

CARDIOMYOPATHY

The Impact of Different Positions and Thoracic Restraints on Respiratory Induced Cardiac Motion

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ABSTRACT

One of the limiting factors for high resolution magnetic resonance coronary angiography (MRCA) is the motion of the heart during breathing. Current approaches use mainly motion correction in one dimension. We aimed to determine the relation between diaphragmatic motion and cardiac motion as well as the potential influence from external restraints reducing thoracic anterior posterior (AP) motion. Four real time navigators were used to collect motion parameters, diaphragmatic cranio-caudal, cardiac cranio-caudal, diaphragmatic anterior-posterior, and thoracic anterior-posterior. Measurements were performed in prone and supine position and supine position with a thorax restraint. In supine, the highest correlation was found between cranio-caudal diaphragmatic and cardiac motion ($r^2 = 0.71$, slope = 0.26; $p < 0.05$). Prone positioning or external restraints led to significant changes of motion patterns, with a lower correlation between diaphragmatic and cardiac position. External manipulation of breathing by prone positioning or thoracic restraints leads to a less accurate prediction of cardiac position from assessment of diaphragmatic positions compared to standard supine positioning.

INTRODUCTION

One major problem for high resolution coronary MRCA is the motion of the heart induced by respiration. It is possible to minimize cardiac breathing motion using breath hold techniques (1). This approach, however, requires limits in acquisition times and restrict maximal spatial resolution (2). Alternatively, navigator techniques can be applied, which have been reported to generate identical or even superior image quality in comparison to breath hold approaches (3). This technique (4, 5) al-

lows the patient to breathe freely. Cardiac position is predicted based on the position of the diaphragm and data is only acquired within a defined range (gating window). The disadvantage of this approach is the long measuring time, caused by the necessity to synchronize the cardiac and the breathing cycle. While imaging time is usually acceptable in patients with stable and reproducible diaphragmatic positions, it can be very long in patients with unfortunate breathing patterns. Improvements have been achieved by allowing larger gating windows for peripheral k-lines (6). Alternatively, a better prediction of the three-dimensional diaphragmatic position would allow larger gating windows.

A standard method, which has been successfully applied in multiple recent coronary artery imaging studies, uses one navigator placed on the dome of the right hemidiaphragm (7, 8). It has been shown, that a correction of 60% of diaphragmatic cranio-caudal (CC) displacement for cardiac CC position and a correction of 20% of diaphragmatic anterior-posterior (AP) displacement for AP position yields optimal results (9). Left-right displacement of the heart is neglected with this approach. The aim of the study was to evaluate the feasibility and accuracy to predict cardiac positions using navigators in AP and CC

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directions and the possibility to influence cardiac AP and CC motion by restricting thoracal breathing excursions.

Our hypotheses were:

1. A constrained motion of the thorax will lead to a longer, more stable and more reproducible diaphragmatic position.
2. The AP motion of the heart is decreased and the CC motion is increased during the breathing cycle by constraining thoracal breathing excursion.
3. This reduction of the complex three-dimensional (CC, AP, left right) displacement of the heart to a more one-dimensional displacement (CC only) yields a better correlation of cardiac position with diaphragmatic position.

METHODS

Subjects/study population

The study population included 13 healthy adult subjects (3 females and 10 males; age 24 ± 4 years) without contraindications to magnetic resonance (MR) exams. Written informed consent was obtained from each subject prior to the study.

Magnetic resonance imaging

The MR examination was performed on a commercial 1.5 Tesla system (Gyrosan ACS-NT, Philips Medical Systems, Best, The Netherlands) equipped with cardiac software (Gyrosan release 8.1.3) and a commercial gradient system (23 mT/m, 150 mT/m/ms).

Navigators

Each navigator beam consisted of a cylindrical 2D spiral excitation with four gradient cycles (diameter of 25 mm) with a flip angle of 10° . The time between the excitation and the readout of the navigator was 61 ms for the first navigator, 31 ms for the second navigator and 1 ms for the third navigator.

Positioning and fixation

The subjects were examined in the common supine position. Additional scans were performed in prone position and in supine position with suppressed thoracal breathing using a 20 cm wide belt positioned directly below the axilla. Measurements were performed in random order.

