnosis of AHT
14	3.6	Macrocephaly		Severe hydrocephalus with aqueduct stenosis	None	CPT not consulted

AHT abusive head trauma, *CPT* Child Protection Team, *MRBRscreen* MRI brain injury screen, *SAH* subarachnoid hemorrhage, *SDH* subdural hemorrhage

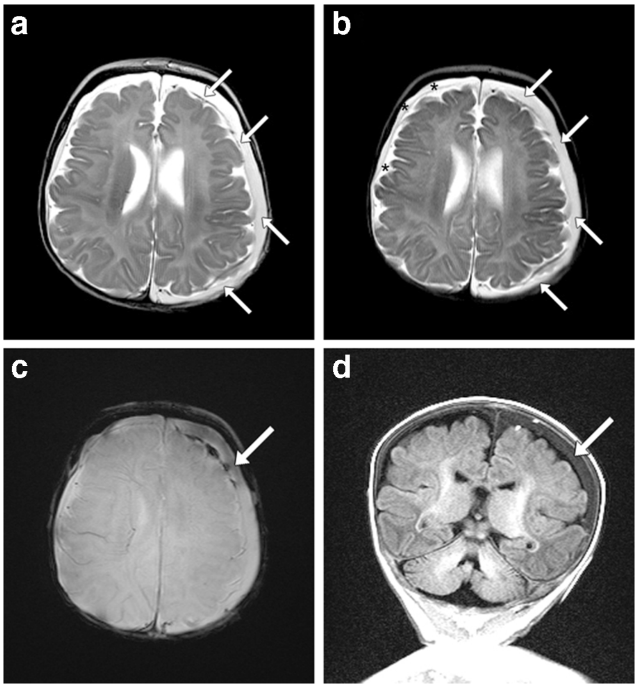

Fig. 1 A 2.4-month-old boy in whom there is congruence between conT2FSE (conventional T2 fast spin echo) and ssT2FSE (single-shot T2 fast spin echo). Bilateral full convexity subdural hemorrhage with evolving membranes between the subdural and subarachnoid hemorrhages, left greater than right. **a, b** The *arrows* on the conT2FSE (**a**) and ssT2FSE (**b**) delineate a relatively thicker left-side full convexity subdural membrane; the *asterisks* (**b**) within the subdural space delineate a relatively thinner right-side full convexity membrane related to displaced arachnoid tissue separate from the adjacent subarachnoid space and pial surface on ssT2FSE. **c, d** The *arrows* demonstrate the blood product on axial gradient recalled echo (GRE) (**c**) and coronal T1-FLAIR (fluid attenuated inversion recovery) (**d**)

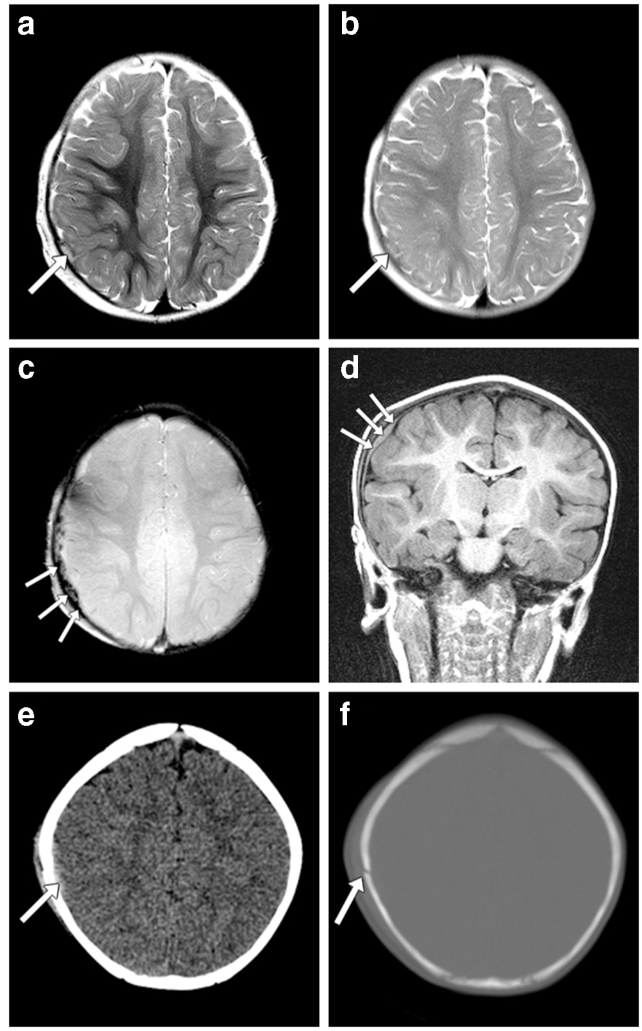

Fig. 2 An 11.3-month-old girl in whom the conT2FSE (conventional T2 fast spin echo) and ssT2FSE (single-shot T2 fast spin echo) are incongruent. **a, b** The intracranial hemorrhage was clearly seen on the conT2FSE (**a**) (*arrow*) and was believed to be possible, but not definite, on the ssT2FSE (**b**) (*arrow*). Soft-tissue swelling is noted in the right parietal region on all the MR sequences. **c, d** Of note, the other non-T2 sequences of the MRBRscreen (MRI brain injury screen) were clearly abnormal in this case, including the axial gradient recalled echo (GRE) (**c**) and the coronal T1-weighted inversion recovery (**d**) (*arrows*) so that the lack of clarity on the ssT2FSE would not have altered the overall result of the MRBRscreen. **e, f** In addition, the hemorrhage (*arrows*) was clearly seen on the axial CT (**e**) performed on the same patient on the same day and a fracture was also diagnosed (**f**)

MRBRscreen (*n*=2) or due to concern about possibly abnormal findings on the MRBRscreen (*n*=6). All were normal.

