CARDIAC IMAGING WITH UNDERSAMPLED 3D PROJECTION RECONSTRUCTION (VIPR) IN A SINGLE BREATH-HOLD

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Introduction
Undersampled projection reconstruction (PR) has been recently introduced to MR Angiography [1] and cardiac imaging [2,3]. These PR techniques allow for faster image acquisition than spin-warp imaging with tolerable artifacts in selected applications. Reduced SNR and streak artifacts are the limiting factors in undersampled radial trajectories while replication artifacts prohibit undersampling in Fourier encoding.
Block et al. [4] demonstrated a 3D projection trajectory, VIPR (Vastly undersampled Isotropic Projection Imaging), that isotropically images high resolution 3D volumes by undersampling in all three k-space dimensions.

Purpose
Here we investigate the use of VIPR with retrospective ECG gating for cardiac imaging. This technique can provide a multiphase dataset with isotropic resolution over a large volume from data acquired during a single breath-hold. Potential advantages of this approach include the reformatting capabilities from isotropic resolution and the simplified scan prescription without the need for any localizers.

Methods
In VIPR, each projection passes through the center of k-space. The projections are aligned so that their endpoints are evenly distributed over the surface of a sphere. The data are acquired in an interleaved fashion as shown in Figure 1.

Figure 1: (a) The endpoints of the projections in VIPR sample the surface of a sphere. The projections can be subdivided into interleaved subsets as shown in (b) and (c).

A half echo acquisition was used to improve acquisition speed. Each left half of the echo samples an even projection. Once the center of k-space is acquired the amplitude of the gradient is changed so that the right half of the echo samples the adjacent odd projection [5]. The missing data are synthesized using a homodyne reconstruction. This method allows to acquire twice as many projections in approximately the same scan time to reduce the artifact level.
The sequence was implemented on a 1.5 T Signa Horizon CardioVascular scanner (GE Medical Systems, Waukesha, WI) with peak gradient amplitudes of 40 mT/m and a maximum slew rate of 150 mT/m/s. Healthy human volunteers were imaged using a cardiac phased array coil with 4 elements during the injection of a Gd-based contrast agent with a dose of 0.3 mmol/kg. The bolus was venously administered at an injection rate taylored to deliver the dose over the duration of the scan.
The number of samples in each readout was $N_r = 128$, which requires $p/2xN_r2 \sim 26{,}000$ projections to fullfill the Nyquist theorem. A total of 15,000 projections (30,000 half echoes) were acquired over a 40x40x40 cm^3 cubic image volume with a spoiled gradient echo sequence (TR/TE = 3.1/1.2 ms) and a bandwidth of 62.5 kHz. The total scan time was 48 s and the 128 images were zero-filled to a 256x256 in-plane matrix size.
The location of the R-waves in respect to the projection numbers were detected by the internal ECG unit of the scanner and stored for retrospective gating with an offline reconstruction.

Results
Figure 2 shows 2 slices throughout the cardiac cycle reconstructed in the axial plane. Each image volume represents a 150 ms interval of the cardiac cycle. The blood pool is enhanced from the contrast agent and can be well differentiated from the myocardium, e.g. for volume measurements.

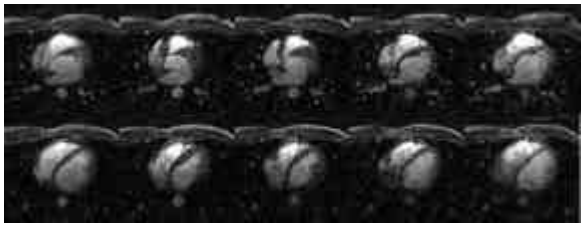

Figure 2: Two axial slices throughout the cardiac cycle. Each image represents a 150 ms period.

An example of a reformatted view is shown in Figure 3. This view demonstrates good spatial resolution in the z-direction also. Note the large volume coverage in all dimensions.

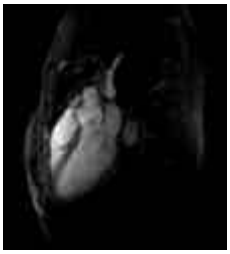

Figure 3: Reformatted images provide isotropic resolution in arbitrary directions.

Conclusion
In this preliminary work we have demonstrated a novel technique for 3D single breath-hold cardiac MR which provides isotropic resolution. With VIPR, the reconstructed images can be reformatted in arbitary orientations without loss in resolution. Therefore, for example, both ventricles can be equally well analyzed contrary to more conventional scans where the orientation of thick slices is optimized for one of the ventricles. In addition, the prescription process is shortened and greatly simplified compared to 2D techniques with double oblique scan orientations.
The in-plane resolution of 3.1 x 3.1 mm^2 is rather large compared to other approaches. However, the resolution in the third dimension is also 3.1 mm, which is much smaller than with most other techniques and might be advantageous for measurements such as volumes and ejection fraction. We are investigating methods to limit the FOV in PR imaging to improve the spatial resolution without introducing artifacts from objects outside the samller FOV.
The temporal resolution of the technique is currently limited by the streaking artifacts from high signal structures such as fat. This is particularly problematic for the VIPR sequence with True-FISP (fast imaging with steady precession). Fat supression techniques can potentially reduce these artifacts.
We have also shown in a previous study [6] that 3D PR acquisitions are well suited for motion detection and correction as they intrinsically provide information similar to navigator echoes. These capabilities may allow for longer acquisition times during free breathing. The additional projections could provide higher temporal resolution within the cardiac cycle or less streaking artifacts.