Flexible Time-Resolved Golden Angle Dual-Inversion Recovery Acquisition to Facilitate Sequence Timing in High-Resolution Coronary Vessel Wall MRI at 3T

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TARGET AUDIENCE: Scientists and clinicians interested in vessel wall coronary MRA.

INTRODUCTION: Positive vessel wall remodeling is an early marker of coronary artery disease and has been associated with plaque rupture and plaque vulnerability [1]. Early detection of this outward remodeling could improve prognosis of early and late adverse cardiovascular events. Black blood (BB) magnetic resonance imaging (MRI) is a non-invasive technique for the visualization of the vessel wall and has shown promising results in detecting positive remodeling of the coronary artery [2]. However, technical shortcomings still limit its use in a clinical setting. Subject's heart rate variability, as well as the need to collect the data during both the period of minimal cardiac motion and the optimal blood nulling time [3], are among the main challenges. In order to address these hurdles, an innovative time-resolved acquisition technique has recently been proposed [4], which enables retrospective selection of the optimal frame, which better addresses the compromise between minimal cardiac motion and optimal blood signal suppression. However, in the original time-resolved technique, the number of acquired frames, as well as their duration, has to be defined prior to the scan. As a result, the best compromise in terms of minimal motion and optimal blood nulling may not easily be reached. In order to further improve flexibility in sequence timing, we propose a continuous acquisition scheme throughout a long acquisition window after dual inversion recovery (DIR). Combined with a golden angle radial acquisition and k-t sparse SENSE, the proposed framework enables a fully flexible a posteriori selection of frame duration, frame number, as well as position of these frames in the cardiac cycle.

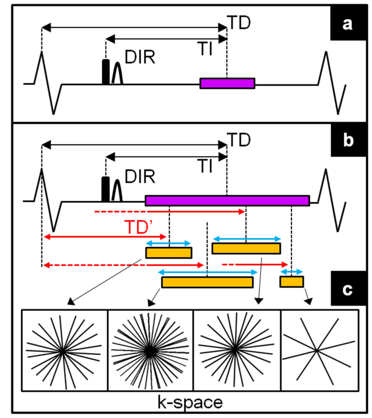

Fig.1: After conventional single-frame DIR acquisition (a), the acquisition window (purple box in a,b) is prolonged by a factor of 3 (b). The long-window acquisition is divided into multiple frames (orange boxes in b) during post-processing. Because of the golden angle trajectory, the frame position (TD', red arrows) and duration (blue arrows) within the acquisition window can be freely selected. Due to the high undersampling in shorter frames (c), image reconstruction was performed with k-t sparse SENSE.

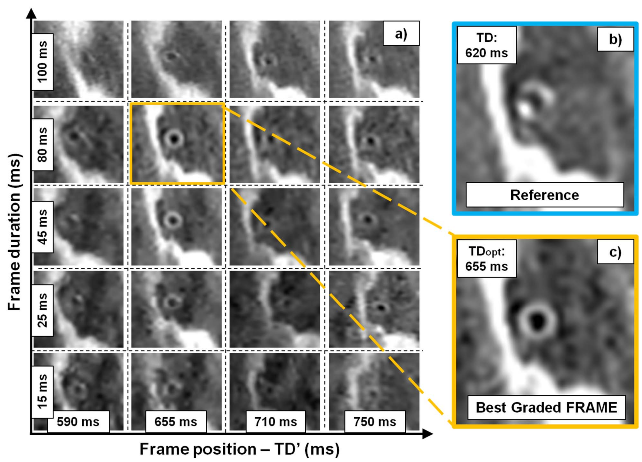

Fig. 2: Multiple frame reconstruction in one volunteer. For each dataset, multiple frames were created by freely choosing their position and duration (a). Images were then graded and that with the highest grade (frame (c)) was quantitatively compared to the reference (b). A clear improvement in vessel wall delineation between b and c is apparent. TD of the standard acquisition is compared with TD_{opt} of the best graded frame.

