A Study of the Motion and Deformation of the Heart due to Respiration

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We describe a quantitative assessment of respiratory motion of the heart, and construction of a model of the motion. 3D MR scans were acquired on 8 volunteers and 10 patients at multiple breath-hold positions. The exhalation volume was used as a template to which the other volumes were registered using rigid registration followed by non-rigid registration. We assessed the non-rigid motion of the heart at the right coronary artery, right atrium, and left ventricle. We show that the rigid-body motion of the heart is primarily in the CC direction with smaller displacements in the RL and AP directions. Non-rigid deformations of up to 10mm were observed for the right atrium. A statistical model of the motion and deformation of the heart was built that could be used to assist motion correction.

Introduction

The motion of the heart during the cardiac cycle is effectively overcome with ECG gating. Respiratory gating can be used in a similar way but leads to a large increase in scan time. Navigator echoes partly address the motion problem but as yet are not efficient enough for routine clinical use and generally only correct for motion in the cranio-caudal (CC) direction. Breath-hold acquisitions are a popular way of freezing motion with fast scan times. This is satisfactory for relatively fit patients but as yet large volumes or high resolution scans can not be covered without considerable image artifact. Continuous scanning would be desirable if the motion problem can be overcome.

Methods

Experiments were performed on a Philips Gyroscan Intera 8.1 scanner at 1.5T. 3D, steady state free precession volume images were acquired in the transverse plane. The following parameters were used for volunteer scans, and those in parentheses for patient scans. The volume covered a 350×245(350×333)mm^2 FOV with 25slices of 6mm thickness, a 128×102(192×94) k-space matrix was interpolated to 256^2. TR=2.5(4)ms, TE=1.2(2)ms, flip angle=30(50)°. A SENSE factor of two was used in the anterior-posterior(AP) direction. Subjects were asked to hold their breath for the duration of the scan (~25s). Six different positions were acquired on the volunteers and two on the patients, including full exhalation and full inhalation.

For each subject, the volume data acquired at maximum exhalation was segmented. We removed the regions that were not of interest such as the chest wall and spinal column but included the whole heart and the great vessels below the aortic arch. This segmented volume was used as a target to which the other volumes were registered. Images were registered using an intensity based rigid registration algorithm. These rigid-registration results were then used as starting estimates for non-rigid registration [1].

We looked at deformation fields corresponding to four different breath-hold positions for each volunteer and a single field for each patient. In each subject three points were chosen on each of the right coronary artery, the right atrium and the left ventricle. The points were chosen to be reproducible for each subject and were areas that under initial inspection of the deformation field showed the most deformation. Validation of both the rigid and non-rigid registrations was by visual inspection and consistency measurements. Consistency measurements were calculated on three volunteers using a technique we have used in previous work [2].

The surface model was built by generating surface landmarks on the target volume. The registration results were used to propagate these landmarks to their correct positions through the breathing cycle. A statistical point distribution model (PDM) is then built by performing principal component analysis on the landmarks [3]. The result is a mean surface shape with a number of eigenvectors that encapsulate the main modes of variation [4]. This model can include both rigid body motion and deformations or the two can be separated.

Results

A summary of our results is shown next. Rigid(non-rigid) consistency measurements indicate a registration accuracy of ~0.5(2.0)mm. RA=right atrium, RCA=right coronary artery, LV=left ventricle.

	Translations (mm)			(Rotations degrees)		
	CC	AP	LR	CC	AP	LR
Median	12.2	3.6	1.9	-0.4	3.2	-0.8
10%	5.5	0.8	-0.2	-3.8	0.3	-2.5
90%	19.5	9.0	4.6	1.8	6.4	1.7

Table 1: Summary of rigid registration results between maximum exhale and maximum inhale volumes for all subjects.

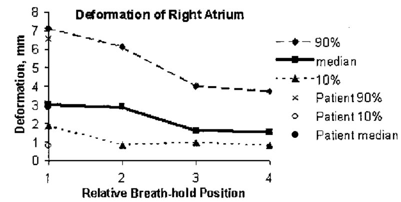

Figure 1: Deformation of landmark on the outer surface of the right atrium (mid-point); deformations measured between maximum exhale and four(one) different breath-hold positions on the 8 volunteers(10 patients). At position 1 the deformation is between maximum inhale and maximum exhale, position 4 is the closest to maximum exhale.

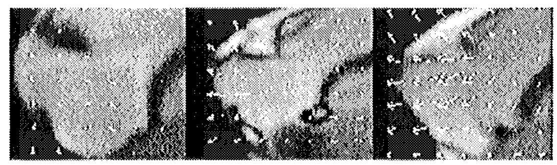

Figure 2: Deformation fields in the right atrium overlaid on the corresponding image for three different patients, increasing deformation left to right. The length of each arrow is the deformation in-plane only.

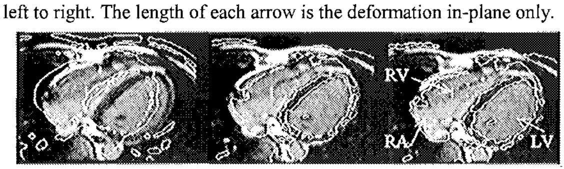

Figure 3:Transverse slice in a volunteer a) No registration, b) Rigid registration, c) Non-rigid registration. Note deformation in right atrium.

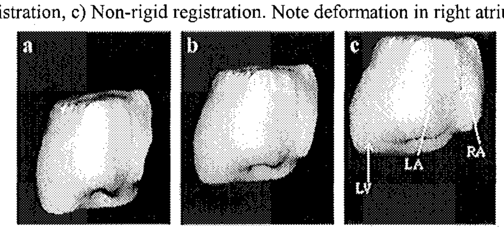

Figure 4:Renderings illustrating the first mode of variation in a volunteer; rigid and non-rigid motion is included. The weightings are a) $-3\sqrt{\lambda}$, c) $+3\sqrt{\lambda}$, b) is the mean position.

Conclusion Large displacements due to translation and rotation were observed in many of the subjects. In addition, deformations of upto 10mm were observed in areas of the heart, including the RA, RCA and LV. These results have clear implications for free-breathing acquisitions and we propose the use of a motion model, similar to the one described here, to overcome the problem of respiratory motion artifact.

References

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