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Navigated Abdominal T1 MRI Permits Free-Breathing Image Acquisition with Less Motion Artifacts

Shreyas S. Vasanawala¹, Yuji Iwadate², Daniel G. Church¹, Robert J. Herfkens³, and Anja C.S. Brau⁴

¹Lucile Packard Children's Hospital, Dept. of Radiology, Stanford University, Stanford, CA

²Applied Science Lab, GE Healthcare, Hino, Japan

³Stanford University Hospital & Clinics, Dept. of Radiology, Stanford University, Stanford, CA

⁴Applied Science Lab, GE Healthcare, Menlo Park, CA

Abstract

T1-weighted imaging in the pediatric abdomen suffers from respiratory motion artifacts. Though navigation has been employed commonly for coronary MRA and T2 imaging, navigation for T1-weighted imaging is less developed. Thus, a navigator pulse was incorporated into a fat-suppressed T1-weighted SPGR sequence such that steady-state contrast was not disrupted. 10 pediatric patients were recruited and scanned after gadolinium administration three times in immediate succession: breath-hold with no navigation, free-breathing with navigation, and free-breathing without navigation. Motion artifacts were scored for each sequence by two radiologists, showing less motion artifacts with navigation compared to free-breathing and greater motion artifacts than with breath-holding. This work demonstrates the feasibility and potential utility of navigation for pediatric abdominal T1-weighted imaging.

Keywords

MRI; navigation; motion artifacts; T1

Introduction

T1-weighted gradient echo and T2-weighted spin echo imaging is a routine component of pediatric abdominal MRI for evaluation of the abdomen. Although respiratory-triggering and navigation is routinely used for T2-weighted imaging and coronary imaging [1–4], there has been less attention to mitigating motion artifacts in T1-weighted imaging. One common approach is phase reordering [5]. More recently, navigation has been proposed for gradient echo T1 imaging in the context of dynamic contrast enhancement (DCE) exams [6]. That work used a navigator during a volumetric breath-held acquisition, and then used the information from the navigator to register data based on an edge-detection algorithm for improved DCE analysis. In part, the paucity of literature on motion artifact reduction in T1-weighted imaging results from the ability of most adult patients to suspend respiration on command. However, children are generally less able to suspend respiration, and when MRI exams are performed with anesthesia, a deeper level of anesthesia is required for an

anesthesiologist to suspend respiration for the patient. Thus, in this work, we develop and test the use of navigation to decrease motion artifacts in T1-weighted imaging for pediatric abdominal MR examinations.

Methods

On a 1.5 T GE Signa system, a fat-suppressed 3D gradient echo sequence (Liver Acquisition with Volume Acceleration, or LAVA) was modified to incorporate a navigator (Fig. 1a). This navigator consists of an intermittent two-dimensional pulse that excites a cylinder of spins, followed by a readout gradient in the direction of the long axis of the cylinder to acquire a 1-dimensional profile of the area of interest. The cylindrical excitation can be prescribed in an arbitrary orientation, though in this work, the excitation was always placed over the right hemidiaphragm with its axis in the superoinferior direction (Fig. 1b). The one-dimensional profile then has a sharp transition between lung and liver, which can be monitored prospectively using an edge-detection algorithm.

The navigator pulse has a duration of 20ms and is executed every 200 milliseconds, after application of the spectrally selective fat inversion pulse and data acquisition segments. The flip angle of the navigator pulse is 10° , and was chosen such that adequate signal could be obtained to determine the position of the diaphragm, yet without a saturation effect that would compromise contrast of the liver. When the diaphragm position as determined by the navigator is within the user-prescribed acceptance range during end-expiration (typically 0.4 cm range), k-space data is accepted for image formation; otherwise, it is rejected (Fig 1a). A representative example waveform from the navigator is shown in Figure 2.

With IRB approval and informed consent/assent, 10 consecutive patients (Table 1) referred to our Children's hospital for abdominal MRI with contrast underwent the following protocol: immediate post-contrast suspended respiration LAVA with two to four phases, followed by free-breathing T1 navigated LAVA, and then free-breathing routine (non-navigated) LAVA (exam parameters: minimum TR, minimum TE, 15 degree flip angle, FOV adjusted to patient size ranging from 24 to 32 cm, slice thickness adjusted for patient size from 3.4 to 5 mm, z interpolation factor of 2, scan time when not navigated of 20 to 30 seconds). All studies were performed with either an 8-channel cardiac coil or a 12-channel phased array body coil. The non-navigated images were performed with acceleration using ARC parallel imaging (Autocalibrating Reconstruction using Cartesian sampling) [7].

For purposes of this feasibility study, navigated images were obtained without acceleration. Navigated, non-navigated and first venous phase suspended respiration images were reviewed together on a routine PACS monitors and were retrospectively scored by two pediatric radiologists independently for motion artifacts on a 4 point scale (0 – severe abdominal wall ghosts, blurred vessels; 1 – moderate ghosts detected, vessels mostly defined; 2 – a few ghosts detected, vessels sharply defined; 3 – no ghosts). A Wilcoxon rank-sum test was used to test the null hypothesis that there is no significant difference in scores between the different methods.

