Self-gated Cardiac Perfusion MRI

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Introduction: Dynamic MRI for characterizing perfusion in the myocardium is becoming a more robust and useful clinical tool. The first pass of gadolinium contrast is tracked by imaging a number of slices each heartbeat. Good ECG-gating is essential to obtaining the same cardiac phase of each slice so that the resulting sets of dynamic images are most valuable. However, ECG-gating is often poor, and can be more problematic at higher field strength scanners and in obese patients. Datasets have been rendered useless due to very long pauses between triggers, or degraded by the need to use a peripheral gate. As well, patients with arrhythmias can be problematic for acquiring high quality images due to the R-R interval variations. Here we propose an ungated perfusion acquisition that runs constantly without any gating signals. The images are acquired so rapidly that it is possible to sort the resulting dataset and create effectively self-gated perfusion images.

Methods: A saturation recovery radial turboFLASH sequence was used in two subjects to investigate the potential of ungated cardiac perfusion imaging. TR/TE=2.2/1.2msec, FOV=260mm, 2.3x2.3x10mm pixel size on a 3T Verio (Siemens) scanner. 24 rays in 4 subsets of 6 rays each were acquired for each slice. Four slices were acquired after a single saturation pulse and a ~50 msec delay. Each image was acquired in 24*2.2=53msec and repeated every 265msec with no gating and during free-breathing. Gd-BOPTA of 0.03mmol/kg was injected and ~230 sets of slices were acquired over a total of a minute. Thus each slice was acquired at various cardiac phases in each heartbeat. The second subject was in severe atrial fibrillation (AF) during imaging.

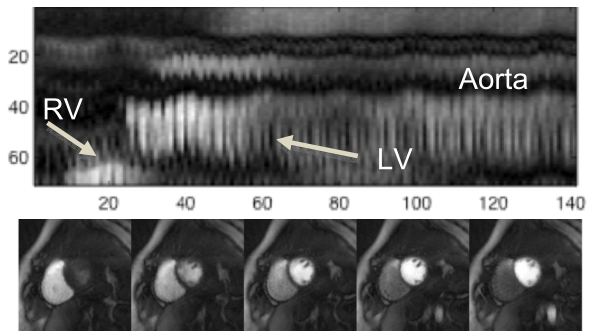

Figure 1: Top: One cropped projection (from images like those at bottom) from continuously acquired perfusion data, all frames. Contrast onset in various structures can be observed, as well as ECG and respiratory motion. This "navigator" corresponds to projecting along columns in the bottom images. Bottom: Example in one slice of self-gated frames as bolus enters (slice 3, see slice 4 in Fig. 3).

Fig. 1 shows an example in the first subject of the same projection of one slice acquired each time frame. The cropped projection corresponds to an area around the heart, and shows a high frequency change due to ECG or cardiac phase, a slower change due to respiration, along with changes due to contrast administration. The figure shows that it is likely feasible to obtain a gating signal from the projection data (e.g. with bandpass filters [1, 2]). However, we focused here on two retrospective image-based gating methods.

First, the images were reconstructed with an iterative compressed sensing method. Then a region of interest around the heart was selected in a reference frame. For the first method, a correlation value between the reference frame and each other frame was computed as in [3]. This gave the 1D curve shown in Fig. 2. Local peaks of the curve were selected by locations where the signal's first difference in time changed sign from positive to negative.

The second method summed the signal from the cropped area of the heart for use as a navigator. This is nearly the same as using the center of k-space value that sums all of the image (and the results were similar but not identical to using the center of k-space).

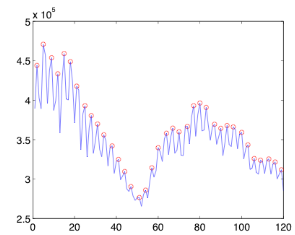

Figure 2: Frames 30-150 shown (after bolus arrival in RV). Red circles denote the frames selected by the correlation self-gating method. Each time frame represents ~265msec.

Results/Discussion: The first self-gating method, the correlation method, gave different results depending on the chosen reference frame. Different reference frames tended to give images at a different cardiac phase, but likely due to how often the image was sampled in each phase, the quality of the results varied. One particular reference frame selection gave the same results as the summing method, which had higher apparent quality and more frames. Fig. 3 shows the results of these self-gating methods in the first subject. Approximately 35% of the images were retained, giving a mean temporal resolution of ~760 msec. For the patient in AF, an example of the self-gated result is shown in Fig. 4. Approximately 32% of the images were retained over the first 170 frames, for similar mean temporal resolution of ~800msec.

Respiratory motion did not cause very local peaks and thus was typically accepted, which permits recovery of datasets similar to the free-breathing datasets obtained with ECG gating. Non-rigid registration methods could be used to combine all of the data to yield improved temporal resolution and/or SNR. In theory, out-of-plane motion could be handled if the slices are contiguous or a 3D acquisition was performed.

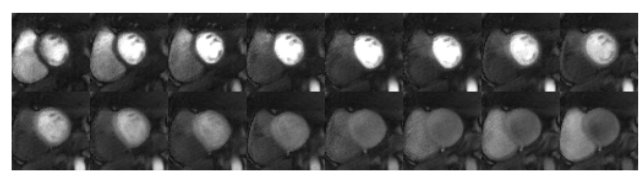

Figure 3: 16 consecutive images chosen by the second self-gating method (time goes left to right and then continues on the bottom row).

The primary application of the self-gating method is for patients with arrhythmias, such as those in AF. Patients in sinus rhythm with perfect gating are best imaged with current methods. However, since gating can often be poor, ensuring that useful data are obtained even if the gating fails could make the self-gated approach applicable in a wider range of patients. The self-gated approach also ensures that maximal information is obtained during the relatively brief first pass – even with careful set-up, it is difficult to choose a number of slices to always stay within one heartbeat yet use the whole time per heartbeat. If the HR changes even slightly this can lead to acquiring only every other beat, which is only 50% efficient even when the ECG triggering is perfect. This self-gating development also permits steady-state acquisitions with a 3D readout to be considered, since a primary reason for using a saturation pulse was to reset the magnetization after any arrhythmias. The studies here show that the self-gated approach has promise. Further studies are needed to evaluate the technique.

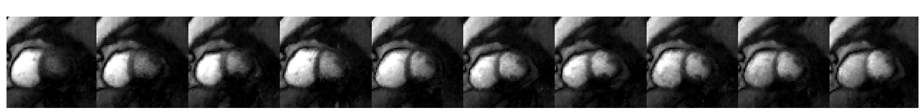

Figure 4: Example of self-gated images from patient in AF. 10 frames as the bolus enters the LV chamber are shown.

References: [1]M. Buehrer, et al., MRM, 60: 683-90, 2008. [2] J. Liu et al. MRM 63:1230-7, 2010. [3] Larson et al. MRM 53:159-68, 2005.