Planning

At first a gradient echo sequence scout was performed to determine the position of the heart and the diaphragm and to position the navigators. One navigator was placed through the dome of the right hemi-diaphragm to detect the CC position of diaphragm (Fig. 1A). A second navigator was placed in AP direction through the right chest wall at the height of the 3rd intercostal space to measure the AP position of the thorax (Fig. 1B). A third navigator was placed over the left cardiac auricle in CC

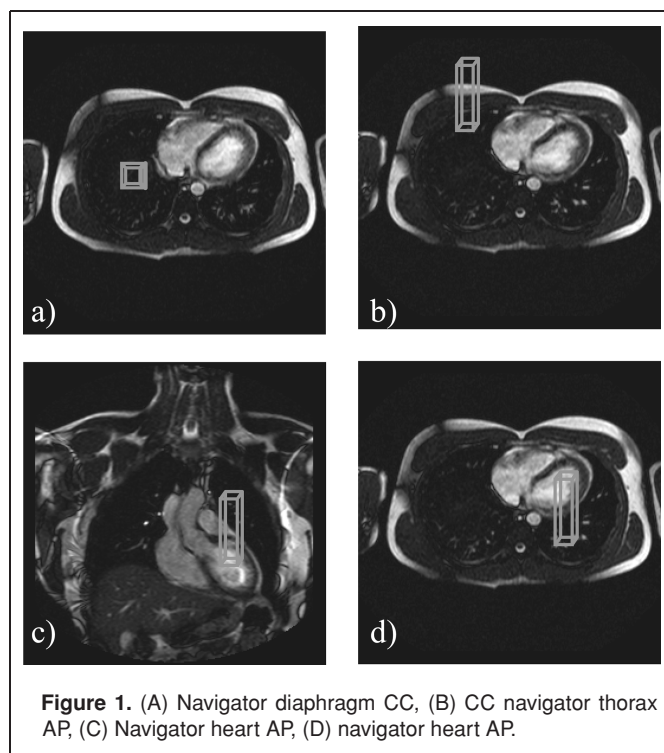


Figure 1. (A) Navigator diaphragm CC, (B) CC navigator thorax AP, (C) Navigator heart AP, (D) navigator heart AP.

direction to detect cardiac CC position (Fig. 1C). A fourth navigator was positioned in AP direction through the left ventricle to measure cardiac AP position (Fig. 1D). Since the available software only allowed to acquire three navigator echoes in one sequence two series with three navigators each were performed, combining $CC_{diaphragm}$, CC_{heart} and AP_{thorax} (Fig. 2) and combining $CC_{diaphragm}$, AP_{heart} and CC_{heart} .

In each series, four minute intervals were assessed, and the acquisition was repeated thrice. No breathing commands were given.

Analysis

The navigator data were exported from the console computer and were converted into SPSS VERSION 10 (SPSS Inc, Chicago, IL, USA) for further processing. The positioning of

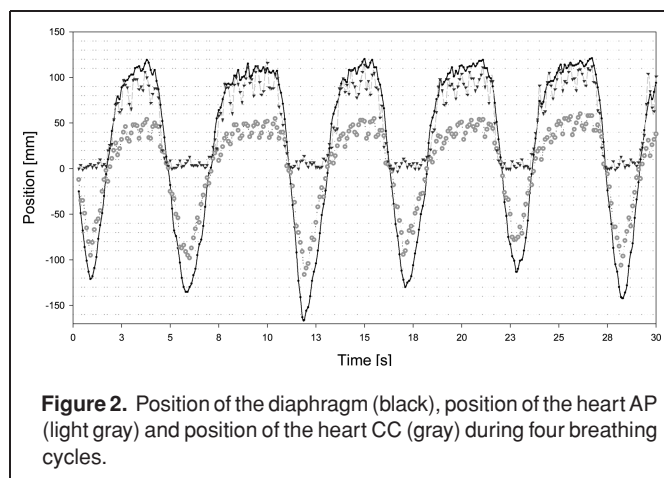


Figure 2. Position of the diaphragm (black), position of the heart AP (light gray) and position of the heart CC (gray) during four breathing cycles.

