Multi-slice Free Breathing Liver Imaging using a 2D CAIPIRINHA Navigator

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Introduction: Simultaneous multi-slice excitation techniques have been primarily used to speed-up imaging [1]. Recently, a Cartesian balanced SSFP navigator approach was presented consisting of two consecutive RF pulses per TR in combination with a respiratory gating scheme [2]. In the present work free breathing multi-slice liver imaging is implemented by simultaneously acquiring a spatially fixed 2D navigator slice with the actual imaging slices. The scheme is applied to time-resolved free-breathing multi-slice Cartesian and radial imaging. The 2D navigator is used to co-register all imaging slices resulting in a dynamic series of 3D data of the liver at different respiratory positions on which breathing motion tissue deformation fields are calculated.

Methods: Acquisition: Dual-slice excitation was implemented based on an RF pulse modulated by a frequency proportional to the slice gap separating image and navigator slice. The FOV shift or the spoke signal cancelation for CAIPIRINHA was achieved by generating a 0,π modulation of the RF pulse phase along the phase encoding line (Cartesian) or the spoke (radial) of the navigator slice (Figure 1a). A gradient echo multi-slice acquisition with 12 sagittal slices (thickness: 8mm, in-plane resolution: 2x2mm^2) and a flip angle of 20deg, covering the liver, was used. Each slice was acquired within 157ms (Cartesian) or 262ms (radial) resulting in a total scan time of 56s (Cartesian) or 1.5min (radial). The navigator slice was chosen as a central slice through the liver. 30 dynamics (repetitions) were acquired consecutively during free breathing. Acquisitions were performed on a 3T System (Philips Healthcare, Best, The Netherlands) using a 6 channel cardiac array coil. Reconstruction: Each pair of simultaneously acquired slices (navigator & image) was unfolded offline using either a SENSE reconstruction (Cartesian) or by modulating the spokes phases (radial) using *Reconframe* (Gyrotools, Zurich, Switzerland) resulting in 12 slices covering the liver, each having its corresponding navigator slice. Registration: An example 2D navigator slice showing the cross-section of a hepatic vein is presented in Figure 1b. 2D translation (FH and AP) parameters of the vessel in all navigator slices (with respect to one navigator slice) was automatically calculated using an intensity-based registration function (Matlab, Mathworks, Natick, USA). The translation was then applied to the corresponding image slices resulting in 30 multi-slice rigidly co-registered acquisitions. Motion fields of co-registered slices were then calculated for each dynamic with respect to the previous dynamic using an optical flow method [5].

Results: Figure 2a shows both (FH and AP) translation parameters in pixel extracted from consecutive navigator slices. It depicts the time extent of acquiring all 12 slices (two consecutive red lines) over all 30 dynamics. Figure 3b shows the mean over all dynamics of one slice without registration, by using one and both extracted translation parameters. Parameters and images are shown for Cartesian and radial acquisitions. Calculated motion fields on a co-registered slice are shown for 3 different dynamics in Figure 3c.

Discussion: The use of a simultaneously acquired 2D navigator using a multiband excitation pulse has been presented for free-breathing multi-slice liver imaging. Cartesian as well as radial acquisitions were successfully unfolded. Using a simple registration algorithm two translation parameters were extracted from each navigator slice and applied to the corresponding imaging slices. Taking the 2D translation into account improved co-registration attesting the advantage compared to a 1D projection navigator. Motion fields show different liver deformations at different respiratory dynamics. Applications of the presented acquisition scheme may include full 3D breathing motion modelling of the liver previously performed using interleaved navigator slices [6] which can be applied for radiotherapy planning or image-guided interventions. The inter-slice registration can be extended to affine transformations and the technique can also be readily applied to other organs and types of motion (e.g. cardiac).

