Zoomed cardiac CINE-MRI using nonlinear phase preparation

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Introduction: Field-of-view (FOV) reduction (rectangular FOV) or zoomed imaging in cardiac CINE-MRI is a very simple way to reduce scan time with Cartesian k-space trajectories, shortening required breath-holds and improving patient comfort. In practice, significant FOV reduction is not possible without signal aliasing, particularly in large patients. Multidimensional signal localization is needed to further suppress the signals originating outside the region-of-interest (ROI). This may be achieved with multidimensional RF pulses or perpendicular excitation and refocusing, however both methods are inappropriate for fast imaging with typical high power steady-state sequences like SSFP. Recently, a multidimensional localization using nonlinear gradients was demonstrated (1,2). In this method, nonlinear gradients are synchronized with phase-encoding, slice rewinder and readout prephasing gradients to perform controlled signal spoiling. Recently, a planar multipurpose high-performance 3-channel nonlinear gradient system has become available at our site (3,4). We demonstrated in phantoms multidimensional localization with this gradient system (5). The objective of this study was to show the feasibility of this approach for multidimensional localization in human cardiac CINE-MRI on a 3 T clinical scanner.

Methods: The monoplanar nonlinear 3-channel gradient system is positioned on the patient table and generates curved locally approximately orthogonal encoding fields (3,4). Combinations of these fields with linear gradients allow for selection of specific sub-volume to be spoiled or rephased. Experiments were performed on a 3T Siemens Trio MRI (Siemens Healthcare, Erlangen, Germany) extended with the TxArray architecture (6) and modified to control an additional set of gradient power amplifiers. Healthy subjects were briefed and consented in accordance with the IRB-approved protocol, taking into account measured acoustic noise and simulated peripheral nerve stimulation. Nonlinear phase preparation gradients were integrated with a standard CINE-FLASH sequence with the following parameters: FA=15°, single 8mm slice, FOV=30mm with 1.6x1.6mm in-plane resolution, TE/TR = 3.5/6.5 ms, BW 1090 Hz/pixel, 11 cardiac phases. The pulse sequence is schematically shown in Fig. 1. Breath-hold images with ECG triggering were obtained using a 32-ch Rx body array for RF reception (Invivo, Gainsville, Florida, USA). A simple algorithm to determine the gradient coil currents to achieve the desired FOV reduction for an arbitrary imaging plane and spatial resolution, based on calculating $||Ax-b||^2$ in a least-squares sense, where A is a N_{voxel} matrix at the center of the target object, vector x contains coil currents to be determined and b is $N_{voxel} \times 1$ vector containing the desired magnetic field at each voxel within the ROI.

Results: Selected frames from the modified CINE-MRI of the left ventricular outflow tract (LVOT) are shown in Figure 2. Fig. 2a) is from a reference sequence without any modifications. In Fig. 1b) prephasing gradients were switched on but the imaging parameters left the same. Fig.1c) shows additionally a reduction of the FOV by 40% along the PE direction. The reduction in imaging time corresponds directly to FOV reduction. To demonstrate the feasibility of clinical applications a short axis view with prephasing and FOV reduced by 60% is shown in Figure 3.

Discussion: Since the scan duration in Cartesian cine MRI is proportional to the total number of PE steps, FOV reduction in the PE direction directly reduces scan time. When respiration does occur, FOV reduction can be used to minimize respiratory motion artifacts by suppressing ghosting signal artifacts from the chest wall. FOV reduction can also be used with fixed scan time to improve spatial resolution. Spoiling by nonlinear phase preparation allows for a significant reduction of scan time. A speed of up to 60% without additional SAR was demonstrated in a clinically-relevant application. Using this method, high resolution breath-hold imaging becomes much more comfortable for patients. The method presented here can also be adapted to image other anatomical regions then the heart. Additionally, a combination with acceleration techniques such as GRAPPA is possible to further reduce scan time and enhance image resolution.

References: (1) Witschey, et al. MRM 2011; (2) Witschey, et al. ISMRM 2012; (3) Littin, et al. ESMRMB 2011; (4) Littin, et al. ISMRM 2012; (5) Witschey, et al. ISMRM 2012; (6) Fontius et al. ISMRM 2006.

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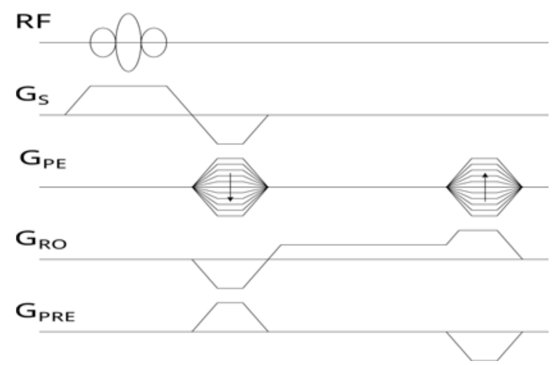
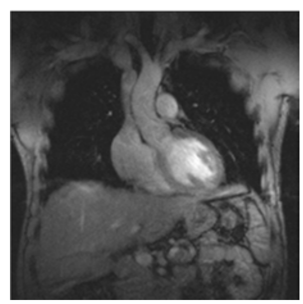
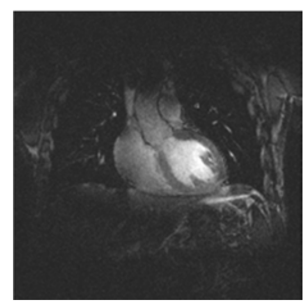


Figure 1: Schematic diagram of the pulse sequence. In addition to standard gradient axes (G_S, G_{PE}, G_{RO}) a combined prephasing signal (G_{PRE})is shown, which in may contain contributions of all 6 available axes.



a)



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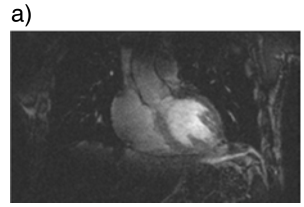

c)

Figure 2: Selected LVOT frames: a) no prephasing for reference; b) prephasing on; c) prephased and reduced FOV in PE direction.

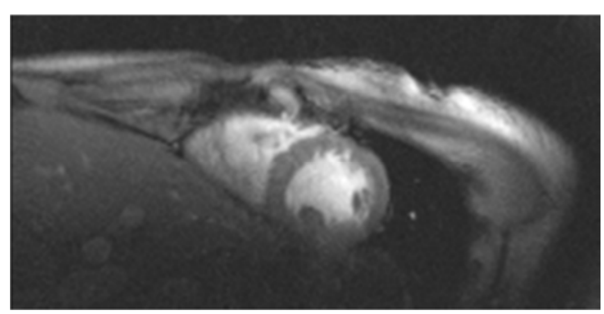

Figure 3: Diastolic timeframe of a short axis view with prephasing gradients FOV reduction of 60%.