Cardiac Magnetic Resonance Imaging with Doppler Ultrasound as alternative trigger method at 3T

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Introduction

Especially with increasing availability of high-field MRI, accurate synchronization of the cardiac cycle is one of the main challenges in cardiac magnetic resonance imaging (CMR). Doppler Ultrasound (DUS) is not objected to magneto-hydro-dynamic effects (MHD), does not interact with the electromagnetic field of the MRI (1) and measures the physiological motion of the heart rather than electrical activation (2). Moreover, depending on the location of the transducer, the DUS signal corresponds to distinct times in the cardiac cycle, potentially providing more information for cardiac triggering than conventional ECG (3). The purpose of this work was to evaluate Doppler ultrasound as an alternative trigger method at 3T and to evaluate its potential for an automatic selection of quiescent heart phases for e.g. coronary magnetic resonance angiography (MRA).

Materials and Methods

Cardiac MRI was performed at 3T (Philips, Medical Systems, Best, Netherlands) in 9 healthy subjects. A MRI compatible ultrasound transducer was placed in an apical location under the body coil to record transmitral flow. The E-wave in early diastole was selected as trigger time point to obtain a marker for quiescent heart phases. Vector ECG (VCG), DUS and pulse oximetry (POX) trigger signals were acquired simultaneously during MRI and were stored by the logging function of the MR. Breath hold gradient echo 2D cine balanced Turbo Field Echo (BTFE) sequences (matrix: 352x352, TR/TE: 4. 8/1.4 ms, FA 45°, turbo factor: 13, slices:14, SENSE:2, 30 cardiac phases) were acquired in short axis for left ventricular (LV) function analysis. Endocardial border sharpness (EBS) between left myocardium and ventricular blood was measured by calculating the slope of the gradient between normalized myocardial and ventricular signal intensities. Breath hold 2D cine phase-contrast angiography sequences (matrix: 288x288, TR/TE: 4.2/2.6ms, FA: 10°, Slice thickness: 8mm, VENC: 160 cm/s) were used to acquire mean and peak velocities in the descending aorta. Simultaneous acquired trigger signals were compared in respect to RR interval length and sensitivity. The time delay to quiescent heart phases was determined manually using VCG triggered cine images and was compared to the occurrence of DUS and POX trigger signals. The applicability of DUS to select quiescent heart phases for coronary MRA was tested at one subject using a navigator gated free breathing 3D TFE gradient echo whole heart sequence (matrix:480x480x105, TR/TE: 4.8/1.4ms, FA: 20°, slices: 53, fat saturation: SPIR, SENSE:2) with ECG and DUS as trigger source.

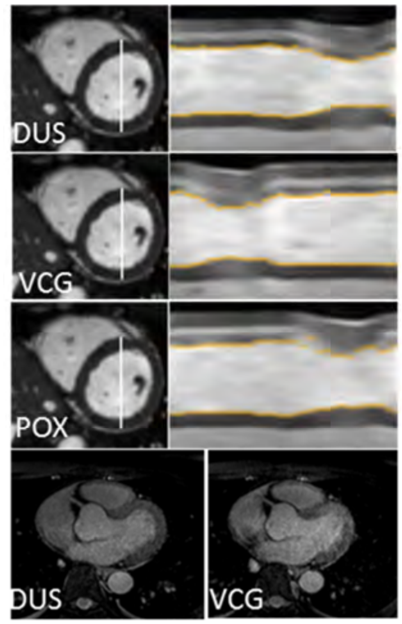

Fig.1: Cine images of each trigger method and plot over one cardiac phase with marked EBS (yellow). Coronary images are shown in the bottom row.

Results

No interferences between DUS and MRI were observed. DUS and POX signals were free from interferences from electromagnetic fields or MHD effects. The mean sensitivity of trigger recognition for all sequences was similar between DUS (99 ± 1%), VGG (98 ± 1%) and POX (99 ± 1 %) with a mean RR interval of 914 ± 29 ms (VCG), 914 ± 26 ms (DUS) and 915 ± 29 ms (POX). The manually determined mean time delay to quiescent heart phases was 564 ± 15 ms and correlated strong with DUS trigger signals ($R=0.9, R^2=0.8$) with a mean difference of -58 ± 7 ms. EBS was significant different in diastole between VCG and DUS ($p=0.004$) but not between VCG and POX ($p=0.1$). Calculated LV function was not significant different in any case. Measured mean peak velocities were similar 132 ± 16 cm/s (VCG), 131 ± 11 cm/s (DUS) and 131±10 cm/s (POX). DUS triggered coronary MRA was performed with a fixed time delay of 60 ms. No difference in image quality could be observed to ECG triggered images.

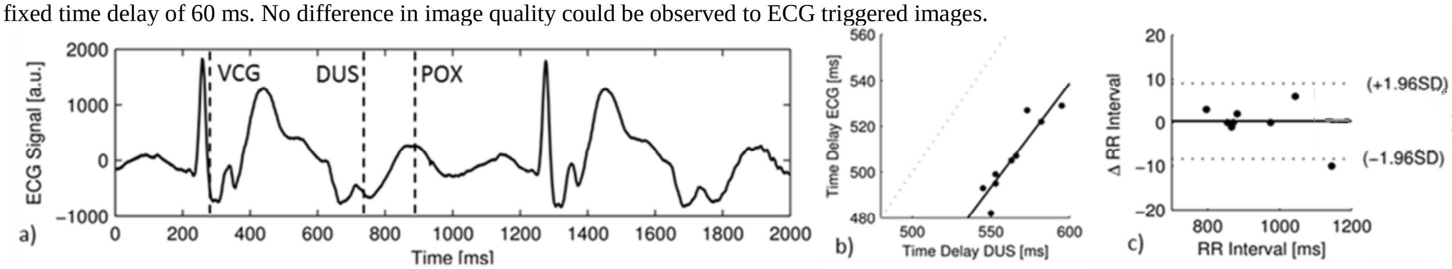

Fig.2: a) VCG Signal during MRI with VCG, DUS and POX trigger marker. b) Correlation between manual time delay to quiescent heart phases (VCG) and time delay of DUS trigger signals. c) Bland-Altman plot of DUS and VCG measured RR intervals

Discussion and outlook

Doppler Ultrasound was successfully applied as trigger method in cardiac MRI at 3T. DUS, VCG and POX trigger methods showed a similar performance in terms of trigger sensitivity and jitter, LV function and peak velocity in the descending aorta. Significant reduced EBS in diastole of DUS triggered images compared to VCG may be due to the MHD effect which is more prominent after contraction. DUS trigger signals marking the E-wave can be used with a fixed time delay of 60 ms for coronary MRA to select quiescent heart phases. In future, this finding has to be evaluated in more detail as the measurement is restricted by a temporal resolution of ~30ms of the VCG triggered cine images.

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