Efficient navigator-gated acquisition of different breathing positions during free breathing applied to flow measurements in the great vessels

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Introduction: Motion-induced artifacts due to breathing are typically avoided in clinical routine by scanning during breath-hold at end-expiration or also inspiration, or using navigator gated sequences allowing data acquisition during free breathing. Although it is known that the respiratory phase can affect the magnitude and timing of blood flow, such effects are often not considered when applying in-vivo flow measurements using phase contrast (PC-MRI). For navigator gated acquisitions,, an acceptance window is typically defined in the end-expiratory position and data is accepted if the current breathing position controlled by the navigator is within this predefined window. Thus, a certain amount of data is rejected, typically ranging from 20 to 60% depending on the subjects breathing pattern and the width of the acceptance window. In order to investigate physiological effects on the breathing position during free breathing at least two different during inspiration and during expiration are necessary. Therefore, a double navigator-gated sequence was implemented defining two acceptance windows during expiration as well as during inspiration (see Fig.1). The method thus permitted to acquire full flow sensitive PC MRI data during both in- and expiration within a single scan with optimal scan efficiency. The sequence was applied to measure the dependency of blood flow on different breathing states, i.e. inspiration and expiration, during free breathing. Furthermore, breath-hold data during in- and expiration and breath-hold in inspiration during valsalva maneuver were acquired for comparison. Measurements were performed in the major vessels Aorta, Pulmonary Artery (PA), Vena Cava Inferior (VCI) and Vena Cava Superior (VCS).

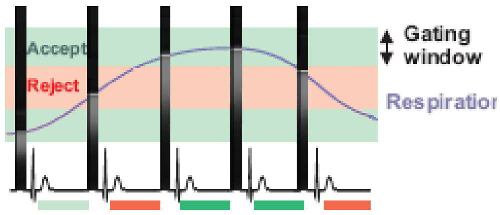

Fig.1: Acquisition scheme of the double-gated navigator sequence defining two acceptance windows (green regions) within end-expiration and end-inspiration.

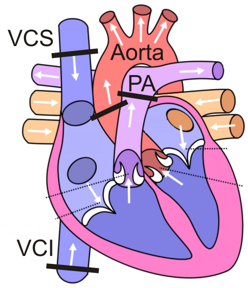

Fig.2: Slice orientation for the four different major vessels.

Methods: Data were acquired in 4 healthy volunteers (mean age = 29.3) at 1,5T (Espree, Siemens,). For the measurements during free breathing a double-gated navigator sequence with two acceptance windows (Fig.1) was used in combination with a respiration adaptive phase encoding line reordering [ref 1]. The width for both gating windows was set to 8mm. 2D PC-MRI images were acquired perpendicular to the vessel with single-direction through plane velocity encoding with a temporal resolution of 31.2ms and a spatial resolution of 1.25 x 1.67 mm^2. The scans for the Aorta (positioned at the level of the PA) and the PA (positioned at the level of the Aorta) were performed with velocity sensitivity (venc) of 1.5m/s. For the VCI (positioned below the apex cordis) and VCS (positioned at the level of the PA) a venc of 0.8m/s was used. Breath-hold scan time was 20-25 sec, scan time for free breathing ranged from 3 to 6 minutes depending on the navigator acceptance rate. Due to the longer plateau of the end-expiratory position, data for this respiration phase was typically acquired about 2-3 times faster. Data evaluation was performed using a homemade Matlab tool and included vessel segmentation and quantification of blood flow over time and mean flow within the cardiac cycle.

Results: The graphs in figure 3 show the blood flow over the ECG cycle for the different measurements averaged over all volunteers. There were only minor differences between the different types of scans in the Aorta and in the PA except for the valsalva maneuver as indicated by the mean flow in table 1. The breathing state had a considerably more pronounced effect for the blood flow in veins. In the VCS, flow for valsalva maneuver and breath-hold during inspiration was strongly reduced in during peak systole compared to the other breathing states, whereas the differences in the diastolic peak were less pronounced. However, mean blood flow over the cardiac cycle demonstrates only a distinct change during valsalva maneuver. In the VCI, blood flow of the all types of inspiration (breath-hold, free breathing and valsalva) was clearly reduced during systole whereas only the free breathing data acquired during inspiration revealed a decreased flow during diastole. For the mean flow over the cardiac cycle a moderate decrease was observed for the breath-hold inspiration scan and a clear decrease for free breathing during inspiration and the valsalva scan.

