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TECHNICAL NOTE

Eight-second MRI scan for evaluation of shunted hydrocephalus

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Abstract
Introduction Pediatric patients harboring shunts placed early in life are subjected to numerous radiographic studies during development of their central nervous system. Radiation is detrimental to these young patients. MRI avoids the risk of radiation but is thought more difficult due to the increased time a young patient must lie motionless during scan acquisition. Optimal radiographic interrogation would be quick, radiation-free, and allow adequate ventricular evaluation.
Methods We queried the electronic medical records system of the senior author (SE) for the terms "hydrocephalus" and "shunt malfunction." All patients currently younger than 18 years were included. In the last 5 years, pediatric patients have been evaluated in an office setting with a limited MRI sequence (T1 sagittal, T2 axial, T1 axial, and DWI) lasting a total of 178 s. In the event of significant motion artifact, the total sequence is abandoned and an 8-s T2 diffusion-weighted scan is performed.
Results Forty-four patients were included in the study (20 males, average age 10.4 yrs). Eighty-eight rapid acquisition scans were obtained. Adequate ventricular evaluation was performed without sedation in every case. In each instance where there was motion, the 8-s scan provided adequate ventricular evaluation.
Conclusion Rapid acquisition MRI scanning avoids the deleterious cumulative effects of radiation in pediatric patients and allows adequate evaluation of the ventricles without the need for sedation.

Keywords Hydrocephalus · Magnetic resonance imaging · Shunt · Radiation

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Introduction

Pediatric patients harboring shunts for the treatment of hydrocephalus often undergo imaging utilizing ionizing radiation to evaluate their ventricular system and shunt. The deleterious effects of ionizing radiation in pediatric patients are well documented and include: increased risk of radiation-induced cancers, increased risk of death due to radiation-induced cancers, decreased adult intelligence quotient, and lens opacification. Furthermore, the increased sensitivity of growing organs, small cross-sectional area of the radiated organ, and long lifespan over which to develop cancers make these issues more problematic in children [4, 8, 9, 13]. ALARA (as low as reasonably achievable) standards advocate for decreased radiation exposure in each CT scan and reduced use of CT as a diagnostic modality when other examination methods exist [2, 3, 5–7]. Despite these attempts to reduce radiation dose, many patients are subjected to large cumulative doses of ionizing radiation over their

lifetime, particularly patients with complex hydrocephalus and frequent shunt failure.

MR imaging is radiation free and affords superior evaluation of soft tissues including brain and cerebrospinal fluid. Standard MR scanning requires a patient to lie supine and largely motionless for the duration of each study acquisition. Pediatric patients often require sedation, and even general endotracheal anesthesia, to successfully complete a routine brain MRI. A rapid acquisition scan would be optimal for these patients as it avoids exposure to ionizing radiation and can be done quick enough to avoid the need for sedation. Here, we describe a protocol that has been used successfully to evaluate the ventricular systems of shunted pediatric patients in the outpatient setting.

Methods

The electronic medical records at the Semmes-Murphey Clinic were searched for: (1) all patients seen by the senior author (SE), (2) records containing the terms "hydrocephalus" and "shunt malfunction," (3) currently 18 years or younger, and (4) patients who underwent a rapid-sequence MRI scan in the years 2006–present. Patients who met all four inclusion criteria were included in the study. During this time, pediatric patients have been evaluated in an office setting with a rapid-sequence MRI (T1 sagittal, T2 axial, T1 axial, and DWI) lasting a total of 178 s. In the event of significant motion artifact, the total sequence is abandoned and an 8-s T2 diffusion-weighted scan is performed.

Imaging sequence

Initially, the MRI scan consists of attempting a T1 axial, lasting 30 s. Next, a T1 sagittal series, which lasts 25 s is attempted. Third, a T2 axial lasting 28 s is performed and lastly, an 8-s DWI series. Each of these algorithms will produce ten to 12 images.

If at any point, the patient is not cooperating, they will go straight to a DWI sequence, performed in a "single shot," with TR=2,000 ms, TE=97 ms, and NEX=1. This is done in 8 s and produces ten images. Movement does not affect the images.

