Myocardial perfusion assessment by using contrast-media-free Fourier decomposition MRI

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Introduction

The myocardial perfusion plays a critical role in the diagnosis and treatment of coronary heart disease. Dynamic contrast-enhanced MRI is a validated method to assess myocardial perfusion [1]. However, the administration of contrast medium is contraindicated in allergy, renal failure and infants. A new MRI method based on Fourier decomposition (FD) can be used to obtain information about the regional tissue perfusion without the administration of contrast media [2]. A fast dynamic image acquisition combined with image registration is mandatory. Signal intensity variations observed at the cardiac frequency are used to determine amplitude and temporal distribution of the blood flow. The purpose of the study was to test the feasibility of FD MRI for the determination of myocardial perfusion without the use of contrast agent.

Methods

MR measurements and image reconstruction

All measurements were performed on a 3T whole-body MR-scanner (Magnetom Tim Trio, Siemens Healthcare, Erlangen, Germany) using 6-channel body and 24-channel spine matrix coil. Five healthy volunteers were examined for the assessment of myocardial perfusion. A set of 200 short axis cardiac images was acquired in breath-hold using an untriggered 2D radial FLASH sequence [3]. The pulse sequence parameters were: TR/TE/TA = 2.0/1.3/70 ms, 14 frames/s, FA=8º, ST=8 mm, 35 radial spokes per with 5 interleaves, 256 samples per spoke, FOV=256^2 mm^2, bandwidth=1700 Hz/pixel, matrix size=128x128. Every coil channel was reconstructed separately using in the first step non-uniform FFT. Subsequently, compressed sensing algorithm via L1-norm minimization [4] was applied in 25 iterations.

To remove the residual streaking artifacts two postprocessing steps were performed. First, the images were decomposed with independent component analysis [5]. Due to periodic nature of the streaking artifacts in a time-resolved acquisition, components containing this characteristic pattern can be identified and removed. Furthermore, the data sets were filtered using a small median filter (5 frames) along the temporal direction of the data set [3].

Assessment of myocardial perfusion

To compensate the cardiac motion, each image within every acquired slice was registered to a reference image in diastolic heart phase by using a nonrigid image registration algorithm [6]. Afterwards, the first registered image in every acquired slice was segmented with a semi-automatic region-growing technique [7]. Figure 1 shows the process of image segmentation and motion correction along the temporal direction of the data set. Since the total acquisition time of every data set was T=14 s, a spectral resolution of $\Delta f=1/T=0.07$ Hz and a spectral width of $f_B=1/(2TA)=7.14$ Hz were achieved. Fourier decomposition was used to detect and separate periodic changes of signal intensity in the myocardium caused blood flow during the cardiac cycle:

$$\forall\{x,y\} \quad s(x,y,f) = |\mathcal{F}(S(x,y,t)) \cdot h(t)|$$

where: S – time-resolved data set, h – Hamming window. Spectral line representing cardiac frequency (Fig. 2) was integrated pixel-wise to calculate perfusion-weighted images. Furthermore, phase angle images containing information regarding the temporal distribution of myocardial perfusion were calculated:

$$\forall\{x,y\} \quad \phi(x,y,f) = \operatorname{atan}(\operatorname{Im}[s(x,y,f)])/\operatorname{Re}[s(x,y,f)])$$

For the cardiac frequency f_C, the angle values in calculated phase map lie within a time duration of one heart cycle $[0,1/f_C]$.

Results

The measurements were succesfully performed in all volunteers. Figure 3 presents images of amplitude variation at the cardiac frequency and a phase map obtained in a healthy volunteer for the same slice location. The myocardial perfusion-weighted image and temporal distrubition of the blood inflow in the left ventricle is depicted in figure 4 after segmentation of the left ventricle.

Discussion

The presented technique allows for spectral analysis of the blood flow induced signal variation in myocardium without ECG-trigger nor administration of contrast agent. In this experiment the data acquired in a group of healthy volunteers showed no signal voids in myocardium, or large temporal delays in the blood flow. It is unclear, why we found regions with slighly decreased signal amplitude variation and minimal delayed blood inflow as shown in figure 4. It may be physiological variations since the signal changes correspond to the anatomical location of sinus venous. However, imperfections in the image registration could also contribute to unexpected changes in the signal amplitude. The feasiblity of the technique for detection of pathological tissue has to be tested in patients and compared with validated dynamic contrast enhanced MRI.

References:

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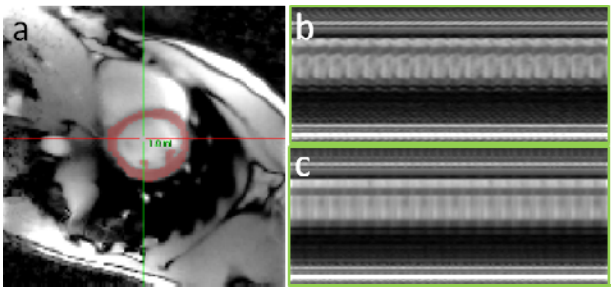

Figure 1. Semi-automatic segmentation of myocardium in short axis view in a healthy volunteer (**a**). Evolution of a line (displayed as the vertical green axis in image **a**) through the time-resolved data set prior to (**b**) and after (**c**) image registration to correct for cardiac motion.

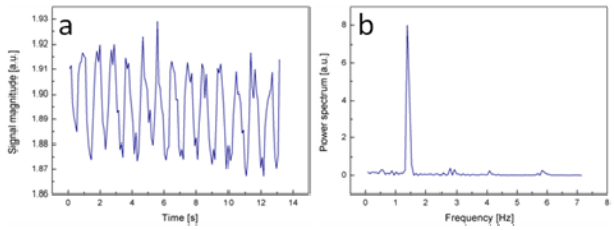

Figure 2. Signal intensity in a segmented myocardium as a function of time (**a**). Power spectrum of the signal intensity time-course showing a peak at approximately 1.4 Hz (cardiac frequency) and small peaks at harmonic frequencies (**b**).

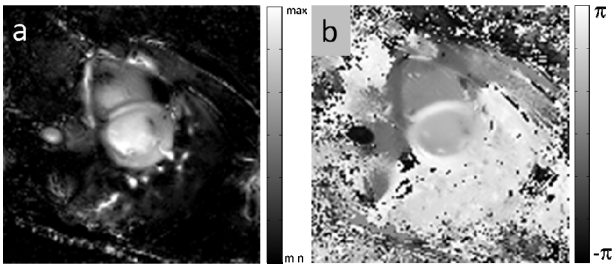

Figure 3. Perfusion-weighted image (**a**) obtained by pixel-wise integration of cardiac frequency peak. Phase map presenting temporal shift in signal amplitude variation within a heart cycle. (**b**).

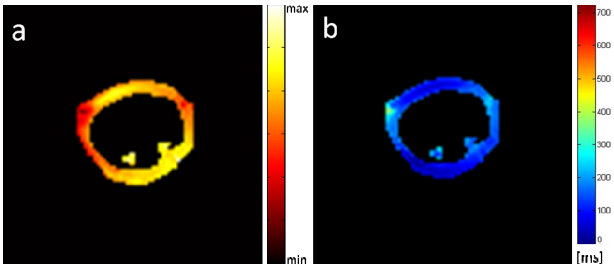

Figure 4. Example of perfusion-weighted image (**a**) and temporal distribution of blood inflow (**b**) in myocardium of a healthy volunteer.