Gold Fiducial Marker Visualization with Multifrequency Reconstruction for Frequency-Modulated bSSFP

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JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Gold Fiducial Markers (GFMs) are commonly used in clinical practice in prostate cancer radiotherapy. It remains a challenge to automatically and accurately localize of GFMs in an MRI-only workflow for prostate treatment planning. Phase-cycled bSSFP has been proposed to identify GFMs using multiple frequency offsets to compensate for the large B_0 inhomogeneities in prostate MRI. Typically, 8 repetition of the same 3D bSSFP sequence with different phase cycling is needed to cover the frequency range [1].

A novel MR imaging and processing approach, multifrequency-reconstructed Frequency-Modulated bSSFP ((FMbSSFP), has been introduced as a fast alternative to phase-cycling bSSFP [2]. In this work we implemented a radial FMbSSFP sequence and tested the feasibility of GFMs visualization in a phantom study.

METHOD

1. An agar gel phantom was constructed with five spatially distributed GFMs implanted.
2. A stack-of-stars 3D radial FMbSSFP sequence was developed. The excitation RF pulses were frequency modulated, so that a phase-cycling range of 2**π** was covered in the whole 3D sequence.
3. Sixty-four 3D complex bSSFP datasets were reconstructed at different f_0 frequencies using the raw dataset of a single MRI scan.
4. To compensate for the slow background signal change due to global B_0 inhomogeneities, a voxel-wise B_0 field map was derived from frequency difference at the maximal signal of each voxel. The resulting B_0 field map was then low pass filtered and used to generate 64 B_0-corrected 3D datasets for FM identification and localization.

RESULTS - IMAGES

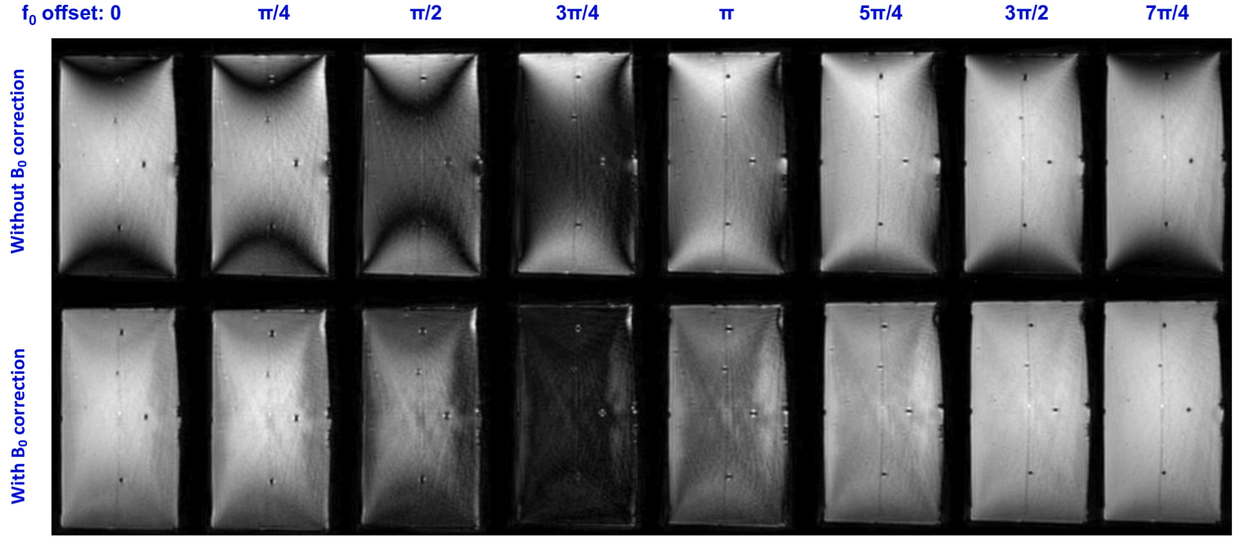

Fig. 1. Representative FM-bSSFP images (8 out of 64 sets) reconstructed at different f_0 offset frequencies. Note the much easier GFM identification when global background signal is corrected.

FMbSSFP Sequence Parameters

TR (ms)	3.2
TE(ms)	1.6
FA(°)	25
FOV(mm)	260x260x120
Voxel Size (mm)	1x1x1
Readout BW(kHz)	187
Scan Duration(min)	1:42

RESULTS - OBSERVATIONS

A complete set of GFMs to background contrast at different f_0 offsets (corresponding phase cycling frequencies) could be generated using multifrequency reconstruction from a single FM-bSSFP scan raw dataset.

The on-resonant images had bright background with dark GFMs. The off-resonant reconstructed images had dark background with bright artifacts centered at the GFMs. All GFMs were easily identified on background signal corrected datasets, particularly on images with dark background.

Radial k-space sampling also generated symmetric artifacts around the GFMs compared to asymmetric distortion using Cartesian sampling, which further helped improve GFM localization accuracy.

DISCUSSION & CONCLUSIONS

We developed and validated a novel FMbSSFP MRI sequence, which allows bSSFP images reconstructed at multiple f_0 off-resonances, in the application of implanted GFMs visualization in a phantom study.

This new MRI approach can potentially be used for direct visualization of GFMs in the prostate for MRI-only radiotherapy. Only one single fast FM-bSSFP scan is needed for multiple GFMs to background contrasts through multifrequency reconstruction. The full spectral coverage of each voxel also allows flexible image processing for easy and potentially fully automated GFM localization.

This imaging approach requires 6~10 times less MR scan time with higher spatial resolution, and much improved performance for GFM identification than existing state-of-the-art method. The fast single sequence can also potentially reduce motion artifacts and mis-registration, therefore improve overall prostate radiotherapy planning and tracking workflow. We therefore conclude that this FMbSSFP technique is a better alternative in prostate GFMs localization than the time-consuming bSSFP sequence using multiple repetitions of RF phase-cycling.

REFERENCES

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2. Slawig A, Wech T, Ratz V, et al. Multifrequency reconstruction for frequency-modulated bSSFP. Magn Reson Med. 2017;78(6):2226-2235.

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