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Breath-held MR Cholangiopancreatography (MRCP) using a 3D Dixon fat–water separated balanced steady state free precession sequence

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ABSTRACT

A novel 3D breath-held Dixon fat–water separated balanced steady state free precession (b-SSFP) sequence for MR cholangiopancreatography (MRCP) is described and its potential clinical utility assessed in a series of patients. The main motivation is to develop a robust breath-held alternative to the respiratory gated 3D Fast Spin Echo (FSE) sequence, the current clinical sequence of choice for MRCP. Respiratory gated acquisitions are susceptible to motion artifacts and blurring in patients with significant diaphragmatic drift, erratic respiratory rhythms or sleep apnea. A two point Dixon fat–water separation scheme was developed which eliminates signal loss arising from B_0 inhomogeneity effects and minimizes artifacts from perturbation of the b-SSFP steady state. Preliminary results from qualitative analysis of 49 patients demonstrate robust performance of the 3D Dixon b-SSFP sequence with diagnostic image quality acquired in a 20–24 s breath-hold.

1. Introduction

Magnetic resonance cholangiopancreatography (MRCP) involves imaging fluid in the biliary tree while suppressing the background signal from non-fluid structures, and is most commonly performed using respiratory-triggered or navigator-gated three-dimensional (3D) fast spin echo (FSE)-based sequences, supplemented by thin and thick section single-shot fast spin echo acquisitions [1–6]. 3D FSE pulse sequences provide high spatial resolution volumetric images with excellent background suppression which can then be used to generate 3D reconstructions.

Respiratory or navigator gating performs well in subjects who have a steady respiratory rhythm. However, in patients with irregular or shallow respiratory rhythms, respiratory-gated acquisitions may fail to trigger correctly, prolonging scan times, or may result in images with substantial motion artifact. Several modifications of the standard respiratory-gated 3D FSE MRCP pulse sequence have been proposed, including parallel imaging [7], navigator triggering in place of respiratory triggering [8], navigator gating with prospective acquisition correction (PACE) [9,10], sampling perfection with application optimized contrasts using different flip angle evolutions (SPACE) [11–14], and respiratory compensation using a reference respiration model [15]. These techniques have all resulted in improved image quality and reduced artifact in small series; however, they are not all widely available, and have not succeeded in eliminating motion artifact in all patients. Taylor et al. [16] have demonstrated that longer scan times result in a greater prevalence of diaphragmatic drift, further worsening image quality. In our experience a small but significant percentage of 3D FSE MRCPs are compromised by motion artifacts — we surveyed our last 100 clinically indicated 3D FSE MRCPs and found that approximately 5% were significantly limited by artifact to the extent of possibly compromising the diagnostic ability of the exam, while an additional 20% had mild-moderate artifact which reduced image quality without obviously affecting the diagnosis. While 2D single shot fast spin echo images generally provide diagnostic information in these cases, spatial resolution is compromised and 3D reconstructions of 2D data are of limited value.

Balanced steady state free precession (b-SSFP) pulse sequences have a number of features suggesting their potential utility for MRCP imaging, including short TRs and consequent short acquisition times, high signal-to-noise ratios (SNR), and T_2/T_1 contrast weighting, rendering fluid-containing structures bright. B-SSFP sequences are increasingly employed in standard hepatic MRI protocols, and have seen limited use as accessory techniques for MRCP [2,17,18]. The feasibility of 3D b-SSFP for MRCP has been demonstrated [19] where high spatial resolution images depicting the biliary tree with good SNR and contrast-to-noise ratio (CNR) were obtained in a single breath-hold. Fat suppression could be applied to improve the image quality further, increasing conspicuity of the biliary tree by reducing the background signal and consequently improving the quality of the

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3D reconstructions. However, fat suppression in b-SSFP pulse sequences is non-trivial. The use of fat saturation pulses inevitably results in saturation of water signal due to B_0 heterogeneity. Furthermore, the use of intermittent fat suppression pulses to improve scan efficiency causes a perturbation of the SSFP steady state, resulting in ghosting artifacts and necessitating the use of steady-state catalyzing preparation schemes which can further prolong scan times. In areas with poor B_0 and B_1 homogeneity, the quality and degree of fat saturation are compromised.

In this study, we investigated the use of a two-point Dixon fat–water separated 3D b-SSFP sequence for robust fat-suppression as an adjunct to the standard respiratory-gated 3D MRCP acquisition. The elimination of explicit fat saturation pulses makes the technique robust to B_0 and B_1 heterogeneity and also eliminates artifacts resulting from any perturbation of the SSFP steady state. The use of high receiver bandwidths enabled the incorporation of both echoes in a single TR, minimizing the total scan time and permitting coverage of the entire biliary tree in a single breath-hold. Breath-held Dixon 3D b-SSFP acquisitions were obtained in 49 patients scheduled for clinically indicated hepatic or pancreatic MRI/MRCP and compared with conventional clinical respiratory-triggered 3D FSE acquisitions.

