Flexible phase-encoding in 3D coronary MRA with balanced SSFP

E. T. Tan[1], L. Marinelli[1], T. K. Foo[1], and C. J. Hardy[1]
[1]GE Global Research, Niskayuna, NY, United States

Introduction: Breath-held, cardiac-gated 3D coronary MR angiography (CMRA) is challenging in part because cardiac quiescent periods and breath-hold abilities vary among patients. Standard linear phase-encoding provides linear modulation in cardiac phase, but is restrictive in two ways. Firstly, the number of triggered heartbeats (HB) is limited to integer multiples of the number of slice-encodes (SE). Secondly, the acquisition window (τ) is determined by the number of phase-encodes (PE). Hence, linear PE does not allow HB-τ to be optimized for a specific patient. Here we apply recent PE/SE schemes [1-3] to CMRA and introduce a novel variation to improve flexibility while reducing eddy-current artifacts.

Methods and Materials: A flexible-linear PE scheme [1] removes the restrictions imposed by the PE/SE dimensions, while providing linear modulation. With flex-linear PE, a continuum of HB-τ combinations can be obtained (Fig. 1), allowing HB-τ to be optimized for the patient's quiescent period and breath-hold ability. In addition, a 25-30% reduction in acquisitions can be achieved by removing the corners of k-space from sampling [2]. Flex-linear may however be prone to eddy-current artifacts that result from large k-space 'steps' in balanced SSFP imaging [3]. A novel modification to the flex-linear scheme is introduced that divides the sampling matrix into groups in the PE dimension prior to sorting in the SE dimension, resulting in 'compact flex-linear' encoding (Fig. 2b). This reduces k-space steps, particularly in thin-slab imaging that has a large dimension in the PE direction relative to the SE direction.

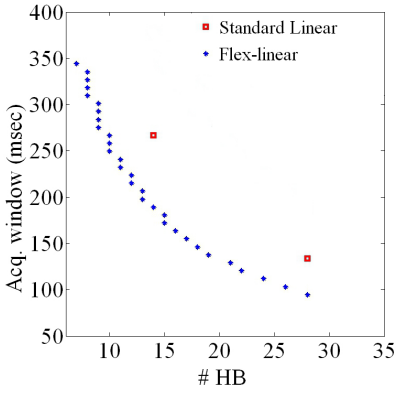

Fig. 1. Acquisition window (τ) vs. number of HB for the tested PE schemes. With linear PE, only two HB-τ permutations are possible. Flex-linear allows for HB and τ to be flexibly optimized.

Four normal subjects (HR = 55-75 beats/min) were imaged at 1.5T (GE Excite) with a 32-channel phased array [4] for targeted oblique slab acquisition of the right coronary artery (RCA) (bSSFP, 256x224x14 matrix, FOV = 29 cm, slice = 2 mm, flip angle = 65°, TR/TE = 4.4/2.1 msec, ASSET R = 2). Linear PE (HB = 14, τ = 270 msec) was compared against compact flex-linear with either the same breath-hold duration (HB = 14, τ = 190 msec) or the same acquisition window (HB = 9, τ = 270 msec).

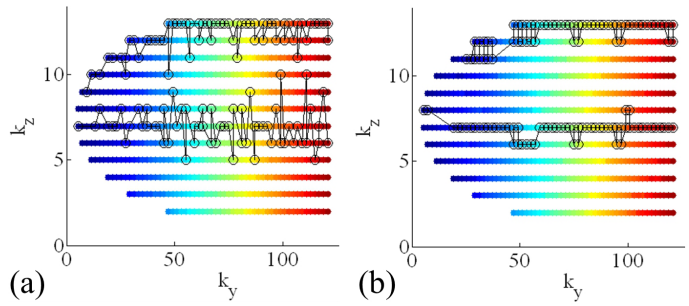

Fig. 2. Flexible PE schemes with partial Fourier acquisition in the PE (k_Y) dimension and k-space corners removed from sampling, colorized from red to blue to reflect the sequence of acquisition. Plots of the first and last acquisition trains are shown, reflecting centric ordering in the SE (k_Z) dimension. Flex-linear (a) has large 'steps' in k-space, whereas compact-flex-linear (b) has smaller steps due to grouping of the sampling matrix in the PE dimension that limit large steps when sorting in the SE dimension.

Results: All PE schemes provided good vessel conspicuity (Fig. 3). As compared to linear PE, both compact flex-linear acquisitions had a similar artifact level with either reduced acquisition window or reduced breath-hold duration.

Discussion and Conclusion: A compact and flexible PE scheme was demonstrated in breath-held 3D CMRA, providing flexibility in optimizing both HB and τ while providing 25-30% time savings. This should be useful in imaging patients with either short quiescent durations or difficulty performing long breath-holds. To further cancel eddy-current artifacts, a double-averaged [5] flexible acquisition was tested, which required doubling of scan time. Artifact improvement due to double-averaging was prominent in phantom imaging, but was less pronounced in *in vivo* breath-held CMRA. The compact flex-linear PE scheme and its double-averaged variant should both prove useful in whole-heart and respiratory-gated CMRA.

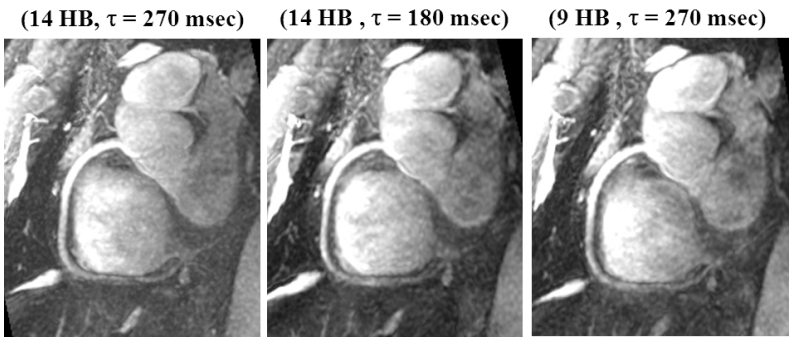

Fig. 3. Comparison of PE schemes in bSSFP CMRA of the right coronary artery. Conspicuity of the distal RCA was good in all three schemes.

References: [1] Busse RF et al. Magn Reson Med 2008;60:640-649. [2] Bernstein MA et al. J Magn Reson Imaging 2001;14:270-280. [3] Bieri O et al. Magn Reson Med 2005;54:129-137. [4] Hardy CJ et al. Magn Reson Med 2006;55:1142-1149. [5] Markl M et al. Magn Reson Med 2005;54:965-974.