Radial Tagging of MR images: a continuous RF excitation approach

A. N. Moghaddam[1,2], Y. Natsuaki[3], and J. Finn[1]
[1]Radiology, UCLA, Los Angeles, CA, United States, [2]Caltech, Pasadena, CA, United States, [3]Siemens Medical Solutions, Los Angeles, CA, United States

Introduction: Spatial modulation of magnetization, applied to tag the image object in MRI, is a well established method for non-invasive measurement of deformation and strain. In principle, many different tagging patterns can be generated through combinations of RF excitation and gradient pulses[1]. The usefulness of the patterns as well as the stability and efficiency of the sequences, however, limits these choices in practice. The conventional tagging sequence is based on short alternating RF and gradient pulses that generate a pattern of parallel lines in one or two directions[2]. Another pattern of interest is radial tagging that facilitates the measurement of angular information reflected in shear and twist of the left ventricle[3]. This radial modulation of longitudinal magnetization has not been widely used due to lack of an efficient preparation sequence to generate the pattern robustly. In this work we introduce a continuous RF approach that acts on a rotating excitation plane. Its theoretical basis and practical details as well as initial results in phantoms and human hearts are presented.

Methods:

a) Theory: A rotating excitation plane with an alternating RF pulse (figure 1(a) and following formula) generates a radial pattern for longitudinal magnetization:

$$B_1(t) = B_1 \sin(2\pi f_c t) \cdot \sin\left(\pi t N / T_g \right)$$

$$G_x = G_0 \sin\left(\pi t / T_g \right)$$

$$G_y = G_0 \cos\left(\pi t / T_g \right)$$

where parameters defined in figure 1(a). A spoiler gradient destroys the net transverse magnetization prior to the imaging module of the sequence. The combination of the changing gradient magnetic field and the RF pulse results in an off-resonance type of excitation around a moving effective magnetic field in the rotating frame (figure 1(b)). The magnetization for the central part of the rotational excitation slab completely remains in the longitudinal direction when the RF pulse envelope crosses zero. Each zero-crossing of the RF pulse therefore results in a bright radial line in the final image. The number of these zero-crossings determines the number and density of the radial tags.

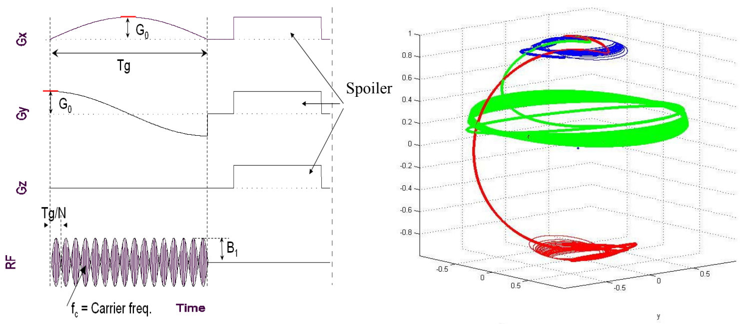

Figure 1. (a) Schematic of a pulse sequence to be used with this method. (b) simulated path of the magnetization tip for three precessing spins and three different locations.

(b) Implementation: The preparation sequence is followed by a spoiled gradient echo (GRE) cine readout module. The actual implementation and programming of this cine sequence was performed on a commercial imaging platform (Siemens Medical Solutions, Erlangen, Germany) by using developmental software (Integrated Development Environment for Applications [IDEA], VB15A*;* Siemens Medical Solutions) and WIP: a_CV_proto for the Cine sequence source codes.

Results: The developed sequence was tested on phantoms as well as healthy volunteers. Figure 2 shows one image of a double oblique plane of a stationary phantom followed by diastolic and systolic phases of a short axis imaging series from a volunteer. Each image has 15 radial taglines in the half circle. Images acquired by a 1.5T scanner. Other MR parameters are as follows: 250mm FOV, 5mm slice thickness, 250Hz/pixel, 15° flip angle, TE/TR = 4.6/86ms, 128x128 matrix size.

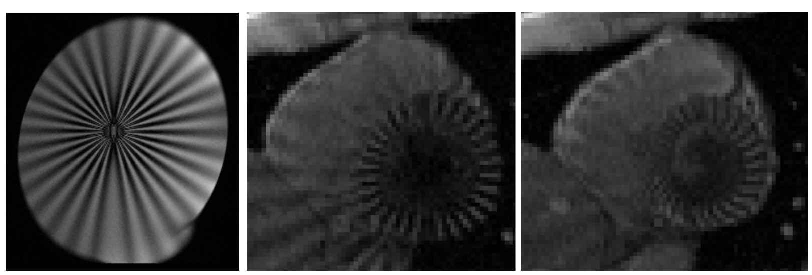
Figure 2. (Left) image of a stationary uniform phantom in a double oblique imaging plane. (Middle and Right) radially tagged images of the short axis view of a healthy volunteer at diastole and systole. The tortional motion of the left ventricle is well pronounced at the posterior wall of the myocardium.

Comparison of the taglines at diastole and systole demonstrates that the transmural differences in rotational motion and circumferential strain of the ventricle can be obtained from this technique.

Conclusion: A new tagging sequence was theoretically described and actually implemented. The sequence has been successfully tested on phantom and also used to acquire short axis images of the left ventricle. The spatial resolution and density of taglines are considerably higher compared to previous schemes of the radial tagging and allows for relatively simple derivation of myocardial shear rate and angular strain.

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