	Aorta	PA	VCS	VCI
Bh exp	80.4 ± 9.2	82.7 ± 16.7	25.5 ± 4.4	39.3 ± 4.2
Bh insp	80,7 ± 5.2	80.1 ± 16.1	23.2 ± 9.3	35.4 ± 3.6
Free exp	80.6 ± 11.1	82.9 ± 13.9	27.4 ± 4.1	40.8 ± 3.7
Free insp	78.0 ± 9.7	83.5 ± 15.0	25.1 ±4.0	28.0 ± 1.3
Valsalva	67.4 ± 20.4	71.1 ± 9.8	19.2 ± 9.5	30.9 ± 9.1

Table 1: Mean flow over a ECG cycle for the different vessels and breathing conditions in ml/s

Discussion: Previous studies have shown that an increase of the intrathoracic pressure (due to breathing) is responsible for a decrease of flow especially in the venous system due to the lower blood pressure [2]. The demonstrated double-gated sequence allowed for an efficient measurement of inspiration and expiration data and could detect difference in the mean blood flow in the VCI even during free breathing as indicated in table 1. One limitation of this study is the small number of investigated subjects that does not allow for a statistical analysis. Future work could include the subdivision of the complete respiration window in more than the demonstrated two acceptance windows (multi-gated navigator sequence) to collect data for multiple breathing positions as similarly presented in the work of Thompson et al using respiration bellows.

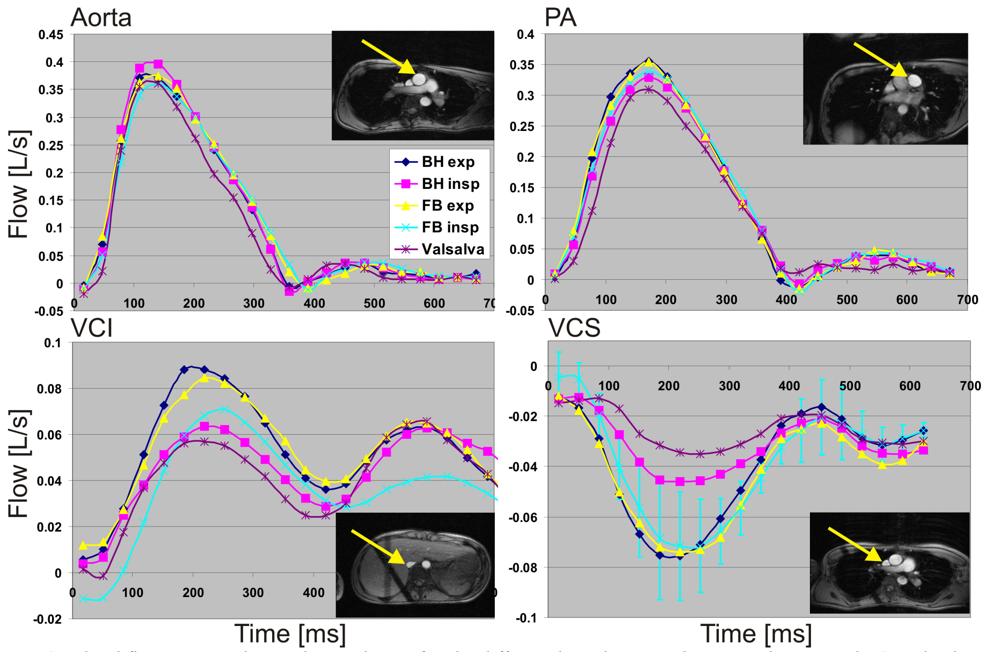

Fig. 3: Blood flow averaged over the 4 subjects for the different breathing conditions in the 4 vessels. Standard deviations are exemplarily given for the free breathing inspiration scan in the VCS.

References: [1] Markl M, et al. *JMRI* 2007;25. [2] Thompson R, et al. *MRM* 2006;59.
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