Optimization of the radial tagging profile and validation using the Cardiac Atlas Project database

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Introduction - In both research and clinical settings myocardial tagging is a proven and frequently used technique to non-invasively assess and quantify myocardial deformation. We have previously shown that due to the gross annular geometry of left ventricle (LV) a new pulse sequence that uses time-varying RF pulses and gradients to generate radial tags [1] [2], may have an advantage for the measurement of LV contraction and myocardial twist compared to conventional line or grid SPAtial Modulation of Magnetization (SPAMM) [3] tags. The radial tagging pulse sequence, in general, requires shifting the patient table away from iso-center of the magnetic field to generate a tagging profile that is both sharp and centered at the middle of the LV cavity. Currently, it is unknown whether the range of short-axis slice positions and orientations that are encountered in clinical practice can be used to acquire acceptable radial tagging patterns. In this study we retrospectively analyze the short-axis slice position and orientation information from a large number of patients in the Cardiac Atlas Project (CAP) database [4], from which we can calculate the optimal table position shift for each patient. The ***objective*** of this study was to define the percent of patients that can be acceptably imaged with the radial tagging sequence as a function of table position shift (ΔH).

Theory – The radial tagging sequence uses a sinusoidal-shaped gradient to select a rotating on-resonance plane. The axis of rotation is the gradient's vector direction (**g**), which passes through the iso-center of the main magnetic field and the center of the tagging pattern on the image plane (C_{axis}). The short-axis imaging plane of interest is defined by an image normal (**n**) and the center of the field-of-view (C_{FOV}). By definition **n** need not pass through isocenter, but the ideal radial tagging pattern is obtained when **g** is parallel to **n**. Therefore, we sought to define an objective function (Eqn. 1) that describes the angle (θ) between **g** and **n**, which when minimized results in the optimal ΔH (Eqn. 2) that produces the ideal tagging profile. The vectors **g** and **n** are related by Eqn. 3, which relies on a rotation expressed in Eqn. 4. Experimentally θ can be minimized by a table position shift (ΔH) of the subject relative to isocenter. Furthermore, the FOV is adjusted to ensure that the center of the LV (C_{LV}) is at the C_{FOV}. In general, we seek to define the ΔH that provides minimizes θ (**g** and **n** are nearly parallel) and $C_{axis} = C_{FOV} = C_{LV}$. Under these conditions the ideal tagging pattern is obtained.

Methods – To demonstrate the range of radial tagging image quality the radial tagging sequence was used to acquire images in the short axis plane in a healthy human subject over a range of ΔH with the following parameters: 300x300 mm FOV, 5mm slice thickness, TE/TR=4.52/5.25ms, 25° flip angle, 128x128 acquisition matrix, 300 bandwith,8 k_y lines per segment and ¾ partial Fourier imaging. The pulse sequence was modified to support automatic table position (ΔH) updates based on Eqn. 2. In the second part of the study, ΔH was retrospectively measured in 154 short-axis slice orientations and positions from 75 patients in the Cardiac Atlas Project (CAP) database. C_{LV} was identified manually and information in the DICOM header file was used to define the slice's position and orientation information for basal, mid-ventricular and apical slices. This information was sufficient to calculate L, P, and the components of M_{rot}. Finally, the optimal table position shift (ΔH) was calculated using Eqn. 2

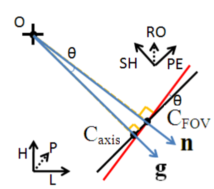


Figure1. The patient left, posterior and head directions (L, P, H) are the three axes used to present the C_{FOV} position relative to iso-center of the main magnetic field when the patient is positioned in the scanner head-first and supine. Phase Encoding, Read Out and Shift (PE, RO, SH) are three axes that represent the C_{FOV} position in imaging plane. The black plane is the imaging plane with the normal **n** and the red plane is the tagging plane with the normal **g**.

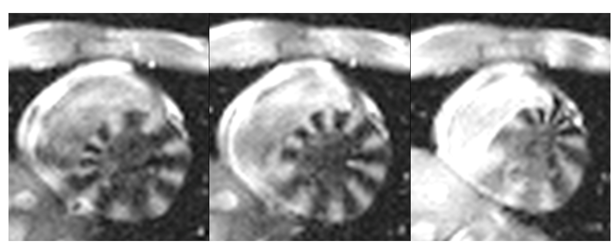
$$\cos\theta = \frac{g \cdot n}{\|g\|_2 \cdot \|n\|_2} \quad \text{Eqn. 1}$$

$$\Delta H = argmin < \theta > = \frac{a_{33}(L^2+P^2)}{a_{13}\cdot L + a_{13}\cdot P} \quad \text{Eqn. 2}$$

$$g = M_{rot} \cdot n \quad \text{Eqn. 3}$$

$$M_{rot} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad \text{Eqn. 4}$$

Results - *In vivo* results are shown in Figure 2. Five half-sinusoid RF pulses were used to generate a total of 10 radial tags. The automatic table position shift produces the best radial tag profile, which was ΔH=30mm for this subject (Fig. 2B). The radial tagging pattern at isocenter (ΔH=0mm, Fig. 2A) is compromised because θ is not minimized. Far from isocenter (ΔH=150mm, Fig. 2C) also results in qualitatively worse radial tagging patterns as a consequence of non-optimal θ, gradient non-linearity, and field inhomogeneity. Figure 3 shows the optimal ΔH and minimum θ in a 2D-histogram for 154 short-axis imaging planes extracted from 75 patients in CAP. The histogram shows that 91% of short-axis slices can be can be imaged with a high quality radial tagging profile when using ΔH<60mm and θ<30°(within the white rectangle boundary in Fig. 3). Qualitative evaluation has shown that ΔH<60mm and θ<30° produces a high quality radial tagging profile. 97% of short-axis slices can be imaged with an acceptable radial tagging profile when ΔH<70mm and θ<40°.



A (ΔH=0mm) B (ΔH=30mm) C (ΔH=150mm)

Figure 2

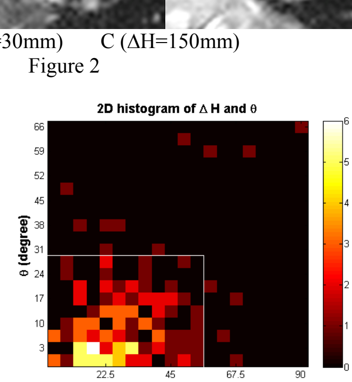


Figure 3

Discussion and Conclusion – A method for optimally determining the table position shift for radial tagging has been described and implemented. In practice due to the hardware limits of gradient linearity, it is not ideal to move the table more than about ±70mm away from the isocenter. By using images from CAP database a large number of patient table position shifts (ΔH) and θ were calculated retrospectively. Using histogram analysis of the optimal ΔH and minimal θ we demonstrated that >90% of patients can be imaged with an acceptable radial tagging profile.

References 1. Moghaddam AN JCMR 2008, 10(Suppl 1):A199. 2. Wang Z ISMRM 2010. 3. Axel L Radiology 1989.174:841-845. 4. Fonseca CG, Bioinformatics 2011;27(16):2288-2295 [PMID 21737439].