3D Dynamic Contrast-Enhanced Using Undersampled Golden-Radial Phase Encoding

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INTRODUCTION: 3D Time-Resolved Dynamic Contrast Enhanced MRI (DCE-MRI) is an important tool to depict anatomic and dynamic information (bolus pass) of thoracic vessels. The current limitation of this application is the requirement of both high spatial and temporal resolution. Several methods have been proposed to overcome this problem [1-3], however, these techniques usually need an accurate timing of the bolus arrival and a fixed, predetermined trade-off between spatial and temporal resolution. As an alternative, we propose a new dynamic undersampled acquisition scheme, which combines a 3D radial phase encoding trajectory [4] with the golden angle profile order [5]. This approach allows retrospective adaptation of the spatial-temporal resolution trade-off according to the different stages of the bolus pass. For instance, images can be reconstructed with high temporal resolution for the first dynamic frames and high spatial resolution for the later ones, without the need of a previous bolus track acquisition. Moreover, the proposed method takes advantage of the flexibility and properties of the trajectory to provide an explicit good regularization for iterative reconstructions.

This abstract describes the method and the results of an application of this technique using a *32*-channel coil and iterative SENSE [6] reconstruction. Simulations were used to determine the amount of undersampling and the resulting spatial and temporal resolution. Furthermore, the method was tested in phantoms and in time-resolved thoracic vessel angiography in patients. The obtained data was reconstructed retrospectively with temporal resolutions of *11s* and *4.3s* (undersampling factors of *19* and *49* respectively), and a temporal resolution of *2.7s* was used to estimate the bolus arrival.

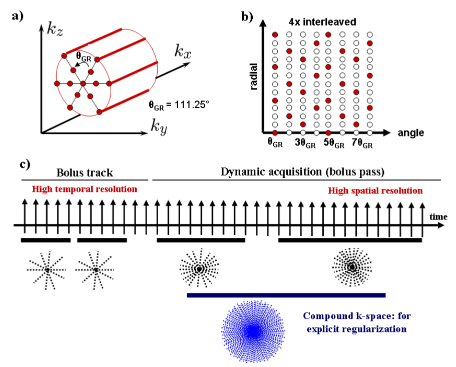

Fig1: a) Golden angle RPE trajectory b) Interleaved radial scheme c) Dynamic acquisition diagram and compound k-space for explicit regularization.

METHODS: A modification of the 3D Radial Phase Encoding (RPE) trajectory [3, 4] for time-resolved applications was implemented. The acquisition combines Cartesian sampling in the readout direction with an undersampled radial scheme in the phase encoding plane. The angular step between two radial profiles was given by the golden angle of θ_{GR} = *111.246° (Fig. 1a),* which allowed retrospective reconstruction with different temporal resolutions from the same data set (Fig.1c). In addition the golden angle approach allows view sharing reconstruction with a high number of frames. An interleaved undersampling was used in the radial direction for every profile (Fig.1 b) to ensure good point spread function (PSF) properties (large FOV and aliasing incoherence). Finally the golden angle radial phase encoding trajectory can be used to reconstruct compound images and to use these images to regularize dynamic iterative reconstructions (Fig1c).

a) Simulations: The accuracy of the proposed method was tested in simulations using a numerical phantom (*256^3 matrix, 20 frames*). An undersampling factor of *4* in the radial direction, and *55*, *34* and *26* profiles in the angular direction were used (*19x*, *30x* and *39x* undersampled respectively).

b) In vivo studies: To test the method, the sequence was implemented on a Philips Achieva 3T scanner and *3* patients were scanned with a *T1-TFE* sequence, *(FOV=384 mm^3, resolution=1.5mm^3, TR/TE/flip angle =3.2/1.6ms/15°*) using a *32*-channel coil. Isotropic CE volumes were acquired during the first-pass of the contrast agent (*0.2ml/kg* Gd-DTPA at *4ml/s*), without previous bolus-track scan. The bolus timing was retrospectively determined from the same data set. A sequence of *6* dynamic frames was retrospectively reconstructed with three different temporal resolutions: a) Two high temporal resolution (2.7s, *79x* undersampled), b) Two medium temporal resolution (4.3s, *49x* undersampled) and c) Two high spatial resolution (11s, *19x* undersampled).

