# On the Advantages of Retrospectively Gated Radial Acquisitions for Cine Phase Contrast Flow Imaging

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**Introduction:** High quality dynamic cardiovascular MRI requires synchronization of the data acquisition and cardiac pulsatility. In most clinical applications, this is accomplished with prospective cardiac gating with an ECG or pulse oximeter (PO) signal. This approach results in incomplete coverage of the cardiac cycle (CC) because a rejection window (usually 10% of CC) at the end of the cardiac cycle is required due to expected variability in the patient heart rate and the potential for arrhythmias. Triggering off the ECG or PO waveform also requires peak detection and a feedback loop to the acquisition that can result in later acquisition starts within the CC than desired. Here we show the benefits of dynamic radial acquisitions with flexible retrospective gating schemes.

**Background:** While retrospective ECG gating with a Cartesian trajectory is principally feasible, it often results in prohibitively long scan durations to image within a breath hold [1]. Radial undersampling has been proposed for accelerated 2D and 3D imaging in scenarios with high contrast-to-noise ratios such as MRA, bSSFP cardiac imaging, and phase contrast (PC) MR. Radial acquisitions mitigate the effects of motion artifacts and enable accelerated acquisitions through angular undersampling. They are ideally suited for retrospectively gated scans that continuously acquire k-space data while the time stamp of cardiac triggers is recorded but not used to steer the acquisition. Radial data can be sorted during the reconstruction based on the recorded gating stamp as shown in Fig. 1. Several options exist for image reconstruction of dynamic data with and without view sharing. This approach has similarities to radial time-resolved MRA acquisitions with temporal filtering [2]. Such a scheme is not possible with typical Cartesian acquisitions, because the center of k-space is not continually sampled with each TR.

Gating off the pulse oximeter signal is compelling in exams were only one or two cardiac gated sequences are required and/or it is desirable to reduce the time for patient setup. However, PO waveforms are usually acquired off a finger and the peak is delayed compared to the R-wave detection in ECG triggering. This delay results in later starting frames for prospectively gated sequences.

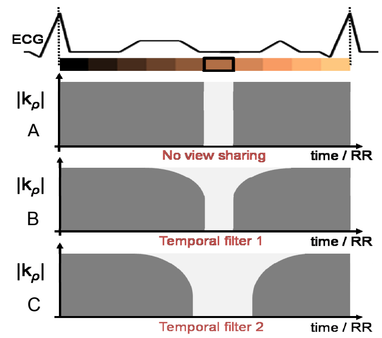


**Fig. 1.** Temporal filter for cardiac cycle. The projections of the current cardiac phase alone can be used (A) or shared with high spatial frequencies from adjacent time frames (B) or shared with high and low spatial frequencies from adjacent phases (C). Increased view sharing reduces streak artifacts, but introduces some degree of temporal blurring.

**Methods:** To compare the sampling coverage of a retrospectively gated radial sequence and a prospectively gated sequence, 2D PC MR measurements on healthy volunteers were conducted in the ascending aorta and the carotid arteries. Prospectively gated images were acquired with a product Cartesian 2D cine PC sequence optimized for high temporal resolution for aortic pulse wave velocity measurements. A 2D radial cine PC MR sequence with retrospective ECG gating was implemented on a clinical 3T system (Discovery HD 750, GE Healthcare).

*Aorta protocol-prospective Cartesian:* VENC=150 cm/s, TR/TE/flip=5.1ms/2.9ms/30°, FOV=41x41cm$^2$, spatial resolution = 1.6x1.6mm$^2$, slice thickness=7mm, prospective ECG triggering, 55 cardiac phases, temporal resolution= 10ms, scan time = 22.4 s (breathhold)

*Aorta protocol-retrospective Radial:* VENC=150 cm/s, TR/TE/flip=7.2ms/3.5ms/15°, FOV=32x32cm$^2$, spatial resolution = 1.3x1.3mm$^2$, slice thickness=5mm; retrospective ECG gating, # of projections = 1000; 55 cardiac phases, temporal resolution= 14.2ms, scan time: 17 s (breathhold)

*Carotid protocol:* Additional images were acquired from a second consenting volunteer axially through the common carotid arteries using both the prospectively gated Cartesian 2D PC acquisition and the retrospectively gated radial 2D PC acquisition, with both ECG and peripheral (pulse-oximeter) gating signals. Scan parameters were similar to the above, with voxel size reduced to 0.78x0.78 mm$^2$ in plane with 8 mm slice thickness, and VENC reduced to 90 cm/s for both trajectories.

