Adaptive Steady State Triggering adds confidence to the Thoracic ECG-Gated Contrast Enhanced MR Angiography

Yutaka Natsuaki[1], J Paul Finn[2], Randall Kroeker[3], and Gerhard Laub[4]

[1]Siemens Healthcare, Los Angeles, CA, United States, [2]Radiology, UCLA, Los Angeles, CA, United States, [3]Siemens Healthcare, Winnipeg, MB, Canada, [4]Siemens Healthcare, San Francisco, CA, United States

Target Audience: Clinicians and researchers working with Contrast-Enhanced MR Angiography (in particular with thorax)

Purpose: Thoracic ECG-gated CEMRA with flexible segmentation [1] has shown great promises in its ability to depict detailed cardiac anatomy (e.g., 5 yo. CHD case, Fig.1). In the gated CEMRA, steady-state triggering plays a key role in maintaining the magnetization and minimizing cardiac pulsatile motion. We assume that the steady R-R interval with the fixed scan window (trigger delay (TD) + segment acquisition). When R-R interval is disrupted due to heart rate variation and ECG failure, scan time substantially increases, which causes problems in timing-sensitive CEMRA scans. The purpose of the current study is to introduce the *Adaptive* Steady-State Triggering, a novel prospective trigger adjustment approach to compensate the early trigger loss and to force the late trigger scan completion within an acceptable range.

Methods: The steady-state triggering performs dummy shots during the trigger waiting and trigger delay (Fig.2). To make steady-state triggering work properly, R-R interval must remain steady and the trigger event must be detected within an expected time frame. In reality, however, due to both physiological (the R-R interval varies during a breath hold [2]) and mechanical (ECG detection device can be failed) imperfections, triggers can be either detected too early or too late to substantially increase the scan time. On one hand, the shortening of the R-R interval with fixed scan window leads to the early trigger miss. On the other hand, the trigger event may not be detected due the mechanical failure to the ECG-scanner interface. While forcing trigger events after the maximum wait time can move forward with the late trigger cases, the substantial scan time increase is inevitable. The adaptive steady-state triggering algorithm is designed to help alleviate these early and late trigger issues.

Early Trigger Cases (Fig.3): The goal is to salvage the early trigger event and retain the original TD from the trigger event. Once the scan window is completed, the algorithm checks if the trigger event has occurred during the segment acquisition and then calculates the Missed Trigger Time (i.e. the dwell time since the latest trigger event). If Missed Trigger Time is less than or equal to TD, the algorithm forces the trigger event and adjusts the TD (=Adj) such that Adj. = original TD – Missed Trigger Time.

Late Trigger Cases (Fig.4): After the maximum wait time (=130% of R-R interval) is elapsed, the trigger event is forced with TD=0. If 2 consecutive maximum wait time is observed (i.e. 4 total heart beats without an event), ECG trigger is considered unreliable and thus emphasizes on scan completion by shortening the maximum wait time to 30% of R-R interval.

The proposed trigger algorithm was implemented on the prototype ECG-gated CEMRA with flexible segmentation [1], and was first verified on 1.5T scanner (Magnetom Avanto, Siemens Healthcare, Erlangen, Germany) with a stationary phantom and ECG signal simulator. The algorithm was then verified with 10 healthy volunteers under an IRB approved protocol by running both gated and non-gated versions of the same thoracic MRA sequence with Gd contrast injections. The parameters were closely matched (single dose Magnevist (Gd-DTPA) or Ablavar (Gadofosveset, MS325) injection, coronal orientation, TR/TE 2.7 ms/ 0.9 ms, 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 23 sec, while the non-gated was exactly 21sec.

Results: The algorithm performed as expected with phantom & ECG simulator experiment. Of 10 volunteer data, 3 showed early detections and none showed the late detections. Scan time remains within the predicted range, and the resulting image quality had no visible artifacts associated with the triggering (e.g. Fig.5). In Fig.5 case, 50% of the ECG triggers were shorter than the captured RR interval at the beginning of the scan (900ms), and would have taken extra 50% of the total scantime (31 sec) with the standard steady state triggering.

