

Subject specific respiratory motion in Cardiac MR

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Introduction

Respiratory motion of the heart poses a problem for high resolution cardiac MR imaging. Prospective slice following uses the navigator position immediately prior to the imaging segment to correct the slice positions throughout the segment [1]. The navigator is typically placed over the right hemi-diaphragm and a fixed correction factor is used to adjust for the difference to the motion of the heart. The relationship between the motion of the heart and the superior-inferior motion of the diaphragm is approximately linear although highly subject specific, with an element of hysteresis [2]. We have developed a technique to enable a more accurate, subject specific scaling.

Methodology

A short pre-scan is performed, capturing a low-resolution coronal image of the entire heart, as well as a navigator reading of the diaphragm during the diastole of each cardiac cycle for 30 seconds. Since subjects breathe freely, a range of positions are recorded. Anterior-posterior motion is small and is ignored. The images are affinely registered and compared to corresponding navigator readings and a transfer function is constructed. The transfer function is a transformation matrix that describes the transformation of the heart for a given navigator position. The coordinates of the slice being acquired are the input and the output is the shift that needs to be applied to the slice position to correct for respiratory motion. When scanning in the transversal orientation, the slice position can be adjusted by the shift to correct for superior-inferior motion in real time.

To validate the improvement offered using subject specific scaling factors, 9 healthy volunteers were each scanned for 3 minutes. A coronal slice (8mm slice thickness) of the heart (see figure 1) was acquired during the diastole of each cardiac cycle as well as a navigator that is placed over the right hemi-diaphragm that was acquired prior to each image.

The images were registered to the first image of the sequence and the first navigator value was used as a zero reference. For this study we focused on the superior-inferior motion of the heart since this is the most significant. The displacement of the a.) superior and b.) inferior walls of the left ventricle were compared to that of the left hemi-diaphragm as shown in Figure 1. The two points were selected to demonstrate how the correction factor varies for different parts of the heart. A mean correction factor for each of these two points for each subject was calculated by averaging the scale factor (ratio of the displacement of the given point to the diaphragm displacement) for all the images (see figure 2). We compared how closely displacements of the two points computed using these subject specific mean correction factors agreed to the actual displacements. We compare this to the alternative, which is to use a fixed correction factor for all the subjects. The average of the subject specific correction factors for the 9 subjects was used as the fixed value, i.e. 0.70 and 0.66, for the superior and inferior walls, respectively.

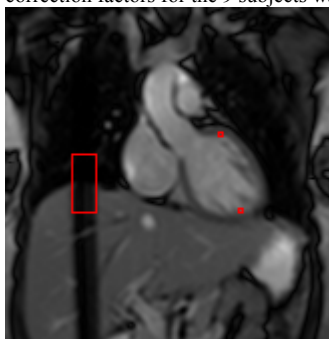


Figure 1: A coronal slice of the heart, with the navigator. The two locations compared to the navigator are indicated with red blocks

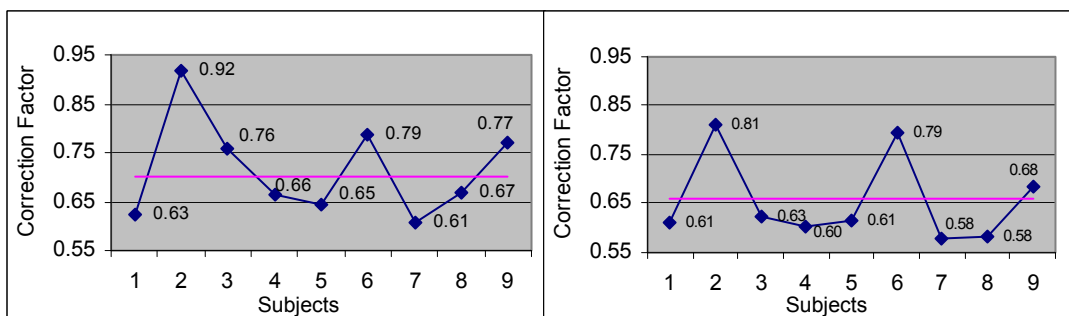


Figure 2.a: Subject specific Correction factor for the superior ventricular wall (blue) and the average of all the subjects (violet)

Figure 2.b: Subject specific Correction factor for the inferior ventricular wall (blue) and the average of all the subjects (violet)

Results

The RMS error and standard deviation between displacements computed with subject specific correction factors and actual displacements for 9 subjects are shown in figures 3. The last (right-most) bar is the resultant RMS error and standard deviation for all the subjects combined when a fixed correction factor was used. It is clear from the graphs that a subject specific correction factor improves the accuracy significantly.

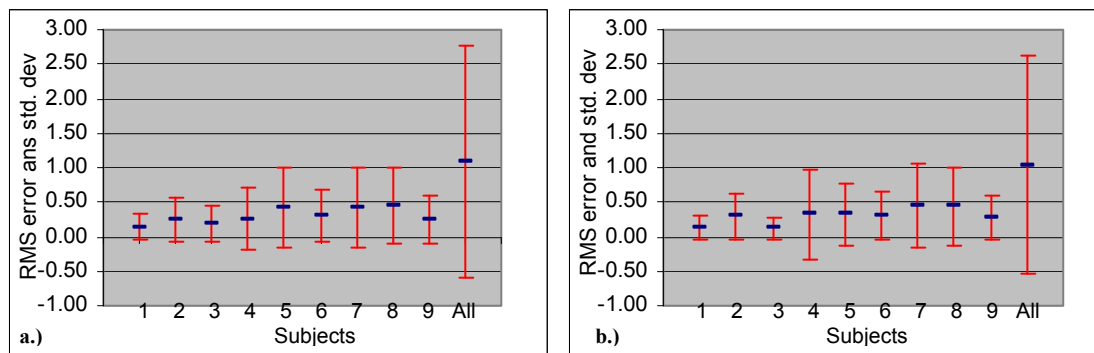


Figure 3 a&b) RMS error (blue) and standard deviation (red) using the subject specific correction factor for the 9 subjects and the last column for all the subjects combined with a fixed correction factor

Conclusion

Using a subject specific correction factor to compute the relative shift of the heart during free breathing offers a significant improvement over a fixed correction factor.

References: [1] I Burger, Prospective diaphragm position prediction for Cardiac MR using multiple navigators, ISMRM Motion correction workshop 2010
[2] A Scott, Motion in Cardiovascular MR Imaging. Radiology 2008