References: [1]Breuer MRM'2005 [2]Celicanin ISMRM'2011 [3]Pruessmann MRM'1999 [4]Yutzy MRM'2011 [5]Horn AI'1981 [6]Siebenthal PhysMedBiol'2007

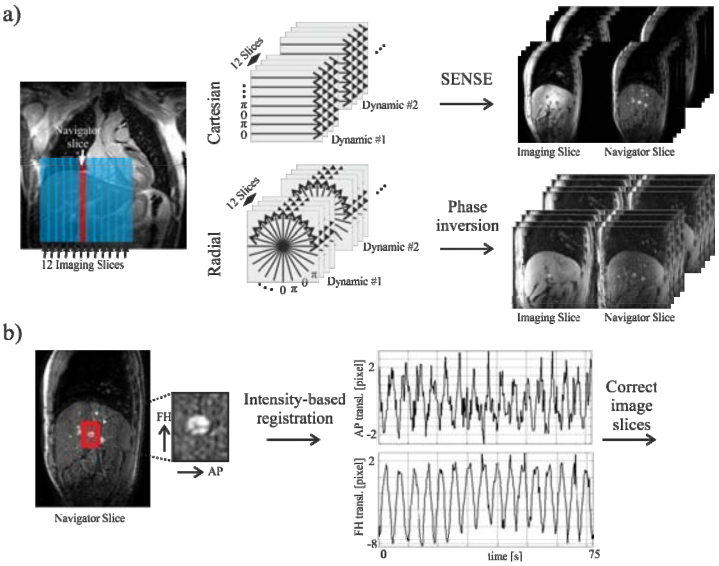

Figure 1: a) 12 slices covering the liver where acquired during free-breathing. The navigator slice (red) was chosen to be a central slice. Cartesian CAIPIRINHA images were unfolded using SENSE whereas radial slices were unfolded by inverting the phase of each π modulated spoke. b) A cross section of a hepatic vein was chosen for an image-based registration of all navigator slices to extract 2D translation parameters. These parameters were then used to co-register all imaging slices.

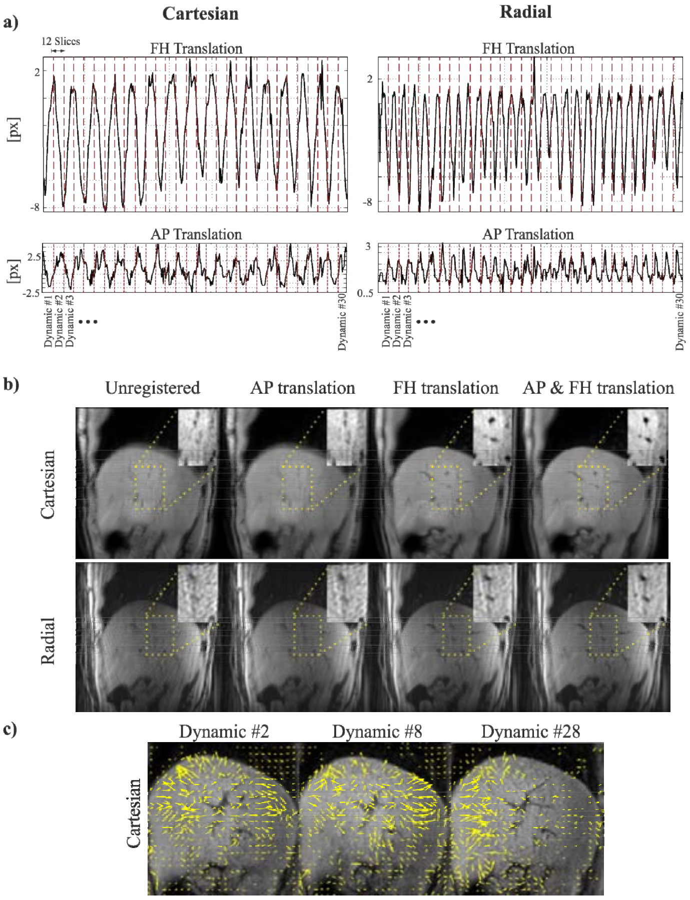

Figure 2: a) Translation values (in pixel) extracted from all consecutive navigator slices (acquisition time for the Cartesian images was shorter resulting in less respiratory cycles). b) mean over dynamics of a slice without registration and using 1D (AP or FH) and 2D (AP & FH) translations for Cartesian and radial images (incl. zoomed area containing hepatic veins). c) Motion fields show tissue deformations in different parts of the liver at different respiratory states.