Investigation of impact of different lung pressures on phasic temporal flow profiles, harmonic content and blood flow of the Right Coronary Artery measured using PC-MRI

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Background: Within the coronary arteries reliable quantification of blood flow and phasic temporal flow profiles containing information about vessel compliance and the returning pressure wave [1,2] would be of clinical significance for evaluation of patients with coronary circulatory disorders, allowing identification and monitoring of stenosis and disease progression [3].

Normally this is invasively measured but phase contrast MRI (PC-MRI) flow measurements offer a non-invasive alternative. Imaging of the coronary arteries however is technically challenging due to the small vessel size 3-5mm combined with rapid movement due to cardiac and respiratory cycles. Navigated PC-MRI techniques are possible but are complex and time intensive. Respiratory suspension techniques offer a simple solution to the problem imposed by respiratory motion but place a limit on scan duration. Suspension of respiration is possible on either expiration or inspiration but physiologically there is the possibility that either technique will alter intra-thoracic pressure altering right and left ventricular filling with a subsequent alteration of the CA blood flow and phasic temporal flow profiles. This study was performed using respiratory suspended PC-MRI high spatial (1X1X6mm) and real temporal resolution (34.2 ms) made possible by scanning at 3T with a dedicated 32-element cardiac coil. Blood flow in the right CA was measured with three different breath holding patterns: 1) single breath-hold acquisition with zero mmHg air pressure within the lungs, 2) single breath-hold acquisition with negative air pressure 20 mmHg air pressure within the lungs, 3) single breath-hold acquisition with positive pressure 20 mmHg air pressure within the lungs.

Aim: This study aims to quantify the physiological variations to right coronary artery (RCA) blood flow and phasic temporal flow profiles to 3 different lung pressure levels.

Materials and Methods: 10 healthy male volunteers (32 ± 1.4 years old) were positioned supine within a 3T MRI scanner (Philips Healthcare, Best, Netherlands) with a 32-element SENSE cardiac coil positioned around the thorax. Following localization scans, detailed localization images were acquired to visualize the position and orientation of the RCA (Fig 1), thus allowing cardiac triggered, phase contrast measurements to be acquired perpendicular to the orientation of the vessel. The subjects where given a mouth piece (air Safety Limited, Lancashire, UK) connected via 3.5mm inside diameter nylon tubing to a differential pressure manometer (HD700, Extech Instuments, MA, USA). Blood flow in the RCA was measured using PC-MRI sequence with FOV 220 x 210 mm, TE= 2.8 ms, TR= 5.7 ms, 30° flip angle, SENSE factor of 3, 40-50 interpolated cardiac phases and a VENC of 30 cm/s with three different breath holding patterns: 1) single breath-hold acquisition with zero mmHg air pressure within the lungs, 2) single breath-hold acquisition with negative air pressure 20 mmHg air pressure within the lungs, 3) single breath-hold acquisition with positive pressure 20 mmHg air pressure within the lungs. Flow quantification was performed retrospectively on the scanner console using the manufacturer's software to quantify blood flow. A region of interest ROI was drawn around the RCA as identified on the magnitude image and the location of the ROI modified for each cardiac phase using a magnitude image as a reference. A separate ROI with a relatively large area was placed on the tissue adjacent to the RCA for each cardiac phase as well, and relative blood flow velocity in the RCA in comparison to the surrounding tissue was then calculated for each phase (Fig 1). Additionally measurements of baseline, systolic peak, negative postsystolic incisure and diastolic peak where extracted from this blood flow data using a mathematical model (Fig.2) [4] and the harmonic content using Fourier analysis to produce frequency spectra. All values are expressed as mean value ± standard error mean (SEM). Statistical significance of the differences between means of the variables in two groups was evaluated with a paired standard t-test.

