A Novel Approach to ECG-Gated High-Resolution Contrast-Enhanced MR Angiography in Thorax: Technical Aspects

Y. Natsuaki[1], P. M. Wagner[2], J. P. Finn[2], R. Kroeker[3], and G. Laub[1]
[1]Siemens Medical Solutions, Los Angeles, CA, United States, [2]Radiology, UCLA, Los Angeles, CA, United States, [3]Siemens Medical Solutions, Winnipeg, MB, Canada

Introduction: Contrast-enhanced MR angiography (ceMRA) [1] is typically performed without ECG gating. Whereas, for most purposes, this approach is entirely satisfactory, in ceMRA of the thorax the cardiac chambers and ventricular outflow vessels undergo variable degrees of blurring with non-gated acquisition. To address this limitation, ceMRA can be acquired with ECG gating, whereby the segmented data acquisition is synchronized with the cardiac cycle (Fig.1). As originally proposed, conventional gated ceMRA acquires a single 3D partition per heartbeat [2,3], limiting slice coverage and /or resolution to the number of heartbeats encompassed by a practical breath-hold. Whereas previously described protocols for gated CEMRA generated < 40 slices per acquisition, modern acquisition protocols for non-gated 3D CEMRA generate >120 slices. Coverage and /or spatial resolution would therefore be inadequate with previously described approaches to gated 3D acquisition. The current work proposes a novel approach to increasing efficiency and flexibility in ECG-gated ceMRA of the thorax, and seeks to achieve full-coverage high-resolution ECG-gated ceMRA within a single breath hold.

Methods: Our approach is based on a Cartesian ECG-gated 3D FLASH sequence optimized for ceMRA. For conventional ECG-gated ceMRA, all of the in-plane phase encoding steps (k_y direction) are acquired within a single R-R interval. The acquisition is then repeated in linear order for all thru-plane phase encoding values (in k_z direction). With this scheme, the total scan time is the average R-R interval multiplied by the total number of thru-plane encoding steps (i.e. total number of slices) and the center of k-space cannot be flexibly manipulated to coincide with the peak of contrast enhancement. With short TR times of 2.7ms and nowadays typically less than 150 in-plane phase encode steps, the data acquisition window during each heartbeat is much less than the average R-R interval, resulting in an inefficient acquisition scheme with extensive wait time (Fig.2 left).

With our proposed strategy, combinations of in-plane and thru-plane phase encoding steps can be selected, generating a Cartesian k-space sub-matrix (segment), which spans most of the R-R interval (Fig.2 right). The direction of the completed phase encoding steps is now flexible, such that the k-space sub-matrix contains all of the points from several adjacent lines (k_y) *or* all of the points from several adjacent partitions (k_z). Parallel imaging and partial Fourier techniques further optimize spatial resolution and scan time. Within the R-R interval, the k-space sub-matrix (segment) is acquired in a saw tooth-like pattern, and the center of the segment can be positioned to overlap the diastolic phase of cardiac motion. In turn, the ordering of the k-space segments is scrollable, such that the center of k-space [$k_z(0)$, k_y0)] can be positioned over the predicted peak of contrast enhancement (time to center, TTC).

Results: The proposed sequence (Siemens IPR#573: Gated ceMRA, Siemens Healthcare, Erlangen, Germany) was implemented at 1.5T (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany), and verified in a series of 8 volunteers under an IRB approved protocol by running both gated and non-gated versions of the same sequence. The parameters are closely matched (single dose Gd contrast agent injection, coronal orientation, TR/TE 2.7msec/ 0.9msec, FA 30, BW 610Hz/pixel, iPAT x 3, image matrix 288x512, slices 120, in-plane resolution 1.3x1.0 mm^2, and slice resolution 1.88mm interpolated to 1.3mm). Scan time for the gated ceMRA was on average 27sec, while the non-gated was exactly 21sec. The results from the direct comparison show greatly improved definition of the heart borders and chamber structures, relative to the non-gated acquisition (Fig.3). Cardiac motion induced edge ghosting artifacts were common in the completed phase encoding direction for the gated ceMRA, while the non-gated simply shows motion blurring (Fig.4).

Conclusion: We have successfully implemented segmented k-space, gated ceMRA of the entire thorax in a breath hold period. The gated ceMRA sequence generates greatly improved image quality of cardiac structures and ventricular outflow and holds promise for a variety of cardiac imaging applications.