Discussion: The current algorithm is limited to mild arrhythmia case. For the severe case, the non-gated CEMRA is still recommended. The current algorithm adapts TD only, and while this is sufficient for the current gated CEMRA, further improvements in scan efficiency may require more elaborated algorithm with prospective R-R estimation [3].

Conclusion: The ECG-gated CEMRA is a proven method that provides vastly improved image quality in thorax. The proposed algorithm adds confidence to the gated CEMRA; it makes sure that the acquisition will be finished in a not-to-exceed amount of time, no matter what happens to the ECG signal.

References: [1] Natsuaki Y, Kroeker R, Finn JP, Schmitt P, Laub G, Proc. ISMRM,2013. [2]Ashman R, Hull E. Essentials of electrocardiography for the student and practitioner of medicine, 2nd ed. New York: Macmillan; 1945. p162–163. [3] Roes SD, Korosoglou G, Schar M, Westenberg JJ, van Osch JP, de Roos A, Stuber M. JMRI 27:1046–1053,2008
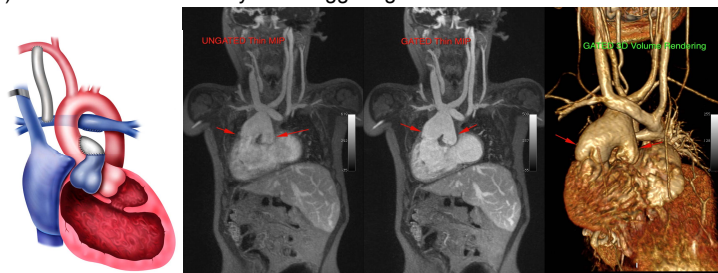
Fig 1. Five year old female patient with single outlet right ventricle and heterotaxy, status post Stansel procedure and Glenn shunt (cartoon on left). Comparison of the ungated CEMRA and gated CEMRA shows greatly improved definition of cardiac anatomy with gating and clear depiction of the aortic and pulmonary valve planes (arrows).
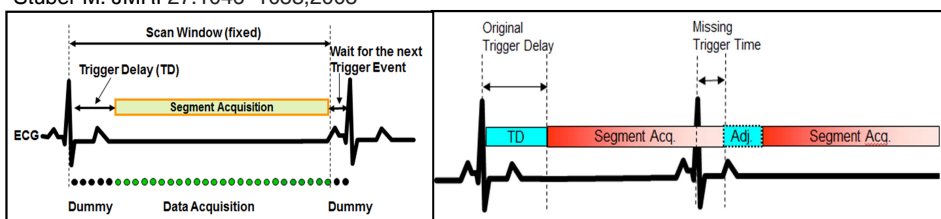

Fig.2. Steady State Triggering.

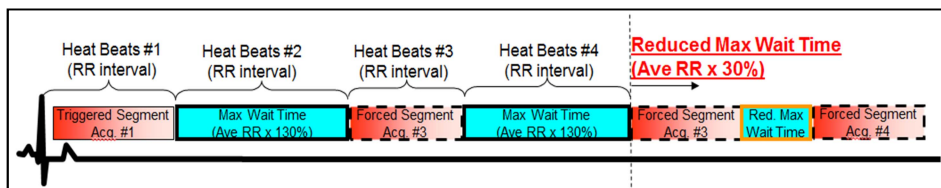Fig.3. Early Trigger Cases (with Missing Time < TD)

Fig.4. Late Trigger Cases (with 2 consecutive trigger event failure to detect).
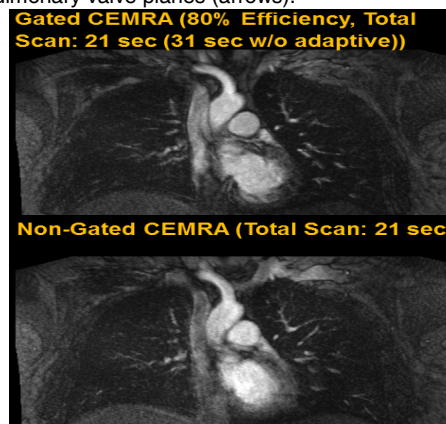

Fig.5. Early Trigger Case volunteer. Despite RR time reduced during the scan, the proposed triggering method shows no effects in the gated CEMRA image with improved image quality.