Combined free breathing, whole heart self-navigation and "pencil-beam" 2D-T_2-Prep for coronary MRA

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Introduction: Self-navigation (SN) techniques[1,2] may be used to perform respiratory motion correction in whole-heart coronary MRA, improving scan efficiency and ease of use when compared to traditional navigator-gated approaches[3]. In one SN implementation, the 1D superior-inferior (SI) projection of a 3D radial trajectory is used to track the blood pool, correcting displacement to an initial respiratory position[4]. In such cases, however, signal from the chest wall complicates motion detection and correction. Even when motion correction is successful, streaking artefacts secondary to both radial undersampling and displacement correction may be introduced from the hyperintense chest wall signal, adversely affecting image quality. Suppressing signal from unwanted tissues may thus improve image quality.

Note that SN MRA is often paired with T_2 preparation[5], or T_2-Prep, to improve blood/myocardium contrast. Meanwhile, 2D spatially selective radiofrequency (RF) pulses[6,7] are sometimes used to constrain the location from which an MR signal is obtained. By incorporating a "pencil beam" 2D pulse into a T_2-Prep module, one may create a "2D-T_2-Prep" that combines T_2-weighting with the intrinsic spatial selectivity of a 2D pulse[8]. In this study, we test the hypothesis that SN will benefit from the introduction of a 2D-T_2-Prep and present initial *in vivo* results demonstrating that image quality in free-breathing, SN whole-heart MRA improves with a 2D-T_2-Prep.

Methods: The first RF pulse of an adiabatic T_2-Prep[9] was replaced with a jinc pulse and spiral gradients (Fig. 1). This excites a cylindrical volume[10] (Fig. 2). Meanwhile, the final RF pulse remains non-selective. It thus restores the cylinder of T_2-prepared magnetization, while rotating outer magnetization into the transverse plane, where it is then spoiled[8]. This "2D-T_2-Prep", and its conventional counterpart, were used prior to the whole-heart SN protocol described below.

For image acquisitions, free-breathing, self-navigated, ECG-triggered coronary MRA was performed in healthy volunteers (n=5), using a prototype interleaved 3D radial trajectory[11] specifically adapted to SN via the collection of an SI readout at the start of each data interleave[2]. All images were collected on a 1.5 T clinical scanner (MAGNETOM Aera, Siemens Healthcare), with a bSSFP readout, 18 channel chest coil and 12 channel spine coil, $(1.15\ \mathrm{mm})^3$ isotropic voxels, FoV $(220\ \mathrm{mm})^3$, matrix size 192^3, TE T_2-Prep 40ms, RF excitation angle 110°, 16 readouts/heartbeat, and TE/TR/Tacq=1.82/3.63/58 ms.

For self-navigation, the respiratory position of the heart was identified for each interleave by tracking the blood pool with an SI projection using a subset of coils closest to the heart. Its position was then corrected by introducing a phase shift directly into k-space[1] for each radial projection, after which the images were reconstructed.

Afterwards, an ROI was selected in each of 3 tissues: blood, myocardium, and lung. For both T_2-Preparation techniques (2D/conventional), the SNR and CNR of each tissue were calculated using the formulae[12] $SNR_{tissue}=S_{tissue}/\sigma_{lung}$ and $CNR=|S_{tissue1}-S_{tissue2}|/\sigma_{lung}$. Vessel sharpness was next measured in the right coronary artery (RCA) with Soapbubble[13] for both T_2-Prep techniques. A paired two-tailed student's t-test was then used to compare results from the conventional T_2-Prep+SN and the 2D-T_2-Prep+SN, with $p<0.05$ considered statistically significant.

Results: As can be seen in Fig. 3 (left), the 2D-T_2-Prep maintains high signal in the region of the 2D selective pulse, whereas exterior signal, in parts of the anterior chest and lungs, is clearly attenuated. In the both the coronal (Fig. 2) and axial (Fig. 3) slices, a high T_2 contrast can be seen between the blood pool and myocardium for both the conventional T_2-Prep and the 2D-T_2-Prep. As a result, both the left and right coronary arterial system can be seen and analyzed. Consistent with these observations, and as reported in Table 1, a high blood-myocardium CNR was measured for both approaches, though the CNR of the 2D-T_2-Prep was significantly higher. Similar findings can be reported for blood-lung CNR and myocardium-lung CNR (all $p<0.05$). As compared to the conventional T_2-Prep, the 2D-T_2-Prep also significantly improved SNR of the blood pool ($p<0.05$). Importantly, vessel sharpness in the RCA also increased both substantially (almost 30%) and significantly ($p<0.05$) when using the 2D-T_2-Prep.