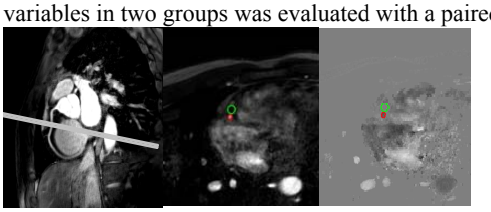

Fig. 1 Localization & flow quantification

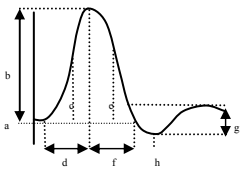

Fig. 2 Model parameters

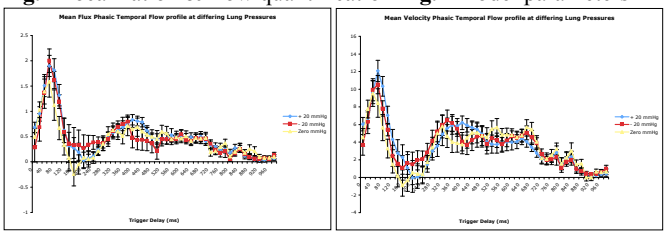

Figure. 3 Mean Flux and Velocity temporal flow profiles

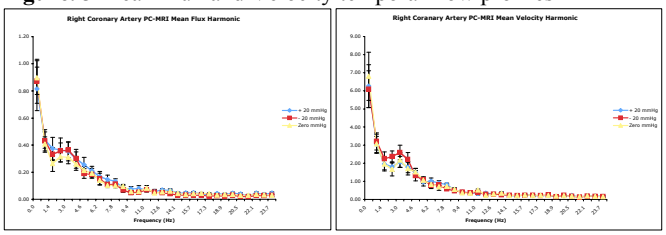

Figure. 4 Mean Flux and Velocity frequency spectra

Results: The results of flow quantification from the proprietary software demonstrated no statistically significant difference between the 3 lung pressures. However analysis of the phasic temporal flow (Fig3) by mathematical model (Fig.2) identified significant differences on the RCA mean flux waveforms for the time-point of postsystolic incisure in the positive 20 flux measurements with positive 20 delayed significantly from zero ($p< 0.04$) mean velocity waveforms differences for negative 20 and positive 20 demonstrated significant differences in the duration of the systolic ascent of 14. 17 ± 6.06 ms ($p< 0.05$), the time-point for the positive 20 systolic descent was delayed 27.05 ± 11.11 ms ($p< 0.05$) compared to negative 20 and the duration of the positive 20 systolic descent was 13.93 ± 5.83 ms ($p< 0.05$) longer. The time-point for the postsystolic incisure of both the negative 20 and positive 20 waveforms were delayed respectively by 12.86 ± 4.35 ms ($p< 0.02$) and 18.05 ± 4.78 ms ($p< 0.009$). Also identified were differences in peak velocity waveforms for the time-point of the systolic ascent of the negative 20 which was 42.68 ± 20.01 ms earlier than zero ($p< 0.03$) The amplitude of the negative 20 postsystolic incisure is 4.52 ± 1.6 cm/s ($p< 0.03$) less than the zero. Comparison of the mean flux frequency spectra (Fig.4) demonstrated significant differences between negative and positive over 12-22 Hz ($p< 0.05$) and positive and zero 16-20 Hz ($p< 0.05$) and mean velocity between positive and zero at 2 Hz ($p< 0.05$).

Discussion: We were able to describe the phasic temporal flow profiles of blood flow of the RCA as measured at different specific lung pressures. Mathematical modelling was able to identify significant changes in phasic temporal flow profiles when no statistically significant differences in flow where detected. Clinically relevant additional information may be gained by using higher temporal and spatial PC-MRI blood flow measurements of the RCA as progressively more information is identified within the phasic temporal flow profiles of blood flow.

References: [1] Laffon E. Eur Radiol 14:875–880. [2] Laffon E. Physiol Meas 24:681–692. [3] Waters D. Circulation 87(4): 1067-1075 [4] Larsson M. JMRI 27:140-147 2008.