Results

All scans were performed in an outpatient MRI setting. Forty-four patients were included in the study (20 males, average age 10.4 yrs). Eighty-eight rapid acquisition scans were performed. Any patient with a magnetic-based adjustable shunt valve was evaluated with a simple skull radiograph or the manufacturers' interrogation device to confirm the correct setting (two patients). Adequate ventricular evaluation was performed without sedation in every case. Fourteen scans were aborted prior to completion of the T1 and T2 portions of the scan, and the 8-s diffusion scan was then completed successfully. In each instance where there was motion during the T1 and T2 scan, the 8-s scan provided adequate ventricular evaluation. There were no complications from MR imaging.

Illustrative cases

Case 1

This 12-year-old male presented with vague symptoms of increasing frequency of headache. He was shunted at age 3 for postmeningitic hydrocephalus. He has had seven shunt revisions, and he is not cooperative enough to lie motionless during standard-length MRI scanning. A rapid sequence MRI was performed, and his initial axial T2 scan is degraded by

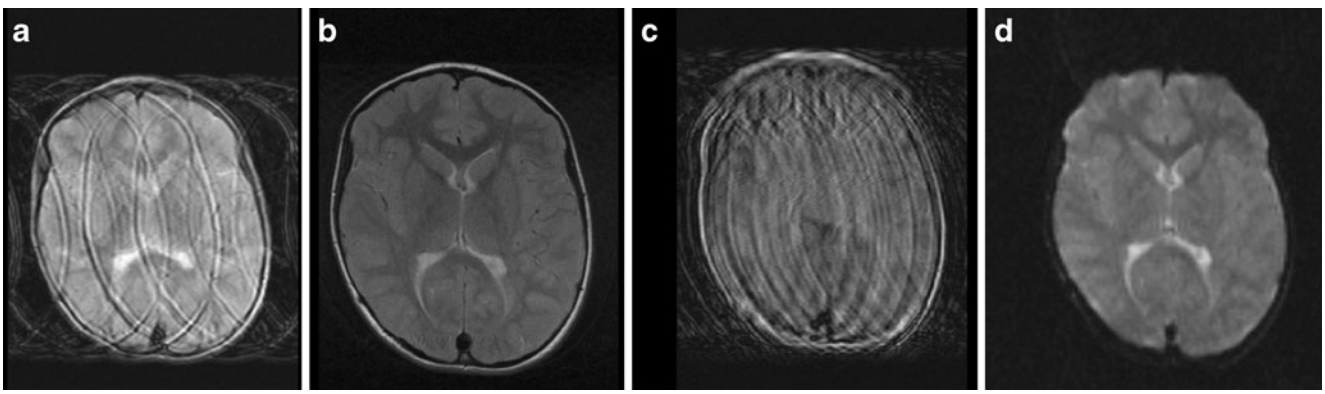

Fig. 1 Rapid sequence MRI performed in a noncooperative 12-year-old male for increasing frequency of headaches. His initial axial T2 scan is degraded by motion (**a**), but his repeat is of good quality (**b**). He has significant motion artifact on his axial T1 but good quality scanning during his axial diffusion scan (**c**, **d**)

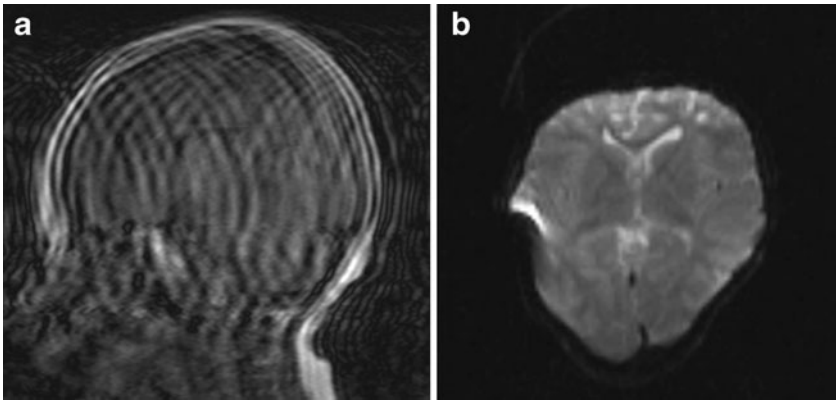

Fig. 2 Initial attempts to obtain T1 or T2 imaging on this noncooperative 3-year-old female resulted in a single, poor quality sagittal T1 image (**a**). Further T1/2 imaging was abandoned and an 8-s diffusion scan was performed successfully, allowing excellent ventricular evaluation (**b**)