2. Materials and methods

2.1. 3D Dixon b-SSFP Pulse sequence

A dual echo 3D balanced steady-state free precession pulse sequence with a bipolar readout was developed (Fig. 1). The bipolar implementation allowed minimization of TR by optimal placement of opposed-phase and in-phase echoes (1.2/2.4 ms at 3.0 T and 2.4/4.8 ms at 1.5 T). This not only minimizes banding artifacts in b-SSFP but also allows breath-held scans despite the dual echo acquisition. The dual echo acquisition was followed by a robust region-growing based 2-point Dixon fat–water separation technique [20]. The resulting fat suppression was relatively immune to B_0 field inhomogeneities. The elimination of explicit fat saturation pulses minimized any perturbations of the steady state magnetization that often cause banding artifacts in b-SSFP sequences. In order to further reduce the total scan time to a reasonable breath bold (<25 s), Auto-calibrating Reconstruction for Cartesian imaging (ARC), a hybrid-space parallel imaging scheme capable of two-dimensional acceleration was employed. For axial scans, a 1-D acceleration factor of 2–3 was used, while for coronal scans a 2D acceleration of 2.5x2 was used.

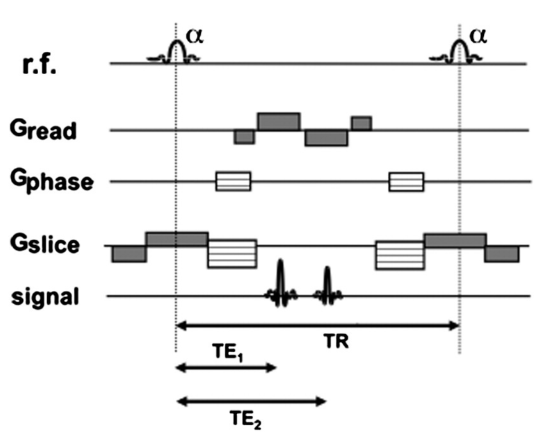

Fig. 1. Dual-echo bipolar readout 3D b-SSFP pulse sequence used for breath-held 3D MRCP. Due to the high receiver bandwidths used, it was possible to position the echoes at 1.2 ms and 2.4 ms (3.0 T) or 2.2 ms and 4.4 ms (1.5 T) in a single TR, resulting in short scan times.

2.2. MRI

Patients were scanned on a 1.5 T GE Signa (n = 35) or 3.0 T GE Excite system (n = 14) (GE Healthcare, Waukesha, WI) using an 8-channel torso phased array coil.

Following localizer scans, a respiratory-gated 3D FSE sequence was acquired in the coronal oblique plane with the following parameters: 320×224 in-plane matrix with 60–70 1.2–1.6 mm sections acquired, 30–36 cm FOV, TR 3750 ms, effective TE ~650–900 ms, ETL 80–120, ±42 kHz receiver bandwidth. Parallel imaging (ARC) was employed with an acceleration factor of 2. The acquisition time depended on the patients' respiratory rate as well as the imaging volume, but generally ranged from 4 to 6 min.

The breath-held 3D Dixon b-SSFP sequence was acquired in an axial oblique plane (n = 33), coronal oblique plane (n = 4), or both (n = 12) with the imaging parameters listed in Table 1.

2.3. Patients

For this HIPAA-compliant and IRB-approved retrospective study, clinical MRI records were searched for MRCP examinations in which both breath-held 3D Dixon b-SSFP and respiratory-triggered FSE acquisitions were obtained. 49 patients had clinically indicated MRCPs performed between 1/16/2010 and 8/17/2010 at 1.5 T or 3.0 T in which both the standard respiratory-triggered 3D FSE sequence and 3D Dixon b-SSFP were acquired.

There were 21 female and 28 male patients ranging in age from 5 to 82 years, with an average age of 52 years. Clinical indications for MRCP included cholangiocarcinoma (13 patients), primary sclerosing cholangitis [11], elevated liver function tests and/or suspected biliary obstruction [9], acute or chronic pancreatitis [6], pancreatic cyst or intraductal papillary mucinous neoplasm (IPMN) [5], and additional indications including choledochal cyst, gallbladder polyp, metastatic disease, hepatic mass, and abdominal pain in single patients.

2.4. Data analysis

Images were evaluated by a fellowship-trained abdominal radiologist blinded to clinical or surgical results. 3D FSE and 3D Dixon b-SSFP images were assessed separately for each patient in reading sessions separated by 4 weeks to minimize recall bias. Within each reading session, 3D FSE and 3D Dixon b-SSFP images were alternated from patient to patient. In a final session, both sequences for each patient were compared side by side and a preferred sequence was selected.

Images were assessed for overall image quality on a scale of 1 to 5 (1 = uninterpretable; 2 = poor; 3 = fair; 4 = good; 5 = excellent) and the presence of artifacts also on a scale of 1 to 5 (1 = severe artifacts with nondiagnostic images; 2 = major artifacts with significant effect on diagnostic quality; 3 = moderate artifact with

Table 1
Imaging parameters for 3D Dixon b-SSFP acquisitions at 1.5 T and 3.0 T.

	1.5 T	3.0 T
TR (ms)	6.0–6.4	4.0
TE_1 (ms)	2.4	1.2
TE_2 (ms)	4.8	2.4
Receiver bandwidth (kHz)	125	142
Flip angle	50	45
Matrix	224 × 256	192 × 224–256
Section thickness (mm)	1.6–2.4	1.6–2.0
# sections	40–54	46–60
Field of view (cm)	32–40	32–40
Acquisition time (s)	20–24	20–24