

Adaptive Method for Black Blood Cardiac Imaging in End-Systolic Rest Improves Visualization of the Right Ventricular Wall

B. Fernandez^{1,2}, J. Oster^{2,3}, M. Lohezic^{1,2}, D. Mandry^{2,4}, O. Pietquin^{2,5}, P-A. Vuissoz^{2,3}, and J. Felblinger^{2,3}

¹Global Applied Science Lab., GE Healthcare, Nancy, France, ²IADI lab., Nancy-Université, Nancy, France, ³U947, INSERM, Nancy, France, ⁴Departement of Radiology, CHU Nancy, Nancy, France, ⁵IMS Research Group, Supelec, Metz, France

INTRODUCTION: The Double Inversion Recovery Fast spin echo (DIR-FSE) sequence [1] is a key component of cardiac MR examination. It allows to homogeneously suppress blood signal for a better depiction of the myocardium. Black blood imaging of the heart is usually performed during the mid-diastolic rest. This is a consequence of the long inversion time (TI) required to suppress the blood signal which is constrained by the T1 of the blood as well as the heart rate (HR) [2]. Moreover, the optimum TI does not necessarily match a cardiac rest period (i.e. the mid-diastolic or the end-systolic rest period). In case of high HR or significant RR interval changes, DIR-FSE are almost impossible to acquire [3]. To overcome these constraints, black blood images can be acquired during the end-systolic rest since it is less sensitive to RR interval variations [4]. Furthermore, images acquired during the end-systolic rest may provide a better determination of the right ventricle (RV) due to its thickening. Two methods have been suggested to perform DIR-FSE during the end-systolic rest, independently of HR and RR interval variations [5]. Briefly, they both rely on delaying the beginning of the DIR-FSE sequence so that the acquisition occurs during the end-systolic rest of the next cardiac cycle. Both methods used a cardiac cycle model to compute the delay. The first one relies on the assumption that the RR intervals are constant (Fixed Delay Method, FDM) whereas the second method is based on an adaptive RR interval prediction algorithm (Adaptive Method, AM). After a quick review of the two methods, robustness and RV visualization enhancement is investigated on 14 healthy volunteers.

METHODS: Both AM and FDM methods used a cardiac cycle model that provided the systolic duration (T^s) as a linear function of the RR interval Δ with parameters A and B [4] (fig.1). The common framework for both methods in the delay computation before starting the DIR-FSE sequence was based on the following formula $D = \Delta - TI + TD$, with TD the trigger delay defined as the time between the R-wave and the FSE (fig.2). By tuning TD, this formula allows to position the FSE in any cardiac phase. The main problem and difference between the two methods were then how Δ and TD were computed to acquired images in end-systolic rest.

Fixed Delay Method (FDM): For the FDM (fig.2-a), the DIR-FSE sequence was simply started after a fixed delay D defined as: $D = \bar{\Delta} - TI + B - A\bar{\Delta}^{-1} - T_{FSE}$, with $\bar{\Delta}$ the average RR interval (over 9 RR intervals before the acquisition), A and B the cardiac cycle model parameters, TI the inversion time, and T_{FSE} the time needed to perform the echo train acquisition. T_{FSE} is required since the systolic duration in the cardiac cycle model includes the end-systolic rest. Moreover, the whole FSE sequence have to be in the end-systolic rest period.

Adaptive Method (AM): The principle of the AM (fig.2-b) is similar to the FDM, except that the delay was made fully adaptive. The two next RR intervals ($\hat{\Delta}_{n+1}$ and $\hat{\Delta}_{n+2}$) were predicted using Kalman filtering, as previously reported [5,6]. Then, the delay is adapted for each new detected cardiac cycle as $\hat{D}_{n+1} = \hat{\Delta}_{n+1} - TI + B - A\hat{\Delta}_{n+2}^{-1} - T_{FSE}$. This method allowed an optimal acquisition positioning with respect to the end-systolic rest.

Protocol: Fourteen healthy volunteers underwent a cardiac MR examination on a clinical scanner (1.5T Signa HDx, General Electric, Milwaukee, WI) to evaluate and compare the different methods. This study was approved by local ethics committee and written consent was obtained for all volunteers. In order to see both left and right ventricles (LV and RV), every acquisition was performed in the same mid-ventricular short axis view. First, a cardiac gated cine sequence was acquired (bSSFP, TR=3.9ms, TE=1.7ms, FOV=36x36cm). Then, the conventional [1] and the AM methods were acquired with TE ranging from 10 to 70 ms to get both T1 and T2 weighted images (TI=500ms BW=125kHz, ETL=16, slice thickness=6mm, matrix size=256x256). For the FDM, from one to seven images, within the same TE range, were acquired to keep total scan duration at an acceptable length for the volunteers. The AM and FDM were supposed to provide images in end-systolic rest whereas the conventional method [1] was supposed to provide images in mid-diastolic rest.

