Clinical application of 3D CAIPIRINHA Dixon TWIST (CDT) for fast time-resolved dynamic volumetric imaging of the abdomen

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Purpose

To assess the feasibility and image quality of a novel highly accelerated T1w-method for time-resolved imaging of the abdomen during first pass of the contrast media transit using CAIPIRINHA (controlled aliasing in parallel imaging results in higher acceleration) undersampling, view-sharing techniques and Dixon water-fat separation (CDT-VIBE).
Methods and Materials

Patients

The institutional review board (IRB) waived the requirement of informed patient consent in this retrospective study. Information gathered on this population was performed in compliance with HIPAA guidelines. All patients who had undergone an abdominal MR-study at Skyra-system from 07/19/2012 when the CDT-VIBE was introduced clinically were included until 08/24/2012. The clinical indications for imaging included characterization or follow-up of hepatic, pancreatic or renal lesions and oncologic follow-up after tumor treatment or resection (liver, pancreas, kidney). The patient population consisted of 47 patients (median age 62 years, range 11-89 years, 25 men, 22 women). All patients signed an informed consent before the MR-exam.

MR-Imaging

All exams were acquired on a 48-channel 3T MR system (MAGNETOM Skyra VD 13, Siemens Healthcare Sector, Erlangen, Germany) with an 18-element body matrix coil and the inbuilt 32-element spine matrix coil. Patients were positioned head first supine. After T2w HASTE localizing sequences a non-enhanced T1w-VIBE with Dixon fat separation and four-fold acceleration using CAIPRINHA was acquired before contrast administration. For the injection of the contrast agent an MR-compatible automated injector pump (Spectris Solaris EP, Medrad, Indianola, PA) and an 18G i.v. line placed in the patients' antecubital vein was employed. After the injection of 0.1mmol/kg body weight of the macrocyclic Gd-DOTA (Dotarem®, Guerbet, Paris, France) at 1.5ml/s followed by a 30ml saline chaser at the same injection rate and a 5s delay the 10s long breathhold-command for the post-contrast T1w CDT-VIBE was given. In a single patient with cirrhosis of the liver a single dose of Gd-EOB-DTPA (Eovist®, BayerHealthCare, Berlin, Germany) was administered. The CDT-VIBE was hence started 15s after the start of the contrast agent injection. This timing was chosen to be able to display the arrival of the contrast agent in the upper abdomen. The CDT-VIBE yields four different series each comprising 14 3D-datasets: the acquired in-phase echo, the acquired opposed-phase echo, the reconstructed fat separated water-only series and the reconstructed fat-only series. After the CDT-VIBE regular T1w-VIBE sequences were acquired to yield a portalvenous phase (50s after start of contrast agent injection) and a delayed phase dataset (100s after start of the contrast agent injection). TThe acquisition scheme is presented in Figure 1.

Image Analysis

The CDT-VIBE images were evaluated by two blinded experienced radiologists (9 years and 6 years of experience with body MRI) independently. For this assessment only the fat-separated water-only series was chosen and loaded into the orthogonal MRP 4D-
viewer of OsiriX 4.0 (OsiriX Foundation, Geneva, Switzerland) running on an iMac with 8GB RAM and an i7-CPU (Apple Inc, Cupertino, CA). This 4D-viewer allows scrolling through the stack of images (in all three orthogonal orientations) while being able provide a cine loop at the same time (Figure 2). If desired the cine loop could be slowed or halted and a MIP function could be activated. As the sequence lasted 29s some patients were not able to hold their breath or diaphragm motion involuntarily occurred and resulted in artifacts. Therefore the radiologists assessed the best and worst image quality of the CDT-VIBE water-only images per frame on a 5-point Likert-type scale (20 on page 000): 5 - excellent, 4 - good image quality, 3 - moderate image quality with slightly disturbing artifacts, 2 - poor image quality with artifacts yet still diagnostic, 1 - non diagnostic image quality. In addition the number of hepatic artery dominant (HAD) phases of the liver was counted. This phase was defined as presence of strong hepatic arterial enhancement and co-existing portal-venous enhancement with no visible enhancement of the hepatic veins as previously defined by Semelka et al. (21 on page 000). Pathologies of the liver, the pancreas, the adrenal glands or the kidneys seen on the CDT-VIBE were correlated with the portal-venous phase of the T1w-VIBE. If the CDT-VIBE provided an added diagnostic value over the portal-venous and venous VIBE a note was made.
Fig. 1: Conventional dynamic abdominal T1w imaging (upper row): after non-enhanced images and contrast injection three measurements are acquired - each lasting 22s. Only one arterial phase with a fixed delay of 20s + 10s for the breathhold command is acquired. New imaging approach for dynamic abdominal T1w imaging (lower row): after non-enhanced images and contrast injection three measurements are acquired. The portalvenous and venous acquisitions last 10s while the acquisition of the arterial phase lasts 29s. During these 29s 14 3D-datasets are acquired with a temporal resolution of 2.1s. After contrast injection the arterial phase is started after a delay of 5s + 10s for the breathhold command. TA - time of acquisition, TR - temporal resolution