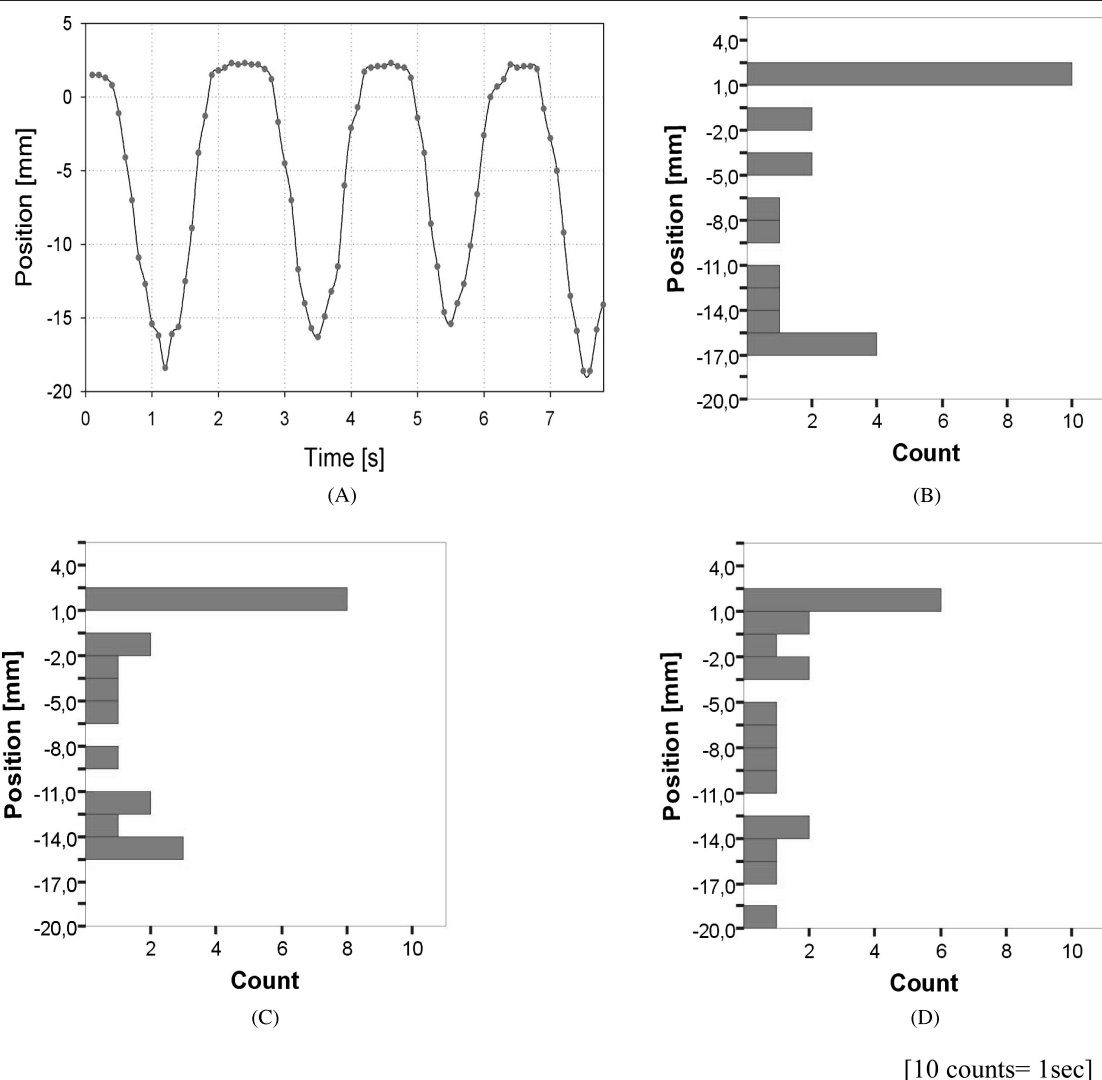


Figure 3. (A) Diaphragmatic position during three breathing cycles. The first breathing cycle starts at 1.2 s the second at 3.5 s and the third at 5.5 s. Fig. (3B–D) shows the histograms of the diaphragmatic positions for the three breathing cycles. The position with the highest number of counts was defined as EEP, in the example shown 1mm. The EED was defined as the number of counts within the EEP interval. Each count corresponds to 0.1 sec, resulting in an EED of 1sec in Fig. 3B.