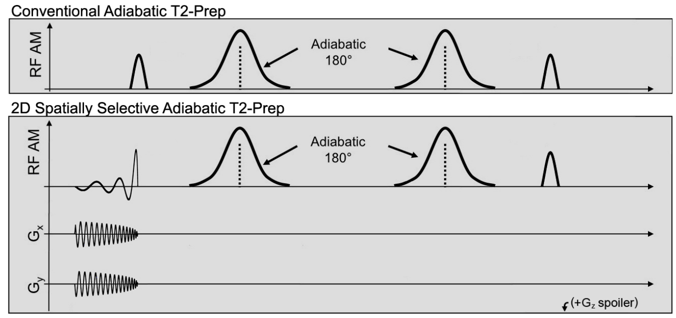

***Figure 1**: Pulse sequence diagrams for the conventional and the 2D-T_2-Prep.*

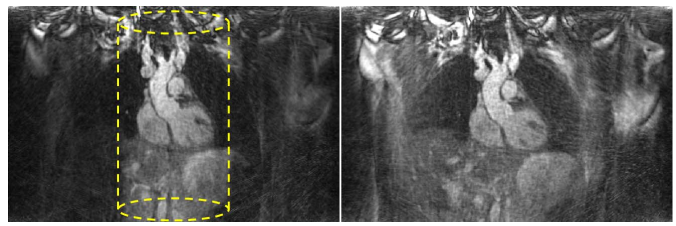

***Figure 2**: Sample slice comparing the 2D-T_2-Prep (left) and its conventional counterpart (right). The area targeted by the 2D-T_2-Prep "pencil-beam" is outlined in yellow. Note the increased background suppression for the 2D-T_2-Prep and the corresponding reduction in streaking artefacts.*

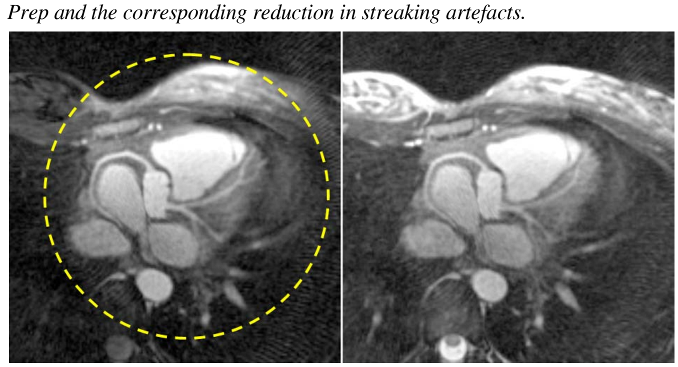

***Figure 3**: Coronary arteries after image reformatting for both T_2-Prep techniques. The area targeted by the 2D-T_2-Prep "pencil-beam" is outlined in yellow. Note the decreased background signal in the 2D-T_2-Prep (left) compared to the conventional T_2-Prep (right), as well as increased conspicuity of the distal left coronary system for the 2D-T_2-Prep image.*

Table 1	**T_2-Prep Technique**		
Measurement	Conventional	2D-T2-Prep	
Blood SNR	15.1 ± 1.5	20.8 ± 2.5	*
Myocardium SNR	6.5 ± 1.0	7.9 ± 1.2	
Blood-Myocardium CNR	8.7 ± 1.3	12.9 ± 1.4	*
Blood-Lung CNR	11.4 ± 1.2	17.7 ± 1.6	*
Myocardium-Lung SNR	2.8 ± 0.8	4.7 ± 1.3	*
RCA Vessel Sharpness %	30.5 ± 10.9	39.6 ± 13.0	*

**Indicates a statistically significant ($p<0.05$) difference between the conventional T2-Prep and 2D-T2-Prep.*

Discussion: This study demonstrates the first combination of SN with 2D-T_2-Prep. As compared to a conventional T_2-Prep, the 2D-T_2-Prep significantly improved SNR in the blood pool, CNR between all measured tissues, and vessel sharpness % in the RCA, when performing self-navigated coronary MRA. We hypothesize that these improvements may be due to the suppression of extraneous signal, such as from the chest wall, which would otherwise contribute to streaking artefacts and/or motion artefacts secondary to cardiac displacement correction. If these artefacts are well-suppressed, the apparent noise is reduced, thereby improving both SNR and CNR - a result consistent with the findings of our study. Although background signal suppression was effective, it remained imperfect outside of the region selected by the 2D-T_2-Prep. Based on previous investigations[8], we hypothesize that this may be related to B_1 inhomogeneity in the non-selective T_2-Prep restoration pulse (i.e. at the end of the T_2-Prep) or due to T_1 signal recovery after spoiling. In either case, improving background suppression may lead to even greater SNR and CNR improvements. The finding that the 2D-T_2-Prep also improved vessel sharpness may suggest that motion correction was more effective when using the 2D-T_2-Prep. Regardless of the cause, the overall improvements in image quality nevertheless suggest that a 2D-T_2-Prep should be considered for use in self-navigation.

References: **1.** Stehning, MRM 54:476 (2005) **2.** Piccini, MRM 68:571 (2012) **3.** Stuber, RAD 212:579 (1999) **4.** Piccini, ISMRM #1316 (2013) **5.** Brittain, MRM 33:689 (1995) **6.** Bottomley, JAP 62:4284 (1987) **7.** Pauly, JMR 81:43 (1989) **8.** Coristine, DOI: 10.1002/mrm.25442 (2014) **9.** Nezafat, MRM 61:1326 (2009) **10.** Nehrke, MRM 55:858 (1999) **11.** Piccini, MRM 66:1049 (2011) **12.** Abd-Elmoniem, MRM 68:822 (2012) **13.** Etienne, MRM 48:658 (2002)