METHODS: Data from 11 healthy volunteers were acquired on a 3T MR scanner (MAGNETOM Prisma, Siemens AG, Healthcare Sector, Erlangen, Germany). First, a scout scan was performed to localize the imaging plane perpendicular to the proximal segment of the right coronary artery (RCA). The BB images were then acquired with both a conventional 2D radial DIR sequence and a modified version that exploits a golden angle radial trajectory. The relevant MR parameters for these sequences include: radio frequency (RF) excitation angle 16°, FOV $(260mm)^2$, TE 3.2ms, TR 6.5ms, slice thickness 8mm, spatial resolution $(0.6mm)^2$. A heart-rate dependent inversion delay (TI) was prescribed by the user for optimal blood signal nulling [3] while the trigger delay (TD) was selected to center the acquisition window at the time point of minimal myocardial motion (Fig.1a,b) as visually determined on a cine scan. First, the conventional 2D radial DIR acquisition was performed as a reference standard using an acquisition window of 50-110ms (Fig.1a). Next, the time-resolved 2D golden angle DIR radial acquisition was performed using a 300% prolonged acquisition window (250-450ms). The long acquisition window was then sub-divided into multiple frames during post-processing (Fig.1b). Because of the golden angle trajectory, the frame position (TD'), duration and overlap among frames could be selected retrospectively without any restriction. To minimize aliasing artifacts associated with shorter frame duration (Fig.1c), images were reconstructed using a k-t sparse SENSE approach [5]. For each dataset, between 50 and 70 BB frames were reconstructed with different durations and TD' (Fig.2a). As a first step during image analysis, the reconstructed frames were visually inspected for vessel wall conspicuity and vessel wall to lumen contrast. The frame with the best image quality was then selected for quantitative analysis and comparison with the reference standard. The following quantitative end-points were evaluated as described in [6]: percentage vessel wall sharpness (%VWS), extent of vessel wall circumference (VWC), and vessel wall thickness (VWT). Further, TD' of the best frame (TD_{opt}) was compared with the original TD (Fig.2b,c).

RESULTS: Data acquisition and reconstruction were successfully performed in all subjects. While the coronary vessel wall was not necessarily visible in every reconstructed cine frame (Fig. 2a), it was either partially or completely visible, with high contrast, in 11/11 of the highest graded frames (100% success rate), and in 10/11 of the reference images (91% success rate). Table 1 summarizes all the quantitative results. Percent VWS and VWC significantly (both $p<0.03$) and substantially improved in the best graded frame in comparison with the reference image (Fig.2b,c). TD_{opt} was consistently higher than TD (Fig.2b,c) which was statistically significant ($p<0.05$), whereas the measured VWT remained unchanged among the two acquisition (p=NS).

	BEST GRADED FRAME	REFERENCE	P VALUE
Centre (ms)	TD_{opt}= 697.1 ± 88.9	TD = 676.4 ± 89.4	p<0.05
% VWS	43.0 ± 7.8	23.5 ± 9.5	p<0.002
VWC (mm)	7.1 ± 2.1	4.8 ± 2.8	p<0.03
VWT (mm)	0.91 ± 0.15	0.89 ± 0.27	p=NS

Table 1: Quantitative results.

DISCUSSION AND CONCLUSION: We successfully implemented a flexible technique to reconstruct multi-frame coronary vessel wall images. A major advantage of our approach includes that the frame duration and frame position within the acquisition window can be freely and retrospectively selected, thus enabling optimal selection of blood suppression time and period of minimal cardiac motion. Such multi-frame reconstruction was enabled at no extra cost in scanning time when compared to a conventional DIR acquisition. Although the reference acquisition already provided a high success rate in visualizing the vessel wall (91%) as a result of a carefully planned imaging timing prior to the acquisition, this was further improved with our proposed technique to 100%. In addition, the above-described framework also substantially improved vessel wall conspicuity in terms of %VWS and VWC, while preserving VWT. Gradually varying vessel wall conspicuity observed in the multi-frame reconstruction suggests that significant cardiac motion may occur during the acquisition, which highly compromises the visualization of the vessel wall. Vessel wall conspicuity may also be compromised when the blood signal is insufficiently suppressed. Even if TD was carefully selected by taking into consideration both the optimal subject-dependent TI and the period of minimal cardiac motion, it was found to be significantly different from the TD_{opt}, which provided the best image quality with our framework. This result suggests that it can be challenging to accurately and optimally define the timing for a conventional 2D BB acquisition in order to obtain an adequate vessel wall depiction. Our proposed technique alleviates these difficulties and, moreover, it makes the DIR acquisitions less user dependent, since optimal image timing can retrospectively be evaluated. In conclusion, with the above-described approach, the need for coronary vessel wall data acquisition using subject-specific sequence timing no longer exists and we speculate that this may increase the overall success rate of coronary vessel wall MR imaging in patients.

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