High-Resolution Free-Breathing 3D T1 Weighted Hepatobiliary Imaging Optimized for Gd-EOB-DTPA

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Introduction: Gd-EOB-DTPA is a gadolinium based contrast agent with 50% hepatobiliary uptake and excretion. Conventional contrast-enhanced delayed hepatic imaging has required breath-hold acquisitions that inherently limit spatial resolution and signal-to-noise ratio (SNR). However, biliary excretion is relatively slow and does not require rapid breath-hold imaging that is needed during dynamic contrast enhanced imaging. In addition, the detection of small parenchymal lesions and visualization of fine biliary anatomy would benefit from improved spatial resolution[1]. The purpose of this work was to develop a navigator based T1-weighted imaging sequence to obtain very high spatial resolution in approximately 5 minutes of free-breathing. In addition, optimization of imaging parameters (delay following contrast administration and flip angle) was performed to optimize visualization of hepatic lesions and biliary anatomy when using Gd-EOB-DTPA.

Methods: The GE product LAVA sequence (spoiled gradient echo [SPGR] with periodic spectrally-selective partial inversion to suppress signal from fat) was modified to add a periodic cylindrical excitation navigator pulse that was used to determine diaphragm position and reject data acquired outside of a prescribed range of motion ("navigated LAVA"). As a proof of feasibility and to determine the optimal contrast timing and optimal flip angles for hepatocyte and biliary phase imaging, eight normal volunteers (average age = 40±14, range = 22-58, 4:4 M:F) were scanned for 30 minutes following administration of 0.05mmol/kg of Gd-EOB-DTPA, alternating between a breath-held 3D LAVA sequence and the navigated LAVA sequence. Scan parameters for the breath-held sequence were: volume = 35 (R/L) x 26 (A/P) x 18 (S/I) cm^3, matrix = 256 x 192 x 44 (true resolution = 1.4 x 1.4 x 4 mm^3), bandwidth = ±63kHz, partial k_z (0.75) acquisition, flip angle = 12°, TR/TE = 5.5/2.6ms. Scan parameters for the navigated LAVA sequence were: volume = 35 (R/L) x 28 (A/P) x 19.4 (S/I) cm^3, matrix = 288 x 256 x 108, bandwidth = ±42kHz, 1 signal average, flip angle = 15°, TR/TE = 5.5/2.6ms. True resolution was 1.2 x 1.1 x 1.8 mm^3, interpolated to 0.7 x 0.5 x 0.9 mm^3 through zero-filling. Beginning 30 minutes after contrast administration, multiple breath-held acquisitions were then performed at varying flip angles to determine the flip angle that optimizes SNR and CNR. The signal in a variety of tissue types and air was measured for both of these experiments. The resulting curves were used to determine the optimal delays and flip angles to be used for hepatocyte and biliary phase imaging. Finally, the resulting optimized navigated LAVA sequence was then used in several patients presenting with a variety of hepatobiliary indications in order to demonstrate the technical feasibility in patients. The clinical protocol used a hepatocyte-phase navigated LAVA scan obtained 5 minutes following contrast administration with a flip angle of 30° and a biliary-phase scan obtained at 20 minutes with a flip angle of 40°.

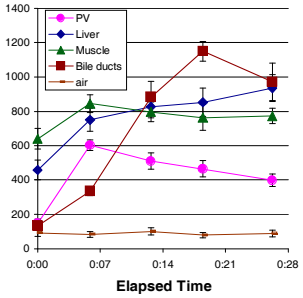

Figure 1. Contrast Uptake Curves. Hepatic contrast plateaus at ~7min. Biliary contrast peaks at ~20min.

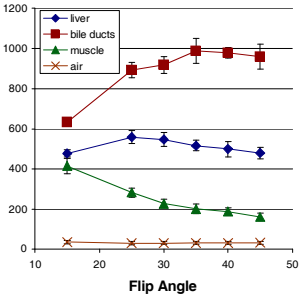

Figure 2. Optimal flip angles for maximal SNR. Hepatocyte: 30° Biliary: 40°

Results: Figure 1 shows contrast enhancement curves from one of the normal volunteers. Similar results were obtained for the other 7 volunteers. Liver parenchyma reaches a plateau at approximately 5-7 minutes following Gd-EOB-DTPA administration, with a continued gradual increase through 25-30 minutes. The greatest contrast between the biliary tree and the hepatic parenchyma occurs at 15-20 minutes. Figure 2 shows the dependence of signal on flip angle for various tissues in the same volunteer. Hepatocyte signal demonstrates a broad plateau from 20-35°. The biliary ducts show progressively increased signal at higher flip angles with a plateau at 35-45°.

The higher isotropic resolution of the free-breathing navigated LAVA sequence is demonstrated in Figure 3. This high resolution and the high hepatic uptake of Gd-EOB-DTPA (50%) allow 3D image processing techniques to be used, including multiplanar reformations, maximum intensity projections (MIP), volume rendering, and thin-slab minimum intensity projections (minIP). Figure 4 shows some examples of these visualization techniques.

Figure 5 shows an example from a patient scanned with this new sequence. In this patient the navigated LAVA sequence enabled two important biliary duct variants to be identified, either of which could lead to post-operative complications following cholecystectomy and neither of which could be positively identified on the conventional breath-held sequence. An anomalous posterior branch of the right intrahepatic bile duct joins the proper hepatic duct in the expected location of the cystic duct, while the cystic duct crosses this anomalous duct to a very low insertion into the common hepatic duct in the pancreatic head. It would be easy for a surgeon to ligate the anomalous posterior branch of the right intrahepatic duct, believing it to be the cystic duct, causing biliary obstruction in the posterior right hepatic lobe and potentially a bile leak from the non-ligated cystic duct.

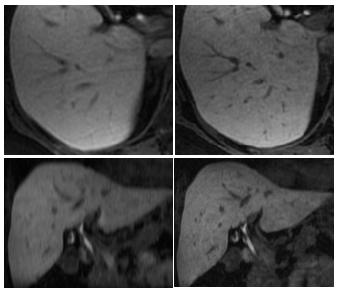

Figure 3. (Left) 25s Breath-hold (Right) 5-min Navigated LAVA (free breathing).

Discussion: The use of free-breathing navigated LAVA enables high isotropic resolution liver imaging in hepatocyte and biliary phases. The optimal flip angle for hepatocyte phase imaging is 20-35°, compared with 35-45° for biliary imaging. The optimal delay is approximately 5 min for hepatocyte imaging and 15-20 min for biliary imaging. The improved resolution allows 3D reconstruction methods to be used with ease. The technical feasibility of the sequence has been demonstrated in volunteers and in patients with a variety of hepatobiliary conditions.

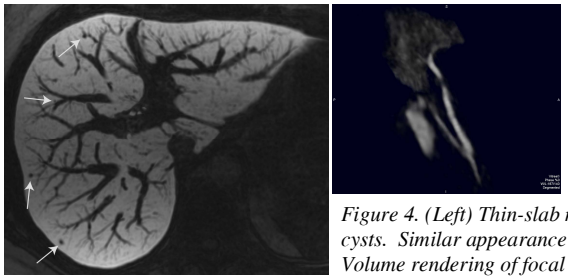

Figure 4. (Left) Thin-slab minIP demonstrating improved conspicuity of cysts. Similar appearance would be seen for small metastases. (Right) Volume rendering of focal narrowing of bile duct due to a crossing vessel.

Figure 5. Thin-slab MIPs showing important biliary anatomic variant in a patient being considered for cholecystectomy. (See text)

Reference:

1. Lee SS, et al, JMRI, 2007;26:323-330