heart, thorax and diaphragm was determined on the basis of the original navigator data. The diaphragmatic end expiratory position (EEP) and the duration of end expiratory (EED) were calculated with histograms for steps of 1.5 mm (Fig. 3) on the basis of the diaphragmatic CC navigator (Fig. 1A). The diaphragmatic position which occurred most frequently for each breathing cycle was defined as the EEP. The SD of all EEPs of each subject was used to determine the reproducibility of the breathing motion.

The EED was determined from the EEP values of the histogram for each breathing cycle. The mean $\pm$ SD for the EEDs for each patient position were compared.

The different navigator echo signals were correlated with each other and the regression coefficient was regarded as a determinant of the relative movement (Figs. 4 and 5). This was done in prone, supine, and supine with thoracal breathing suppression. The slop of this graph equals the correction factor.

Statistic

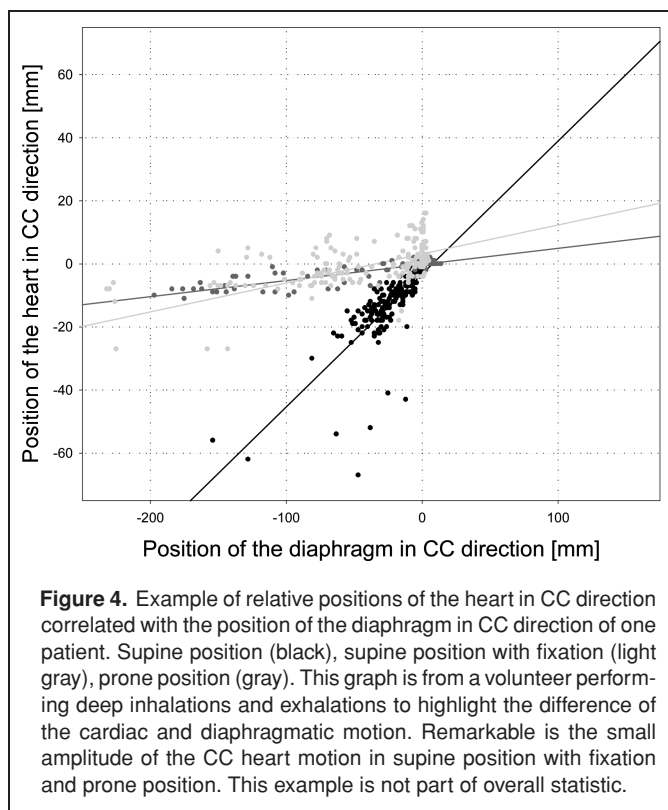
The regression coefficient of relative movements, the standard deviation of the EEP and the mean of the EEP were analyzed with ANOVA-type statistics of Brunner for nonparametric longitudinal data (10). A p value of <0.05 was considered to be significant.

RESULTS

No significant differences of the EED and EEP for different patient positioning or thoracal restraints were found (Table 1).

No significant differences of absolute diaphragmatic excursions were found in prone position or supine position with thoracal restraints compared to supine position.

The thoracal AP motion in relation to the diaphragmatic CC motion decreased in prone position or supine position



with thoracical restraints compared to supine position ($p < 0.05$).