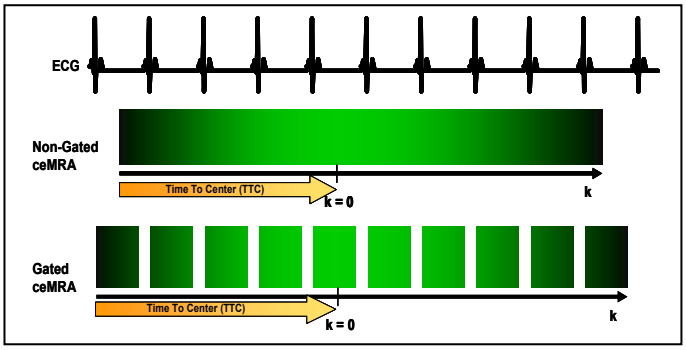

Figure 1: Schematic diagram of non-gated vs. gated cardiac ceMRA acquisition. Time to center (TTC) is utilized for the optimal contrast injection profile.

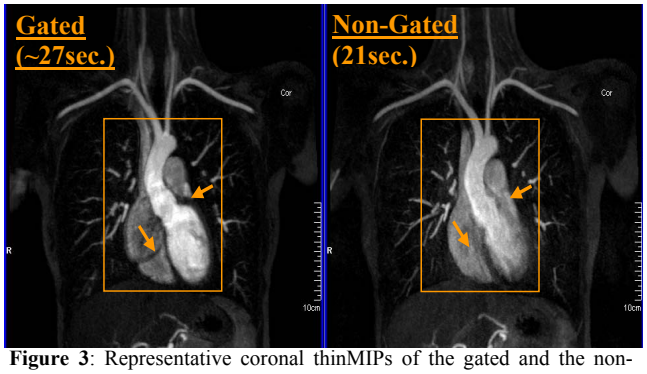

Figure 3: Representative coronal thinMIPs of the gated and the non-gated ceMRA on a same volunteer. With the gated ceMRA, fine details such as aortic root and aortic valve can be depicted.

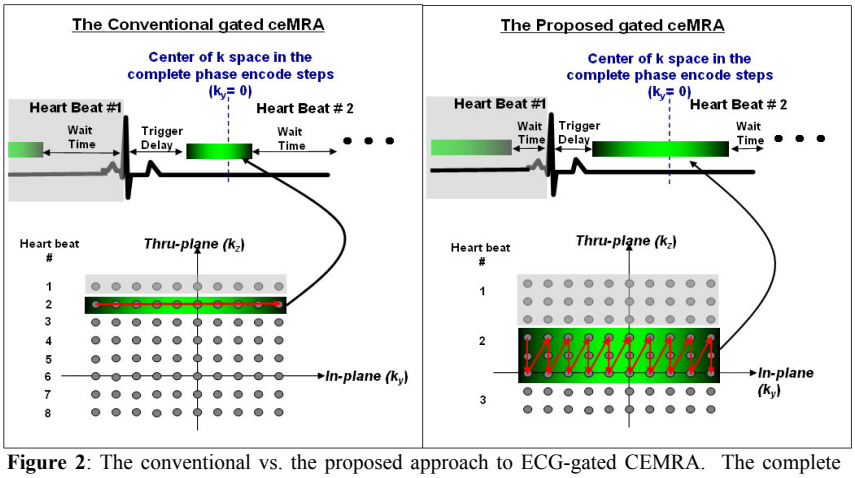

Figure 2: The conventional vs. the proposed approach to ECG-gated CEMRA. The complete phase encoding direction is in-plane (ky) for both (note: for the conventional ceMRA in-plane is the only choice, while the proposed ceMRA can be in either direction). The proposed sequence acquires multiple complete phase encoding steps (3 in current example) in sawtooth-like pattern, resulting in the reduction of the wait time and thus improved scan time efficiency.

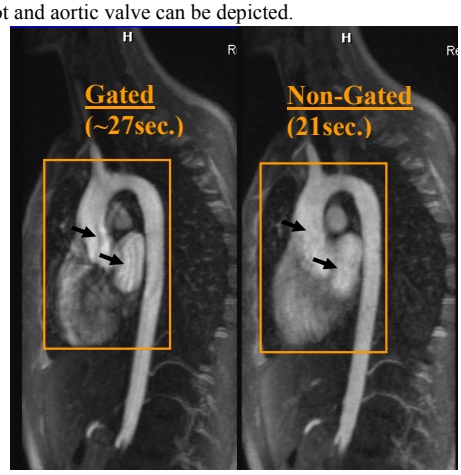

Figure 4: Sagittal thinMIPs of the gated and the non-gated ceMRA on the same volunteer data as with Fig.3. Gated ceMRA shows edge ghosting artifacts, while non-gated ceMRA simply shows motion blurring.

References: [1] Prince MR, Grist TM, and Debatin JF. *3D Contrast MR Angiography*. Berlin: Springer, 2003. [2] Simonetti OP, Finn JP, R.D.W, Bis KG, Shetty AN, Tkach J, Flamm SD, and Laub G. Proc.ISMRM 1996. [3] Groves EM, Bireley W, Dill K, Carroll TJ, and Carr JC. AJR 2007;188:522-528.