Arterial-phase Bolus-track Liver Examination (ABLE): Optimization of Liver Arterial Phase Gadolinium Enhanced MRI Using Centric Re-ordered 3D Gradient Echo and Bolus Track Real-Time Imaging

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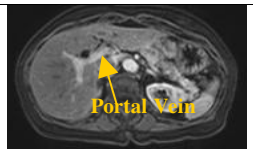
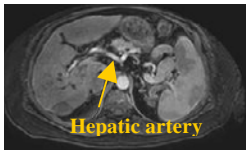
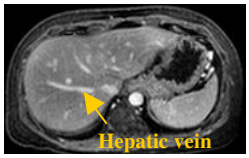
Introduction: It has been shown that amongst the most critical component of a comprehensive abdominal MRI of the liver is the arterial phase of a dynamically gadolinium enhanced series of gradient echo images. Of particular note, vascular tumors that receive predominantly hepatic arterial supply may show maximum conspicuity and characteristic enhancement during the hepatic arterial dominant phase, and may become inconspicuous or show features considered to be non-specific in later phases of enhancement. Transient arterial phase irregular enhancement of liver parenchyma has also been associated in the setting of acute or acute-on-chronic hepatitis. Suggested methods for ensuring an optimal arterial phase liver image set have varied between empirical and pre-scan bolus timing. We believe that it may be possible to simplify the arterial phase acquisition and make this imaging step more reproducible by applying a methodology similar to that currently adopted for contrast enhanced MR angiography. In this technical development study, we use the combination of a real-time bolus track technique with a 3D gradient echo liver imaging technique that has been modified to acquire central encoding of low frequency k-space (CENTRA) at the beginning of the acquisition in order to allow better control of timing of the acquisition of the contrast component of the image, which we refer to as arterial-phase bolus-track liver examination (ABLE).

Purpose: The purpose is to show evidence that the ABLE approach may provide improved reliability and reproducibility for arterial phase image timing.

Materials and Methods: The CENTRA technique (Philips, Best, The Netherlands) orders segments in Ky-Kz space in central and peripheral k-space sectors separately. In the initial phase, the central k-space sector is acquired (~4 sec), followed by acquisition of the peripheral k-space. Signal discontinuities from the segmentation of the central and the peripheral k-space sector is avoided by segmenting the central k-space sector in the Ky direction, and the peripheral sector in congruent radial segments. The intent of this pulse design is to allow for acquisition of critical low k-space frequencies entirely at the beginning of the acquisition as has been developed for MR angiography. Imaging was performed on a Philips 3T Intera system equipped with a 6-element torso array coil. After informed consent was obtained, 20 sequential patients were imaged with ABLE in combination with CENTRA-Thrive. Arterial-phase bolus-track liver examination was performed as follows: A bolus-track sequence, which produces an image approximately every second with on-the-fly image reconstruction (500mm FOV, 128*256 matrix, TR/TE/flip = 4.1/1.2ms/10), was initiated simultaneously with 0.1mmol/kg Gd-DTPA (Magnevist, Berlex, Iselin, NJ), at 3 ml/s. The bolus-track imaging was stopped *when contrast entered the celiac axis*, and the patient was then given breathing instructions. After *8 seconds*, the liver was imaged using a 3D gradient echo sequence with centric re-ordered k-space (CENTRA-Thrive) acquired in 16.5 seconds during the patient breath hold (360 mm FOV, 256 matrix, TR/TE/flip = 2.9/1.4ms/10, 64 lines/segment, 4mm slice thickness, 2 NSA, SENSE factor = 2). The 8 second delay was determined from perfusion analysis of contrast:noise ratios of arterial phase enhancing tumors and correlation with perfusion of the hepatic artery and portal vein. Additionally, a venous and delayed phase image set was obtained 60 and 180 sec after contrast administration, to complete the comprehensive multi-phase examination. For comparison, the routine Thrive sequence with traditional centric ordering (same parameters) was retrospectively evaluated in 21 patient examinations. Evaluation of gadolinium liver enhancement was determined in relation to the hepatic vessels containing contrast. *Optimal timing* was defined as the presence of contrast in the hepatic artery and portal vein, but not in the hepatic veins. *Late timing* was defined as contrast appearing in the hepatic veins. *Early timing* was defined up to the point when contrast appears in the hepatic artery but not yet in the portal vein. Evaluation of image signal contrast in the delayed phase images was determined by placing regions of interest over the liver, spleen, and paraspinal muscle and calculating the relative liver:muscle and spleen:muscle ratios.

Results: Table 1 compares the timing of the ABLE technique (CENTRA-Thrive) with routine Thrive (non-CENTRA). As seen, the ABLE technique was optimally timed in 19 of 20 patients (95%), while the routine empirical timing technique was optimal in 14 of 21 (67%) ($p<0.05$). Examples of optimal, early and late timing are also shown. Image quality was not significantly different between the two techniques when timing was optimal. In the delayed phase, signal ratios were 1.17+/-.28 vs. 1.22+/-.32 (liver:muscle), and 1.43+/-.11 vs. 1.48+/-.11 (spleen:muscle) for non-CENTRA and CENTRA, respectively ($p>0.10$).

Table 1. Timing Stratification for Patients Evaluated using both Techniques

		ABLE (n=20)	Empirically timed (n=21)
Optimal		19	14
Early		1	4
Late		0	3

Conclusions: Although empirically timed examinations have been used routinely in gadolinium-enhanced liver examinations, the approach may fail in cases where the vascular transit time is altered, such as in patients with poor cardiac output. By utilizing the timing protocol outlined by the ABLE technique with the CENTRA-Thrive sequence, we have shown to consistently capture the arterial phase of liver perfusion. This consistency was afforded by the use of the CENTRA technique (acquisition of only low frequency k-space for the initial 4 seconds of the Thrive sequence), which enabled robust image timing 8 seconds following bolus appearance in the celiac axis. This was sufficient time to provide the patient with breath holding instructions. Non-CENTRA Thrive would not allow optimal bolus track timing as the central time for image contrast acquisition would occur near the center of the acquisition time and would therefore result in imaging too late in the vascular phase. The ABLE technique may allow software-controlled automation of a gadolinium-enhanced liver examination, making routine high quality imaging accessible to more centers.