MR Coronary Angiography: Know Thy Rest Period

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Introduction: Physiologic motion during MR coronary angiography introduces blurring and ghosting. Gating the acquisition to both the cardiac and respiratory cycles can reduce motion artifacts. Data are acquired for a short period of time when the two gating triggers coincide. Motion correction can be used to increase the length of the data acquisition window in order to reduce total scan durations without compromising image quality. In this work, we quantified the rest periods of the arteries during the cardiac and respiratory cycles. We also studied the ability of 3 different MR motion correction methods (3D translation, rigid body, and affine) to model the motion of the arteries during breathing, which could be used to effectively increase the respiratory rest period and improve scan efficiency.

Methods: Conventional cine biplane coronary angiograms were acquired for 8 male and 2 female patients referred for diagnostic left heart catheterization (mean age, 65±11 years). In total, 7 left coronary and 4 right coronary angiograms were used. Patients gave written informed consent to participate in this IRB approved study. The patients received no breathing instructions, so that spontaneous tidal respiration was imaged. A time-varying three-dimensional model of the coronary arteries was constructed for each patient using a stereo reconstruction method and an automatic motion tracking algorithm [1]. For this study, we considered only the proximal and middle segments of the right coronary artery (RCA, segments 1&2 as defined in [2]), and the proximal 5 cm of the left coronary tree, which included the left main, left anterior descending, and left circumflex arteries. We used a cardiac respiratory parametric model to separate the free breathing, beating, coronary motion data into separate cardiac and respiratory components [3].

The rest period was defined as the maximum length of time during which the 3D motion of the coronary tree was less than some upper bound. The cardiac rest period was measured in milliseconds at end-systole and mid-diastole (diastasis). The respiratory rest period was measured at end-expiration and end-inspiration and is reported as a percent of the patient's respiratory cycle duration.

The motion of the coronary arteries during a tidal breathing cycle (iso-cardiac phase) was analyzed further. Coronary tree models from different respiratory phases were registered to the coronary tree at end-expiration using one of three MR motion correctable linear transformations: 3D translation; 3D rigid body; and 3D affine. The residual error of this registration step represents the amount of motion that could not be compensated for using the given MR motion correction techniques. To quantify the efficacy of the different transformations, we measured a *motion-corrected respiratory rest period* (MCRRP) for the residual coronary motion.

Results: Cardiac and respiratory rest period durations are provided in Table 1 and 2 respectively. Figure 1 shows the effect of motion correction on the respiratory rest period at end-expiration. The graph shows that as the degrees of freedom (DOF) of the motion model are increased (translation < rigid body < affine), the MCRRP duration also increases.

For a tolerated 3D motion of 0.5mm, the left coronary rest period was 18±14% of the tidal respiratory cycle. 3D translation modeled the motion of the left coronary arteries for 32±13% of the tidal respiratory cycle with the same motion tolerance. The MCRRP increased to 51±28% with the rotational DOF provided by the rigid body transformation. 3D affine motion correction extended the MCRRP to 79±26%. For the RCA, there was no statistical improvement with the rigid body model (MCRRP, 33±11%) over the translation motion model (MCRRP, 27±13%). 3D affine motion correction increased the MCRRP to 64±25% of the respiratory cycle.

Discussion: The motion corrected results (MCRRP) are based on perfectly recovered transformations and therefore reflect a best-case scenario. In practice, the arterial motion has to be measured during the MR acquisition and used to adapt the acquisition online. Further work on MR based techniques for motion estimation, and correlation to signals such as navigator echoes of the diaphragm, is required.

Allowed 3D Motion (mm)	Cardiac Rest Period (ms)			
	Right Coronary		Left Coronary	
	Systolic	Diastolic	Systolic	Diastolic
0.5	41±21	30±19	41±15	55±22
1.0	76±34	65±42	80±25	112±42
1.5	105±40	109±71	114±29	168±65

Table 1 Cardiac rest period for the right and left coronary arteries. The systolic and mid-diastolic rest periods are measured in milliseconds.

Allowed 3D Motion (mm)	Respiratory Rest Period (% of cycle)			
	Right Coronary		Left Coronary	
	EE	EI	EE	EI
0.5	17±8	10±6	18±14	6±3
1.0	26±8	16±8	27±17	11±6
1.5	33±8	20±9	33±16	14±7

Table 2 Respiratory rest period for the right and left coronary arteries. The end-expiration (EE) and end-inspiration (EI) rest periods are measured as a fraction of the breathing cycle duration.

References
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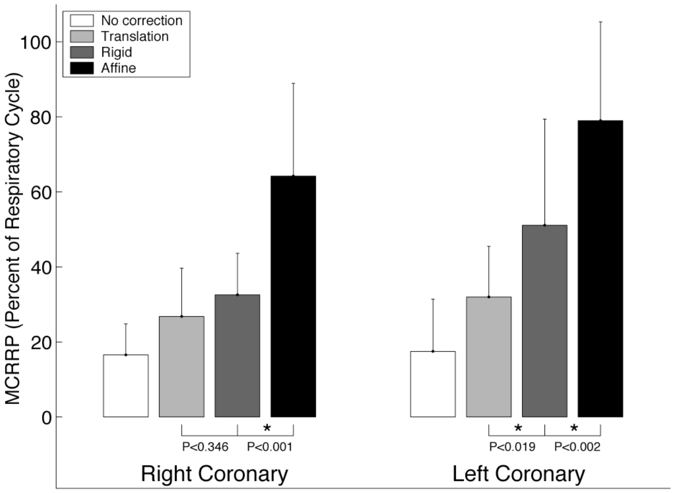

Figure 1 Motion corrected respiratory rest period (MCRRP) at end-expiration: A comparison of three different motion models for an allowed 3D motion of 0.5 mm. Two Bonferroni corrected t-tests were performed for each artery to test for incremental differences in the MCRRP. A group-wise statistical significance of $\alpha<0.05$ is indicated by a star (*). *P*-values are provided for all t-tests.