

# Relationship Between Diaphragmatic Motion and Heart Motion during Prolonged Breath-hold

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## Target Audience

Scientists and clinicians who are interested in respiratory motion correction for cardiac MRI.

## Purpose/Introduction

Pre-oxygenation and hyper-ventilation have been used to extend breath-hold duration<sup>1</sup> in several applications such as coronary MR-angiography<sup>2</sup> and 3D myocardial late gadolinium enhancement imaging<sup>3</sup>. However, despite breath-hold instructions, respiratory-induced diaphragmatic and heart motion can be observed during a prolonged breath-hold. Motion correction techniques may thus be desirable for patients who cannot sustain stable breath-hold. A respiratory navigator which tracks the diaphragmatic motion is commonly used to correct the heart motion during free breathing acquisitions. However, the efficiency of this technique during prolonged breath-hold has not been fully investigated. In this study, we sought to assess the relation between the diaphragmatic motion and the heart motion observed during prolonged breath hold performed with and without pre-oxygenation and hyperventilation.

## Materials and Methods

10 healthy subjects (28±15y, 2m) were imaged using a 1.5T Phillips Achieva scanner (Philips Healthcare, Best, The Netherlands).

**Study design:** Figure 1 shows the imaging protocol used to characterize diaphragmatic and heart motion during a prolonged breath-hold with 4 different breath-hold scans acquired for each subject (Figure 1a). The first (BH#1), second (BH#2) and last (BH#3) breath-holds were performed without pre-oxygenation and hyperventilation. The third breath hold (BH#3) was performed with pre-oxygenation of the subject (4L/min of oxygen during 3 minutes using a nasal prongs) and hyperventilation (three fast maximum capacity deep breath) (Figure 1b). For each acquisition the subject was instructed to hold their breath for the longest time in the end-expiration position. A 2D dynamic real time sequence was acquired during each breath-hold. Two pencil-beam navigators positioned on the dome of the right hemi diaphragm (RHD NAV) and the left ventricle (LV NAV) in SI direction (Figure 1c) were acquired for each dynamic with temporal resolution of 17 ms each. These navigator acquisitions were followed by a 2D dynamic real time steady-state free precession (SSFP) acquisition (Figure 1d). Total scan time for the two navigators and real-time SSFP was 100 ms. This acquisition scheme was continuously repeated for 3 minutes (1800 dynamics) to monitor the motion pattern during breath-holds. The 2D images were not used for motion assessment, which was only based on the analysis of the two navigators.

**Data analysis:** Navigator signals of each acquisition were exported from the scanner and analyzed offline. Breath-hold duration was measured by visual identification of the stable period on the RHD NAV signal. Since the LV navigator contains cardiac motion preventing an accurate detection of the respiratory induced drift, a 3<sup>rd</sup> order polynomial fit of the signal was first performed to remove the influence of the cardiac motion. Regression analysis between RHD NAV and LV NAV restrained to the signal acquired during the breath-hold was then performed for each breath-hold.

## Results

Figure 2 shows example of RHD NAV and LV NAV acquired in two subjects. Although RHD NAV and LV NAV are well correlated, a positive relation is observed in the first subject while a negative relation is observed in the second. Regression analysis confirmed these results where good average correlation between RHD NAV and LV NAV is observed with high slope variations (Table 1).

## Conclusions

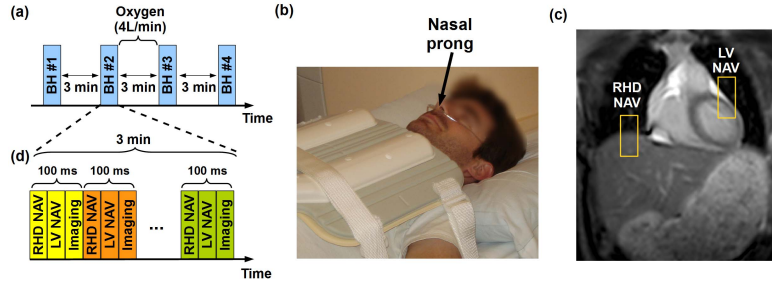
Despite the good correlation observed between diaphragmatic motion and heart motion, there is relatively wide slope variation in the RHD NAV for tracking during prolonged breath-hold acquisitions. This wide slope variation may limit the RHD NAV application in prolonged breath-hold sequences.

## Acknowledgements

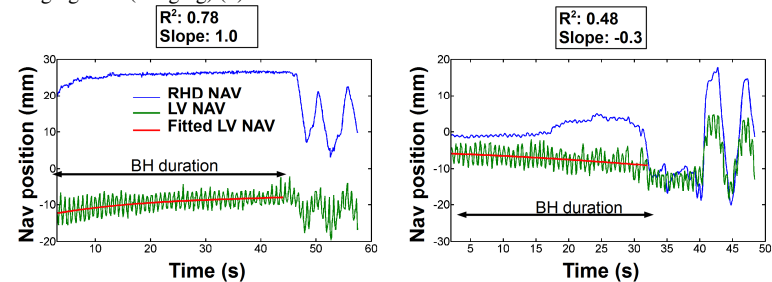
The authors acknowledge grant support from NIH R01EB008743-01A2.

## References

- [1] Danias, AJR. Am. J. Roent., 1998; [2] McCarthy, Radiology, 2003; [3] Roujol, MRM, 2013, In Press.



**Figure 1.** Imaging protocol for breath-hold assessment. (a) Study protocol designed for breath-hold assessment without (BH#1, BH#2, and BH#4) and with supplemental oxygen and hyperventilation (BH#3). Oxygen (4 l/min) was administered using nasal prongs as illustrated in (b). (c) and (d) show the sequence diagram used for breath-hold monitoring. A real time SSFP sequence was used to acquire every 100ms a right hemidiaphragm navigator (RHD NAV), a second navigator located at the left ventricle (LV NAV), and a 2D coronal imaging slice (Imaging) (d).



**Figure 2.** Example of RHD ANV and LV NAV acquired in two different subjects. Good correlation is observed between both navigators in the first subject. Reduced correlation is observed between both navigators in the second subject. Both navigators had a positive relation in the first breath-hold and a negative relation in the second breath-hold.

	Slope	R <sup>2</sup>
BH #1	0.19 ± 0.56 (-0.87;0.87)	0.54 ± 0.22
BH #2	0.16 ± 0.45 (-0.89;0.64)	0.60 ± 0.27
BH #3	0.61 ± 0.55 (-0.17;1.40)	0.66 ± 0.34
BH #4	0.24 ± 0.38 (-0.16;1.09)	0.36 ± 0.37

**Table 1.** Regression analysis between RHD NAV and LV NAV. Slope and R<sup>2</sup> values of the regression are reported for all breath-holds. Moderate/strong correlation was observed in average between RHD NAV and LV NAV. However, high variations in slope values were measured limiting the use of RHD NAV for respiratory tracking during prolonged breath-hold.