Evaluation: A quantitative measure and a qualitative measure were used to assess the reliability of the AM and FDM. The quantitative measure consisted in the comparison of the error made on the trigger delay (TD on fig.2) with respect to the beginning of the end-systolic rest by the AM and the FDM. The qualitative measure consisted in an image quality comparison performed by a radiologist with 8 years of experience in cardiac MRI. First, the radiologist was asked to determine if images acquired with the AM and FDM were effectively in end-systolic rest based on the cine sequence. Then, an image comparison was performed by pairs between AM and FDM to determine in which images the heart was better depicted. Finally, images in end-systolic rest and in mid-diastolic rest were compared to determine if images acquired during end-systolic rest allowed a better depiction of the RV.

RESULTS: Data from a volunteer were rejected from the evaluation due to a poor ECG quality. The overall mean absolute error was 27 ± 39 ms for the AM and 75 ± 98 ms for the FDM. 100% of images acquired with the AM were effectively in end-systolic rest against 70.6% for the FDM. Image quality comparison results are given on fig.3 and 4. The AM was shown to be better at depicting the RV and LV than the FDM (fig.3) and end-systolic rest imaging improved the depiction of the RV wall (fig.4). Note how the right ventricle wall and trabeculae are well depicted in end-systolic rest with the AM (fig.5-c) compared to conventional method (fig.5-e) and the FDM (fig.5-b) where the RV and trabeculae are blurry.

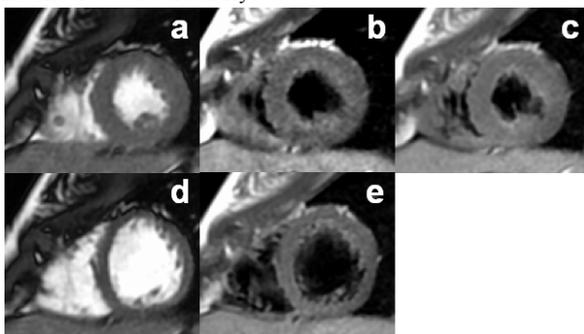


Fig.5: End-systolic (a) and mid-diastolic (d) images from the cine sequence. FDM (b) AM (c) and conventional DIR-FSE (e). (TE=30ms).

DISCUSSION AND CONCLUSION: These results demonstrate the need of taking RR interval variation into account for end-systolic rest DIR-FSE, as achieved by the AM. The robustness of this approach was demonstrated compared to the FDM. The limitation of performing DIR-FSE in the end-systolic rest period is that the preparation is performed in mid-diastolic rest whereas acquisition is performed during the end-systolic rest. Consequently, this may lead to signal loss. The AM could still be improved using a slice tracking method such as [7]. End-systolic rest imaging could provide additional information to those given by conventional DIR-FSE by depicting RV wall abnormalities. This could be useful for pathologies such as arrhythmogenic right ventricular cardiomyopathy. A large patient study has to be conducted to demonstrate the clinical interest of acquisition in end-systolic rest.

REFERENCES: [1] Simonetti *et al.*, Radiology 1996;199:49-57. [2] Fleckenstein *et al.* Radiology 1991;179:499-504. [3] Kellman *et al.*, MRM 2007;57:891-897. [4] Weissler *et al.*, Circulation 1968;37:149-159. [5] Fernandez *et al.*, ISMRM, 2009;4719. [6] Oster *et al.*, ICASSP 2008;513-516. [7] Keegan *et al.*, JMRI 24 563-570 (2006).

$$T^s = B - A\Delta^{-1}$$

	A	B
Male	0.0021*60	0.546
Female	0.0020*60	0.549

Fig.1: Definition of the cardiac cycle model [4].

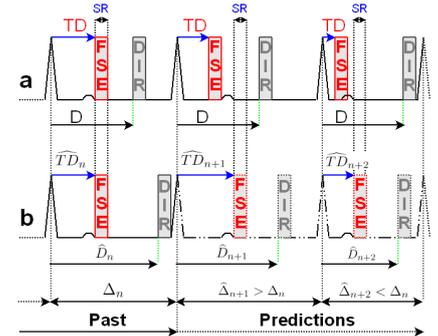


Fig.2: DIR-FSE pulse sequence in presence of RR interval variations for the FDM (a) and the AM (b). In each cardiac cycle the end-systolic rest is denoted by SR. TI is the same for both methods and was omitted for the sake clarity, TI is the time between the DIR and the FSE sequence.

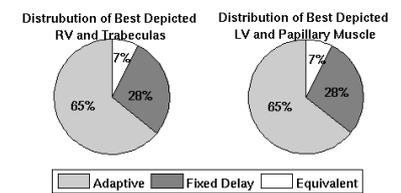


Fig.3: Distribution of methods for which the RV and LV are best depicted.

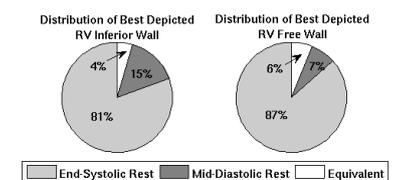


Fig.4: Distribution of rest periods for which the RV inferior wall (left) and free wall (right) are best depicted.