Results

The protocol was completed in all ten patients without complication. Mean motion artifact scores were 2.4 (reader 1) and 2.8 (reader 2) for suspended respiration, 1.5 (reader 1) and 2.0 (reader 2) for navigated free-breathing, and 0.5 (reader 1) and 0.7 (reader 2) for non-navigated free-breathing (Fig. 3). Suspended respiration images had significantly better image quality than navigated free-breathing ($p = 0.004$ and $p = 0.06$ for readers 1 and 2 respectively), whereas navigated free-breathing images had significantly better image

quality than conventional free-breathing ($p = 0.001$ and $p = 0.007$ for readers 1 and 2 respectively). Figures 4 and 5 show representative example images.

Discussion

Respiratory motion significantly degrades image quality in pediatric MRI. Although much work has been done to address this issue for T2-weighted imaging, T1-weighted imaging has received less attention. This is due in part to the ability of adults to breath-hold for the shorter T1 scans, heretofore limiting the motivation to address this problem. However, children often cannot comply with breath-holding instructions and a deeper degree of sedation is required for assisted suspended respiration. We present a novel technique of T1 navigation and a pilot study suggests image quality is improved over free-breathing, but not over suspended respiration. Thus, this method may benefit patients who cannot suspend respiration. Although this method was applied to abdominal imaging, it could be applied to pelvic imaging and contrast-enhanced thoracic magnetic resonance angiography.

This work is preliminary in that the pulse sequence developed with navigation as yet does not support parallel imaging. As navigation results in rejection of imaging data during most of the respiratory cycle, scan efficiency is compromised to approximately 40%, and hence scan time lengthened. The scan efficiency and degree of motion artifacts can theoretically be controlled to some extent by adjusting the navigator data acceptance window. At one extreme, a wide window would result in 100% efficiency, but with no reduction of motion artifact. Decreasing the acceptance window would improve motion artifact at the cost of increased scan time. The precise nature of this tradeoff was not evaluated in this preliminary study, but deserves attention in future work.

Further, as parallel imaging was not employed in the navigated acquisition, SNR is enhanced relative to non-navigated acquisitions and may bias image preference to the navigated acquisition. Thus, the incorporation of parallel imaging to accelerate image acquisition is critical and will be the focus of future work. This work also has the limitation that breath-held, navigated, and free-breathing non-navigated images were obtained at different times after administration of gadolinium. While this did not affect the ability to compare the degree of motion artifacts between different acquisitions, it did preclude blinding radiologists who were scoring the images as to the type of the exam.

Although image quality was improved with navigation, it was still inferior to that obtained with suspended respiration. Given the challenges of obtaining suspended respiration images, either with or without anesthesia, this compromise in image quality may still be acceptable. The residual artifacts with navigation are likely in part due to the finite acceptance window, resulting in some data inconsistency over the acquisition. However, further improvement may be obtained by adjusting the position of the imaged slab after each navigator pulse, i.e. to employ slab tracking. Also, further refinement of motion correction techniques that may be complementary to navigation should also be explored.

Acknowledgments

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Figure 1.

Navigation method. a) Each square reflects three components of the pulse sequence: (1) a spectrally selective inversion pulse for fat suppression, labeled SPECIR, (2) data acquisition via an 3D SPGR sequence, labeled ACQ, and (3) navigation pulse, labeled NAV. The navigator yields a position of the diaphragm, and data is accepted for image formation (light gray dots) only if the diaphragm position is within the acceptance window; otherwise (dark gray dots) the data is rejected. b) Positioning of the navigator pulse on the right hemidiaphragm is shown by bright cylinder.

Figure 2.
Example of waveform obtained from navigator pulse showing relative position of the diaphragm. When the position of the diaphragm is in an acceptance range (between the lines), k-space data for image formation is accepted (dots). Otherwise, the data is rejected.

Mean Motion Artifact Scores

Figure 3.

a) Scoring of motion artifacts between breath-held (BH), navigated free-breathing (Nav FB), and non-navigated free-breathing (Non-nav FB) acquisitions by two radiologists. b) Mean and standard deviation of difference of motion artifact scores between breath-holding and navigation and between navigation and non-navigated free-breathing acquisitions.

Figure 4. 6-year-old male with cavernous transformation of the portal vein. a) Ventilator Off, No Navigator: obtained with respiration suspended by an anesthesiologist. b) Ventilator On, With Navigator. c) Ventilator On, No Navigator. Note the relative clarity of portal vessels (arrowhead and zoomed view in insets) and ghosting artifacts (arrows) between images.

Figure 5.

35 month-old male with resected right hepatic lobe. a) Suspended respiration image has least motion artifacts, whereas image obtained during ventilation with navigation (b) has fewer artifacts than during ventilation without navigation (c) Same image as b, but windowed to show paucity of ghosts. (d). This example shows feasibility of the method even when anatomy in the right upper quadrant is distorted by right hepatic resection. Notice delineation of bile ducts (arrows, insets) and presence of respiratory ghosts (arrowheads).

Table 1

Patient demographics.

Gender	Age (years)	General Anesthesia	MRI Indication
M	14	N	Concern for liver tumor
F	26	N	Liver donor evaluation
F	1	Y	Neuroblastoma restaging
M	6	Y	Portal hypertension
M	3	Y	Hepatoblastoma surveillance after liver transplant
M	2	Y	Hepatoblastoma surveillance after resection
F	2	Y	Neuroblastoma surveillance
F	6	N	Hepatic embryonal sarcoma surveillance after resection
F	14	N	Hypertension, concern for renal artery stenosis
F	17	N	Immunosuppressed, concern for fungal disease