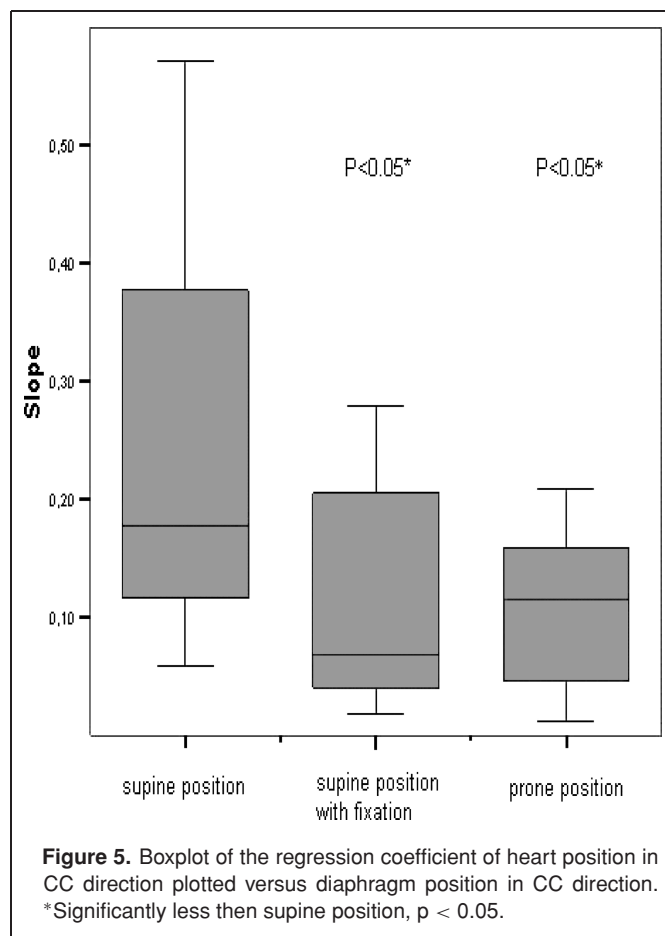
However, the slope of the correlation and the correlation coefficient between CC diaphragm and CC heart decreased significantly with prone positioning or external breathing restraints (Table 2). The highest r^2 values were found for supine positioning, followed by prone position and supine position with breathing restraints (Table 2). The regression coefficient of diaphragmatic and cardiac CC motion for all three positions varied individually from $r^2 = 0.905$ to 0.08 with an average value of 0.55.

No difference of cardiac AP motion in relation to the diaphragmatic CC motion was found for the three methods (Table 3).

Table 1. Duration of end expiratory (EED) and end-expiration position (EEP)

	EED [sec]			EEP		
	Mean	SD	Range	Mean	SD	Range
Supine Position	0.88	0.37	0.45–1.54	10.89	14.12	0–60.00
Supine Position with fixation	0.86	0.30	0.39–1.27	8.67	6.04	0–19.36
Prone position	0.82	0.29	0.42–1.41	6.131	6.17	0–21.90

No significant difference between supine position versus supine position with fixation and versus prone position were found.



DISCUSSION

Prone patient positioning or thoracical restraints did not influence duration or diaphragmatic position of end expiration. However, the correlation between cardiac and diaphragmatic cranio-caudal displacement was significantly altered. In prone position or with thoracical fixation a reduction of cardiac CC motion relative to diaphragmatic motion was found in comparison to supine position. The correlation between the two was significantly reduced.

Table 2. Heart position in CC direction plotted versus diaphragm position in CC direction

	Heart positions in CC direction versus diaphragm positions in CC direction			
	Slope		r^2	
	Mean	SD	Mean	SD
Supine Position	0.259	0.185	0.708	0.226
Supine Position with fixation	0.115*	0.103	0.440 [†]	0.198
Prone position	0.110*	0.070	0.509 [†]	0.256

Slope and measure of determination (r^2):

*Significantly less than supine position, $p < 0.05$.

[†]Significantly less than supine position, $p < 0.001$.

Table 3. Heart position in AP direction plotted versus diaphragm position in CC direction

	Heart positions in AP direction versus diaphragm positions in CC direction			
	Slope		r^2	
	Mean	SD	Mean	SD
Supine Position	0.293	0.149	0.679	0.188
Supine Position with fixation	0.376	0.100	0.836	0.087
Prone position	0.314	0.095	0.717	0.100

Slope and measure of determination (r^2).

Numerous attempts have been suggested to improve magnetic resonance coronary angiography; the major limitations of navigator approaches are the imperfect correlation between diaphragmatic and cardiac displacement and the great intra-individual differences [2, 11, 13]. This is caused by the complex three-dimensional interactions between heart, lungs, diaphragm and connective tissue during breathing.