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**Fig. 2:** Display of the 4D viewing tool used for image analysis.

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Results

Patient Data

In all patients the CDT-VIBE measurements were successfully acquired as exemplary shown in Figure 3. The image quality was rated diagnostic in 46/47 patients. In all but one patient the sequence allowed to visualize the gradual filling of the hepatic arteries and a gradual enhancement of the upper abdominal organs, particularly also in the patient who received Gd-EOB-DTPA (Figure 4 and Figure 5). The image quality was best on the first frames and tended to decrease towards the end of the measurement. Impaired image quality was most frequently due to failure to hold the breath throughout the entire measurement resulting in coarse artifacts. The continuous motion of the stomach, the intestines and the heart introduced additional slight motion artifacts that were the most common reason for image quality degradation. Both readers assessed the best image quality with a median score of 4 and the worst image quality with a median score of 3. The inter-reader agreement was 0.789 for the best image quality and 0.698 for the worst image quality as assessed by k-statistics. The patient with non-diagnostic image quality did not follow the breathhold commands. In all patients hepatic arterial dominant (HAD) phase frames were acquired. Depending on the arrival of the contrast agent in the liver the number of HAD-frames ranged between 1 and 8 with a median value of 5. Additional findings were present in 10/47 patients (21%). These additional findings included metastases only encountered in the CDT-VIBE (Figure 6), perfusion homogeneities in inflammatory liver disease, altered perfusion of the pancreas and bowel wall in patients with pancreatitis and Crohn's disease.
Fig. 3: Display of the each of the 14 dynamic frames acquired in a single breathhold in a 73 year-old male patient who had undergone selective internal radiotherapy for colorectal cancer before. The liver demonstrates large avascular metastases (arrowhead) in the left lobe of the liver but also a vividly enhancing subcapsular metastasis in segment 8 (arrow) which shows gradually increasing enhancement throughout the total acquisition. A second only faintly enhancing metastasis can be appreciated anteriorly to the metastasis in segment 8 (box). Please also note the gradual filling of the distal portal vein branches.

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Fig. 4: Precontrast (T2w HASTE fs, T1w VIBE Dixon-fs upper row) and Gd-EOB-DTPA enhanced (CDT-VIBE and hepatocyte-specific phase VIBE Dixon) of a 55 year-old male patient with cirrhosis of the liver and a focal HCC. Despite the small volume of Gd-EOB-DTPA the CDT-VIBE provides several HAD-images and clearly demonstrates the hypervascularization of the HCC:

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Fig. 5: Cancer of the head of pancreas (arrows) with intrahepatic cholestasis and decreased ADC in a 57 year-old male patient. The tumor shows a clear
hypovascularization in the CDT-VIBE with slow peripheral enhancement consistent with adenocarcinoma of the pancreas.

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**Fig. 6:** Hypervascularized liver lesions in a 73 year-old male patient with pancreatic cancer (arrow and arrowhead) that are clearly seen in the CDT-VIBE. In the venous phase VIBE imaging only the larger metastasis in segment 4b of the liver can be appreciated (arrow, lower row) while the second lesion cannot be detected (box).

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Conclusion

CDT-VIBE is a robust approach that for the first time allows dynamic imaging of the upper abdomen with high temporal resolution and maintained high spatial resolution.
References