*Data processing:* Radially acquired images were reconstructed offline with regridding and density compensation. All images were analyzed for flow waveforms with in-house software to measure the blood flow over the cardiac cycle. Flow waveforms were registered to one another and plotted for comparison.

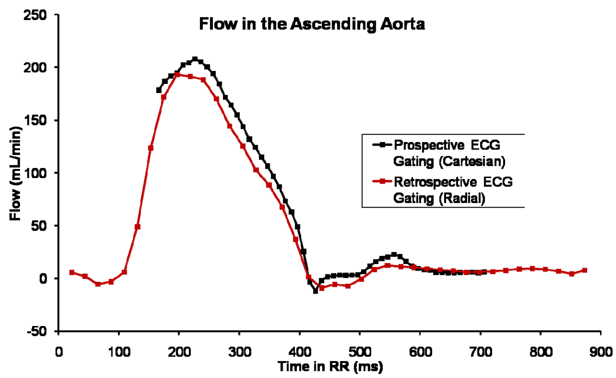


**Fig. 2.**

**Results:** For flow in the ascending aorta, the prospectively gated Cartesian sequence lacked the systolic upstroke of the flow waveform due to the trigger delay (Figure 2). In addition, no measurements were obtained for about 200 ms of late diastole due to the arrhythmia rejection window. The flow waveform measured from the retrospectively gated radial sequence covers the complete cardiac cycle. For measurements in the left common carotid artery, portions of the flow waveform were missing for measurements obtained from the prospectively gated Cartesian sequence using both ECG and pulse-oximeter gating (Figure 3) with the ECG gated waveform capturing the systolic peak, which the PO gated acquisition omitted. The retrospectively gated acquisition produced a complete cardiac cycle with both trigger signals (Figure 3).

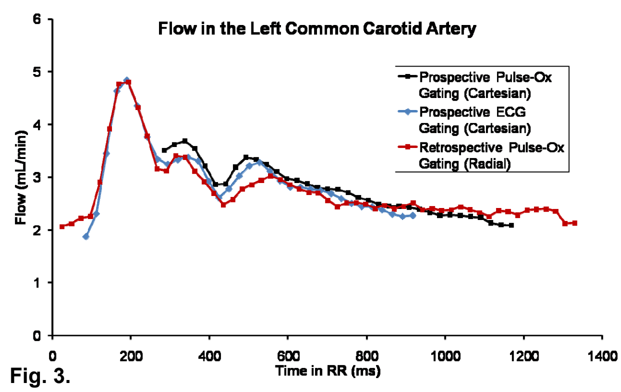


**Fig. 3.**

**Discussion:** The trigger delay and the arrhythmia rejection window employed in prospectively gated acquisitions results in missed cardiac phases. Depending on the application, missing phases in late diastole can possibly be extrapolated from other frames. However, dynamics in early systole such as flow waveforms in the ascending aorta can be missed. This effect is amplified when a pulse oximeter signal is used for gating due to the added delays. Missing data points can lead to erroneous quantification e.g. in measurements of flow or cardiac function. Some applications rely on characteristic features of the waveform such as the onset location of the systolic flow increase for pulse wave velocity data, which cannot be performed from such measurements. Radial imaging with retrospective ECG gating overcomes these problems. An added benefit of the technique is the ability to use peripheral gating in more situations, which involves simpler patient preparation and is less prone to interference from EMG, gradient, and other sources of noise. The reconstruction of dynamic images offers unique possibilities for frequency selective view sharing, trading off imaging time, temporal resolution, and residual artefact level. This concept will be further investigated in future work.

**References**

[1] McCormack *et al.* Magn. Reson. Imag. 25(2):172, 2007, [2] Liu *et al*. IEEE TMI, 25:148, 2006, [3] Markl *et al.*, MRM 63(6):1575, 2010.