High Resolution Whole Heart Cardiac Perfusion Imaging Using CAIPIRINHA

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Introduction:

Being limited by the cardiac cycle, myocardial perfusion imaging generally suffers from low spatial resolution and poor anatomic coverage. The simultaneous multislice Parallel Imaging technique CAIPIRINHA (1) has shown its capability to significantly extend the anatomic coverage while keeping the image quality on a high level (2). However, the CAIPIRINHA technique also allows for acceleration factors higher than the number of simultaneously excited slices. This acceleration can be applied to further enhance the spatial resolution. In-vivo measurements demonstrate the high potential of the approach for whole heart myocardial perfusion imaging with high spatial resolution.

Material and Methods:

In CAIPIRINHA simultaneous multislice imaging, several imaging slices are excited at the same time using multi-band radio frequency (rf)-pulses. Each simultaneously excited slice is provided with an individual dedicated rf phase cycle, which leads to a shift of the simultaneously excited slices with respect to each other in the FOV. Adapting the rf phase cycles allows maximizing the coil sensitivity variations and hence guarantees a high quality separation of the overlapping slices using Parallel Imaging reconstruction techniques.

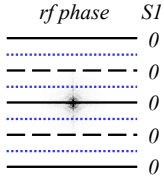

Fig. 1: *Image acquisition. The multi-slice excitation is applied to a regularly under-sampled k-space. Acquired phase encoding lines are depicted in solid black, non-acquired lines in dotted blue. Note the different rf phase cycles in the two simultaneously excited slices.*

The basic principle of the CAIPIRINHA approach presented in this work is to apply the simultaneous multi-slice excitation to a conventionally in-plane accelerated (Parallel Imaging) myocardial perfusion imaging protocol. While the in-plane acceleration (acceleration factor $R_{In\text{-}plane}$), achieved by regular k-space undersampling allows for an increased spatial resolution, the multi-slice excitation provides extended spatial coverage.

Measurements were performed on a 3T Magnetom TRIO system (Siemens Healthcare Sector, Erlangen, Germany) using a dedicated 32 channel cardiac array (Siemens Healthcare Sector, Erlangen, Germany) for signal reception and an ECG-triggered Saturation Recovery FLASH sequence for imaging. An in-plane accelerated high resolution myocardial perfusion imaging protocol was set up (FOV: 320 x 300 mm^2; matrix: 160 x 150; $R_{In\text{-}plane}$ = 2.5; slice thickness: 8 mm; TR: 2.8 ms; TE: 1.44 ms; TI: 110 ms; flip angle: 12°; T_{Acq}: 191 ms) and CAIPIRINHA was applied to excite two slices at the same time. By providing the first slice with a constant and the second slice with an alternating rf phase (Fig. 1), the images of the simultaneously excited slices, including their specific in-plane acceleration induced aliasing artifacts, were shifted by a ½ FOV with respect to each other. Every second heart beat, a total of 12 slices, 8 in short axis and 4 in long axis orientation (distance between simultaneously excited short-axis/long-axis slices: 36mm/16mm) were acquired by performing 3 consecutive saturation recovery CAIPIRINHA acquisitions during every RR interval. Thus, the first-pass of the contrast agent (Gadovist, 4 ml) through the myocardium was sampled over 40 heart beats with a temporal resolution of 1 measurement / 2 heart beats.

Slice separation and image reconstruction was performed using an adapted offline GRAPPA (3) reconstruction (R=5) in combination with an additional calibration scan. In order to assess the spatially variant noise enhancement during the image reconstruction, additional noise scans were performed and geometry (g)-factor maps were calculated according to Breuer et al. (4).

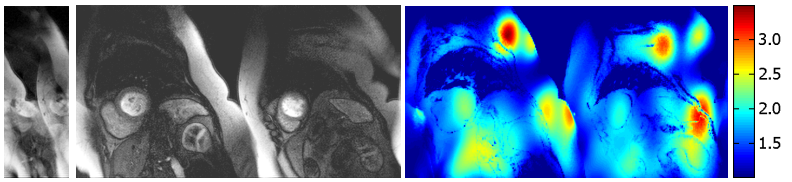

Fig. 2: *Fourier transform of the 2.5 fold in-plane accelerated acquisition with two slices excited at the same time* ***(left)****, the corresponding image reconstruction with both slices completely separated* ***(middle)*** *and the g-factor map of the reconstruction* ***(right)****.*

Results:

Based on a pure Parallel Imaging approach, 12-slice cardiac perfusion imaging could be successfully performed with a high spatial resolution of 2.0 x 2.0 mm^2. Although exciting several slices simultaneously at 3T, the SAR limit was clearly not exceeded. In all studies, slice separation and image reconstruction could be performed without visible artefacts (Fig. 2). While using a high effective acceleration factor of R_{eff} = 5 the calculated geometry factor map (Fig. 2 right) reveals only moderate noise enhancement. In Fig. 3, the passage of the contrast agent through the myocardium is displayed for all 12 measured slices, particularly demonstrating the capability of the presented approach.

Discussion:

Utilizing CAIPIRINHA with an acceleration factor higher than the number of simultaneously excited slices, myocardial perfusion imaging could be performed with high spatial resolution and whole heart coverage. Exciting several slices at the same time and exploiting coil sensitivity variations in slice and phase encoding direction, the presented technique provides a significantly higher signal-to-noise ratio than a corresponding pure in-plane Parallel Imaging approach with the same effective acceleration factor. In the current setup, the sequence allows stress examinations up to 104 bpm and is expected to be suitable for myocardial blood-flow quantification even on a pixel by pixel basis. Providing short image reconstruction times and being easy to implement, the presented technique is suitable for an immediate application in clinical routine.

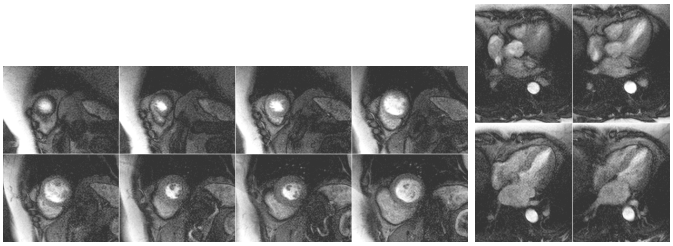

Fig. 3: *High resolution cardiac perfusion imaging in 12 slices using CAIPIRINHA with an effective acceleration factor of R_{eff} = 5. Shown is the pass of the contrast agent through the myocardium in 8 short* ***(left)*** *and 4 long axis slices* ***(right)****. The slices shown in the upper row were acquired exactly at the same time as the corresponding slices in the bottom row.*

References:

[1] Breuer, Magn. Reson. Med. 53: 684-691 (2005)
[2] Stäb, Magn. Reson. Med.: doi: 10.1002/mrm.22600 (2010)
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