motion (Fig. 1a), but his repeat is of good quality (Fig. 1b). He has significant motion artifact on his axial T1 but good quality scanning during his axial diffusion scan (Fig. 1c, d). His ventricles are stable compared to previous nonfailure scans.

Case 2

This 3-year-old female has undergone three shunt revisions for neonatal posthemorrhagic hydrocephalus. She has severely reduced function and is fed by a gastrostomy tube. She presented with increased fussiness. Initial attempts to obtain T1 or T2 imaging resulted in a single, poor-quality sagittal T1 image (Fig. 2a). Further T1/2 imaging was abandoned, and an 8-s diffusion scan was performed successfully allowing excellent ventricular evaluation (Fig. 2b). She was later diagnosed with a gastrointestinal illness.

Case 3

This 3-month-old female (not included in the study sample) was followed for symptomatic subdural fluid collections resulting from an automobile collision. These were surgically drained. At 2-week follow-up, she has mild ventriculomegaly seen on her 8-s diffusion scan (Fig. 3a) but not on her axial T2 with excessive motion (Fig. 3b). After a rescan 3 weeks later, she has developed significant hydrocephalus noted on both axial diffusion (Fig. 3c) and T2 (Fig. 3d) scans.

Discussion

Children with shunt-dependant hydrocephalus will undergo numerous radiographic evaluations over their lifetime and

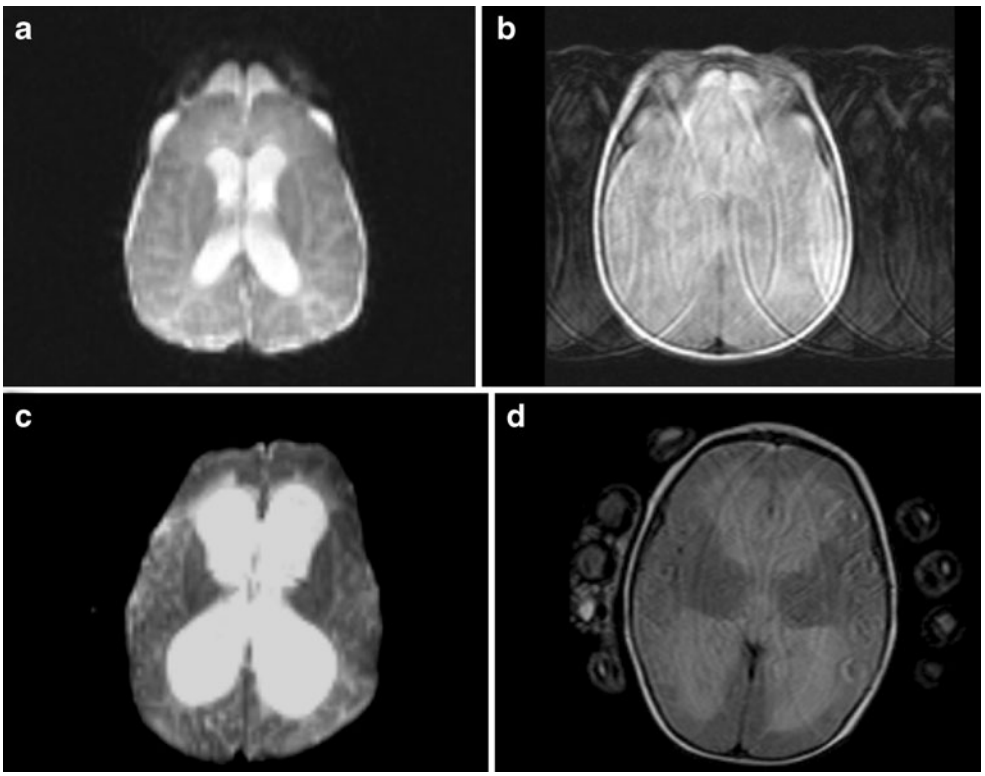

Fig. 3 Rapid sequence MRI performed on a 3-month-old infant shows mild ventriculomegaly on her 8-s diffusion scan (**a**) but not on her axial T2 with excessive motion (**b**). After a rescan 3 weeks later, she has developed significant hydrocephalus noted on both axial diffusion (**c**) and T2 (**d**) scans