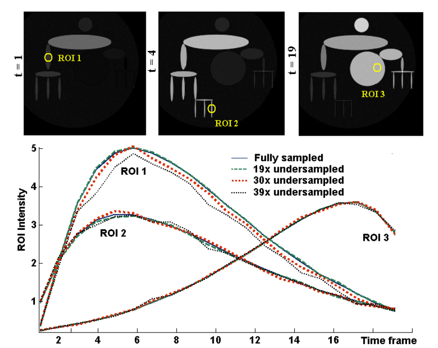

Fig2: Dynamic intensity evolution for 3 ROIs with 19x, 30x and 39x undersampled reconstructions. ROIs and phantom used are included in the first row.

RESULTS: *a) Simulations*: Dynamic intensity evolution for *3* regions of interest (ROIs) with *19x*, *30x* and *39x* undersampled reconstructions are shown in Fig.2 in comparison with the fully sampled image. An accurate reconstruction was achieved in all cases with RMS errors of 1.2%, 1.8% and 2.1%, respectively.

Please note that all ROIs profits from a higher temporal resolution to recover the correct bolus (early phase), whereas a higher spatial resolution is beneficial to depict small structures (ROI 1-2).

b) In vivo studies: Reconstruction results for *3* dynamic frames (high temporal resolution) are shown in Fig.3a-c, showing the pass of the contrast. Two maximum intensity projections (MIPs) of the 6th dynamic frame (high spatial resolution) are included in Fig.3d-e. The dynamic pass of the bolus and the excellent spatial resolution (in d-e) are highly noticeable in the small capillaries (see arrows).

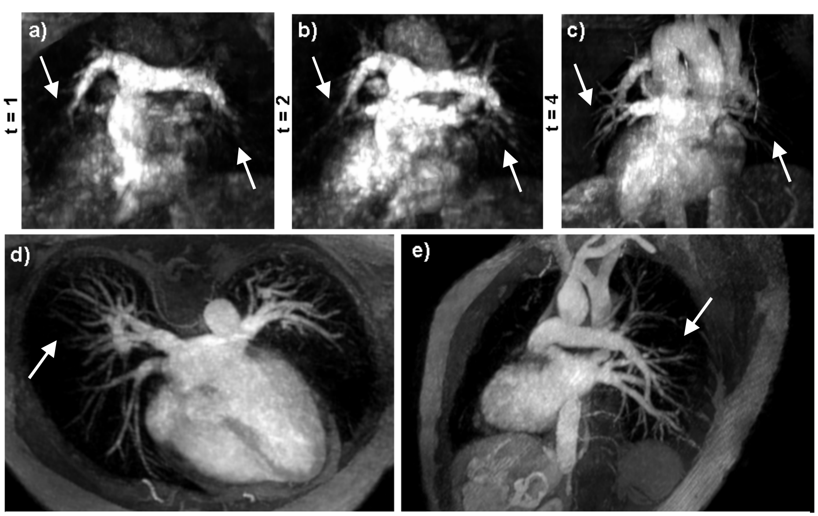

Fig3: 79x undersampled reconstruction a) frame 1 b) frame 2, c) 49x undersampled reconstruction frame 4. d)-e) MIP's for 19x undersampled reconstruction (frame 6).

CONCLUSION: We have proposed a method to acquire 3D isotropic DCE-MRI, which can achieve high spatial and temporal resolutions. It allows retrospective reconstructions with different combinations of spatial-temporal resolutions and therefore the exact bolus timing is no longer required. The method was tested in phantoms and successfully applied in patients, showing a good temporal resolution and excellent image quality.

REFERENCES: [1] Willinek et al, JMRI 2008 [2] Song et al, ISMRM 2008 [3] Huang et al, MRM 2006 [4] Bourbertakh et al, ISMRM 2008 [5] Winkelmann et al, IEEE 2006 [6] Pruessman et al, MRM 2001.