Eight additional subjects had a subsequent CT (*n*=5) or full MRI (*n*=3) within 6 months of the MRBRscreen; one of the MRIs was done as part of a research study and not for clinical care. All were normal.

Reduction in head CT use

In this cohort of 145 infants with normal neuroimaging who would normally have undergone head CT, only 8 required a head CT or a full MRI with sedation after the MRBRscreen. Therefore, 94% (137/145) of infants avoided both radiation from head CT and sedation from MRI (Fig. 3).

Discussion

This study is the first to our knowledge to evaluate whether an MRI screen – the MRBRscreen – can be performed without sedation in a cohort of neurologically normal infants who are at high risk for AHT. The very low rate of failed MRIs suggests that infants can be successfully fed and bundled for the 6 m 15 s it takes to complete the MRBRscreen. While the attending neuroradiologist noted a concern for patient motion in 27% of cases, the quality was still of diagnostic quality in all but 2% of cases. The fact that none of the infants in whom there was concern for motion returned within the subsequent 6 months with abnormal neuroimaging also supports the neuroradiologist's interpretation. Because the result of the ssT2FSE was congruent with the conT2FSE will allow the

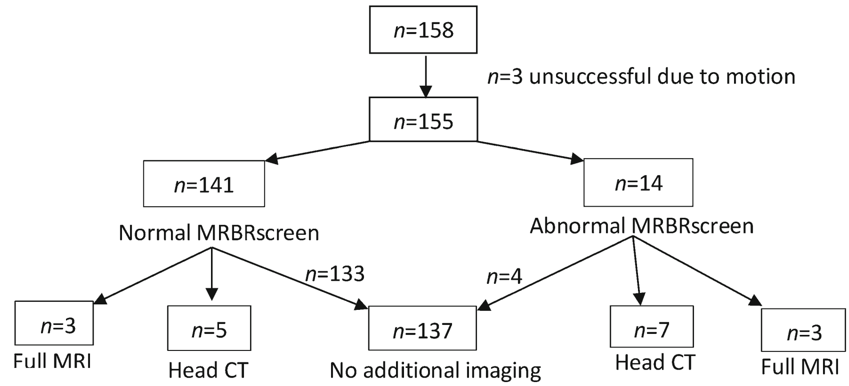

Fig. 3 The flowchart demonstrates how many subjects underwent MRBRscreen (MRI brain injury screen) only or MRBRscreen plus either head CT or a full-brain MRI

MRI to be completed more than 1 m faster, which will likely decrease the motion artifact even more.

While the primary goal of developing the MRBRscreen was to improve identification of AHT, it is also important that use of the MRBRscreen can *decrease* head CT usage in this population of infants who should undergo neuroimaging to screen for occult intracranial hemorrhage [24]. The 94% decrease was even higher than the 83% projected based on data from our initial study [23]. The reason is likely related to increased comfort with interpreting the MRBRscreens by our pediatric neuroradiologists over time.

The sensitivity of the MRBRscreen for detecting intracranial hemorrhage in our prior publication was 100% [23]. Although we can't calculate the sensitivity of the MRBRscreen in this cohort since subjects did not undergo both head CT and MRI, the fact that no infant with a normal MRBRscreen returned with an abnormal CT or MRI within 6 months supports a high sensitivity. Using a lack of subsequent, abnormal neuroimaging to validate sensitivity was also used by Kuppermann et al. when deriving and validating the Pediatric Emergency Care Applied Research Network (PECARN) rule for identifying children at very low risk of clinically important brain injuries after head trauma and in whom there is no concern for abuse [25].

Whether the 9% positive rate is too high or too low given the risk to benefit ratio in this population is an important question, although it is beyond the scope of the current study. A cost-effective analysis is a next step now that the accuracy and feasibility of the MRBRscreen have been established.

There are several limitations to the current study. While the MRBRscreens were interpreted prospectively as part of clinical care, comparison of the rapid ssT2FSE and conT2FSE was done retrospectively. It was, therefore, not possible to blind the study reader to additional studies or to prevent them from accessing the clinical read. There is also a selection bias with exclusion of patients who were not well-appearing or had prior abnormal neuroimaging. Infants who are not well-appearing in whom there is concern for brain injury need to undergo a standard head CT. The most significant logistical limitation is the lack of off-hours access to MRI at many hospitals. A 2008 publication reported MRI was available on-site in just over 65% (171/260) of U.S. hospitals [8]. More recent data are not available, but it is likely that the current number is much higher and that accessibility to MRI will increase over time, making the use of a MRBRscreen applicable to a larger proportion of infants. Given our single-study design, our results may not be generalizable to all types of pediatric imaging practices including those with different types of vendor scanners. Also, we did not standardize prospectively our approach to performing repeat imaging sequences that were initially corrupted by motion. Finally, another limitation relates to a limitation of MRI itself. Because MRI is insensitive to skull fracture, infants who undergo an MRBRscreen due to concern for AHT should also undergo a skeletal survey that includes four views of the skull [26, 27]. Importantly, the radiation exposure of a skeletal survey is just 0.2 mSV [28]; this is significantly less than the radiation exposure from a head CT [29, 30].

Conclusion

An MRBRscreen can be incorporated into the clinical practice of a busy pediatric emergency department and has the potential to decrease head CT use by more than 90% in high-risk infants. If an MRBRscreen is readily available, the hope is that it will lower physicians' threshold to evaluate for intracranial hemorrhage in infants and therefore improve early detection of AHT.

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Compliance with ethical standards

Conflicts of interest None

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