be subjected to large cumulative doses of ionizing radiation. Attempts to minimize the radiation dose delivered during CT scans, such as ALARA and the Image Gently Campaign, have brought attention to this issue and advocate for reducing the radiation delivered [2, 7, 13]. MRI offers the potential benefit of increased soft tissue and ventricular detail without subjecting the patient to the radiation associated with CT scanning. The problem with standard MRI is that a patient must lie motionless for much longer than what is needed for a CT scan. Furthermore, CT is better at evaluating the shunt system itself, i.e., catheter placement and continuity of the shunt system. Frequently, emergent evaluation of shunted hydrocephalus occurs at inconvenient hours in emergency departments when easy access to MRI is not feasible. CT is almost always the modality of choice in this situation. However, there are numerous indications for nonemergent brain imaging in patients with shunted hydrocephalus (chronic headaches, failure to thrive, sleeping more, routine follow-up, etc.) that are performed electively both in outpatient and inpatient settings. It is this group of patients that are most appropriate for abbreviated MRI scans.

Neurosurgeons first reported the use of quick-brain MRI in this group of pediatric patients in 2004 [10]. Seventy-two patients underwent a total of 131 images for evaluation of hydrocephalus. The mean total time for the scan was 3.4 min. Single-shot fast-spin echo in three planes was obtained, and image quality was good enough to adequately evaluate the ventricles in all patients. Patients did not require sedation in any case. The authors advocated that MR imaging replace CT scan as the diagnostic imaging modality of choice.

The following year, the St. Louis Children's Hospital group reported their experience using rapid-sequence MRI for evaluation in a similar group of patients [1]. Sixty-seven studies were performed on patients whose mean age was 4 years at the time of scan. The mean study duration was 22 min. Catheter visualization was adequate in 75 % of cases, and image quality was adequate in 60 % of cases. Sedation was not used. Again, MRI was advocated as the diagnostic imaging modality of choice for nonemergent indications.

Over a 4-year period from 2003 to 2007 at Dartmouth-Hitchcock Medical Center, use of "quick-brain" MRI for nonhydrocephalus indications increased each year and was performed without sedation in each case [12]. Over that period 1,146 "quick-brain" scans were performed. The most common indication for scanning was macrocephaly followed by intracranial cysts. Total imaging time was less than 2.5 min.

An effort to improve catheter resolution was reported in 2010 [11]. Rapid steady-state gradient recalled echo (SS-GRE) imaging was performed on 179 nonsedated pediatric patients of which 62 had a shunt catheter. The total scan time was 150 s. The authors report that the catheter was seen better on the SS-GRE scan in 79 % of cases.

Our study population consisted of pediatric patients that are not cooperative enough to lie still for an entire standard MRI sequence. Shunted patients often have comorbid central nervous system and other systemic conditions that reduce their ability to cooperate with scanning. Furthermore, these conditions often reduce their ability to communicate effectively resulting in scans for "rule-out…" or "eval for…" pathology. These issues combined with the fact that shunts frequently fail cause this population to receive some sort of scan an average of four times per year [1]. Elimination of the radiation exposure by using MRI for these indications decreases the risk of radiation-induced malignancies, decrease in adult IQ, and lens opacification without sacrificing the ability to adequately evaluate ventricles.

Conclusion

Rapid acquisition MRI scanning avoids the deleterious cumulative effects of radiation in pediatric patients and allows adequate evaluation of the ventricles without the need for sedation. An 8-s diffusion scan is sufficient for ventricular evaluation.

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