Improved myocardial contrast using novel complementary radial MR tagging technique

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INTRODUCTION – Myocardial tagging is a proven and frequently used technique to non-invasively assess and quantify myocardial motion[(1)]. More recently, a new technique for polar tagging has been described [(2)] and subsequently extended to generate complementary radial tags (CRT) [(3)] and prolonged tag contrast similar to CSPAMM [(4)]. Due to the gross annular geometry of the left ventricle (LV) in the short axis (SA) view, CRT may have an advantage for measuring LV contraction, myocardial twist, and circumferential-radial shear strain compared to conventional line or grid SPAtial Modulation of Magnetization (SPAMM) [(5)] tags. The previous CRT method [(6)], however, required a patient table shift to achieve a high quality CRT pattern. It has been shown that table position shifts can produce an acceptable tag pattern in 92-98% of clinical cases [(5)], but the tag profile may still not be ideal for some SA planes, resulting in measurement inaccuracy. Our objective was to develop a new CRT technique, which generates a high quality CRT pattern in all clinical cases without the need for a table position shift by adapting the principles RF phase shifts [(2)].

THEORY – A requirement for generating CRT images is the acquisition of two sets of tagged images with shifted tag patterns. Previous CRT methods used a single RF waveform and two phase shifted gradient waveforms, but required a table position shift. The new CRT sequence uses two different sinusoidal RF pulses, but the same gradients (Fig. 1) to generate the two radial tag patterns without the need for a table position shift. The longitudinal magnetization I_{total} after the tag preparation pulse can be expressed as the sum of the image (I_{image}) and the tag (I_{tag}) information (Eqn. 1). The two RF pulses have the same magnitude with a phase difference ($\theta = \frac{\pi}{2}$), which generates two sets of tag patterns with approximately opposite signs (Eqn. 2). Since the image information for the two sets of images are the same, I_{tag} is preserved and enhanced after subtraction (Eqn. 3).

$$I_{total}(r,\theta) = I_{image}(r,\theta) + I_{tag}(r,\theta) \quad \text{Eqn. 1}$$

$$I_{tag1}(r,\theta) = I_{tag2}\left(r,\theta+\frac{\pi}{2}\right) \approx -I_{tag1}(r,\theta) \quad \text{Eqn. 2}$$

$$I_{total1}(r,\theta) - I_{total2}(r,\theta) \approx 2I_{tag1}(r,\theta) \quad \text{Eqn. 3}$$

$$\varphi_i = \left|\vec{G}_i\right| \cdot \gamma \cdot \Delta L \cdot cos\frac{\pi \cdot i}{N} \quad \text{Eqn. 4}$$

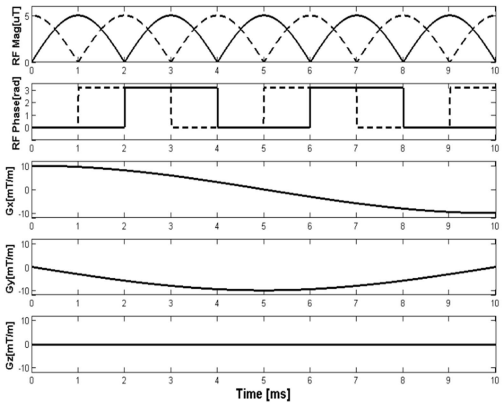

Figure 1. CRT pulse sequence diagram. Two RF pulses (solid and dashed lines) generate the two sets of radial tagged images with a phase difference.

Therein, r and θ are the radius and angle in polar coordinates. The gradients define an on-resonance plane that rotates about an axis that originates from the B_0 isocenter and intersects the imaging plane at the tag center (C_{tag}), which may not be at the center of the LV cavity (C_{LV}). By continuously adding an extra phase (φ, Eqn. 4) to the RF pulse, we shift C_{tag} to be coincident with C_{LV}. $\left|\vec{G}_i\right|$ is the magnitude of the gradient vector, γ is the gyromagnetic ratio, ΔL is the distance from the original C_{tag} to C_{LV}, N is the total number of sample points for the RF pulse and i is the index for each sampled RF pulse point.

METHOD – A cardiac gated and segmented cine SPGR sequence was modified to generate CRT patterns on the basal LV SA planes in healthy human subjects with the following parameters: 350x350mm FOV, 6mm slice thickness, TE/TR=4.52/5.25ms, variable Flip Angle (FA) with 20° FA for the last imaging pulse, 160x160 acquisition matrix, 250 Hz/pixel bandwidth and with GRAPPA-2 on a 1.5T scanner (Avanto, Siemens, Erlangen, Germany). The acquisition duration was adjusted to acquire images through mid-diastole (~850ms). CRT patterns using table position shifts, RF phase shifts, and no shift were compared.

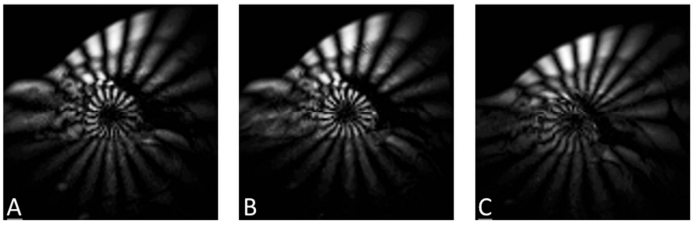

Figure 2. In vivo CRT images. A) is acquired with table shift method. B) is acquired with RF phase shift method. C) is acquired without using either method. Note the C_{tag} is off the C_{LV}

RESULTS – Fig. 2A was acquired using a single RF pulse envelope, two different gradients, and a table shift (original method) while Fig. 2B was acquired using different RF pulses with RF phase shifts, but the same gradients (current method). Fig. 2C demonstrates the CRT pattern without using the table shift nor the RF phase shift method; C_{tag} does not coincide with C_{LV} and the CRT pattern is poor.

DISCUSSION – In this study we demonstrate a new method to generate the CRT pattern without the need for table position shifts. This approach should make it possible to generate excellent CRT patterns in all clinical subjects without the need for table position shifts and the concomitant requirement to image at a distance from isocenter and closer to regions of non-linear gradient behavior. The CRT pattern should always be nearly ideal and therefore improve measurement of LV twist and circumferential-radial strain throughout the cardiac cycle.

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