In our study the r^2 values for the diaphragmatic CC and cardiac CC motion showed large intra individual differences. This may be explained by two reasons. First, little CC cardiac motion in prone position and supine with suppressed thoracic breathing was smaller than in unrestrained supine position, whereas CC diaphragmatic motion was almost unchanged. Thus, the deviation will result in a relatively larger variance. Similarly, the influence of the heart beat itself is relatively increased with the reduction of the CC diaphragmatic motion resulting in a weaker regression. A second reason may be the sometimes very difficult edge detection in the CC direction of the heart.

A previous article from Stuber et al. reported an enhanced vessel definition and a reduced end expiratory diaphragmatic drift in prone position (14).

We hypothesized that a change of patient positioning or thoracic restraints would reduce the complexity of breathing induced cardiac motion which would explain these observations.

However, in contrast to our hypothesis, a worse linear correlation between cardiac and diaphragmatic motion in prone position or supine position with fixation compared with supine position was found.

Regarding our results the normal supine position should be preferred because of the highest correlation between the CC movement of diaphragm and the heart (Fig. 6). This is in contrast to Stuber et al., who found an improved motion correction in prone position (14).

The large interindividual differences of the correlation between diaphragmatic and cardiac motion highlights the necessity for new individual three-dimensional approaches of motion correction (11, 15). In these approaches, the correlation of the diaphragm and the heart are individually determined. The correction factors for the AP (0.293) and CC (0.259) heart motion in your study are different from standard values (AP = 0.2 and CC = 0.6) and closer to those reported in a study from Keegan (AP = 0.04 and CC = 0.04) (16). The difference in the AP value could be a result of different measuring points of both studies. Keegan measured the AP motion of the origin of the right coronary artery and we in the left auricle.

By the use of three navigator echoes in AP, CC direction and an additional in left right direction positioned on the heart, it is possible to determine and correct for the 3D motion displacement of the heart before each data acquisition. With current navigators, this approach is limited by the difficult edge detection of the navigator (17). Another disadvantage would be a prolonged scan time due to a decreased scan efficiency affected by the correction in three planes. With better correction algorithms larger gating windows could be allowed, which would overcome this problem.

CONCLUSION

Prone position or thoracic restraints do not improve the reproducibility or predictability of cardiac position from diaphragmatic navigator measurements.

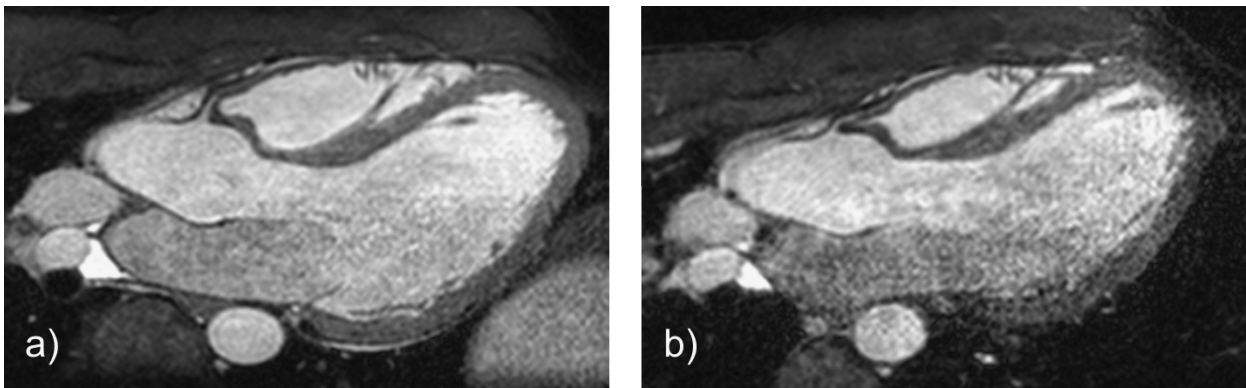


Figure 6. Navigator corrected magnetic resonance coronary angiogram in (A) supine and (B) prone position of one volunteer. The image quality is slightly better in (A) supine position compared to (B) prone position.

ABBREVIATIONS

MRCA Magnetic resonance coronary angiography
 AP Anterior Postior
 CC Cranio-Cauda
 EEP End Expiratory Position
 EED Duration of End Expiratory

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