A 3D Golden-Angle Projection Reconstruction Technique for Dynamic Contrast-Enhanced MRI

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Introduction

A 3D golden-angle, projection reconstruction (PR) dynamic contrast-enhanced MRI is presented. Similar to a previous interleaved PR technique utilizing the angle bisection strategy (1-2), the golden-angle PR technique allows a high level of flexibility during image reconstruction, in which multiple combinations of spatial and temporal resolutions are possible from a single data set. The technique also permits reconstruction using temporally selective data filtering ("dynamic KWIC (k-space weighted image contrast)" or "tornado") (1, 3-4), in which the effective temporal resolution of an image series is equivalent to that of a highly undersampled PR acquisition, but in which the image resolution, SNR, and the level of streaking artifacts are equivalent to that of a fully sampled data set. The theory behind the golden-angle scheme is briefly presented followed by an example in a 3D dynamic contrast-enhanced exam of the breast in which both high spatial and temporal resolution images are desirable for the assessment of lesion architecture and contrast kinetics.

Methods

A simple but elegant selection of successive view angles in PR MRI which permits an arbitrary number of views to create an image was recently described (5). Instead of sampling k-space in equally spaced view angles, a single special angle, known as the "golden angle" given by $\theta_{gc} = (\sqrt{5} - 1)/2 * 180^{o} \approx 111.25^{o}$, is used to increment successive views. A key property of this angle is that each successive view divides the largest remaining angular gap, and this process continues ad infinitum. The result of this view angle strategy is that for any number of views chosen for reconstruction, k-space is approximately uniformly sampled. The technique was originally proposed as a means for rapid T_1 mapping from a series of images (5).

The golden-angle scheme was used in a DCE MRI of the breast to demonstrate its feasibility for 3D dynamic imaging. The following parameters were used: 3D gradient echo PR sequence with phase-encoded slices, 512 readout points, 1536 views, 32 slices, FOV = 24 cm, TE/TR = 4.0/9.6 ms. Successive view angles in the k_x-k_y plane were incremented by θ_{gc}, while the angle remained constant during the slice encoding (the inner-most loop). The total scan time was 8 minutes, with Gd contrast agent injection occurring at the 2 minute mark. For the purpose of comparing various image reconstruction strategies, the following were compared: (a) A series of 4 high spatial resolution images, each reconstructed with 512 readout points and 384 views (2:00 minute temporal resolution); (b) A series of 32 high temporal resolution images using 128 points and 48 views per image (15 second resolution); (c) A temporally selective data filtering series in which the number of views utilized for each image increases linearly with distance from the k-space center (5), with a maximum of 384 views used for each image.

Results and Discussion

Fig. 1 shows the breast images reconstructed with the above 3 schemes. The temporally filtered image in **Fig. 1c** has an equivalent image quality of the high spatial resolution image, but has a temporal resolution equivalent to that of the dynamic time series (**Fig. 1b**), reconstructed with lower spatial resolution to preserve image SNR and minimize streaking. **Fig. 2** shows the time-intensity curves of a breast lesion (arrow in **Fig. 1**) from the latter two series, showing equivalent time intensity curve characteristics. Unlike the angle bisection strategy described previously (4), the golden angle technique permits the use of an arbitrary number of views during image reconstruction, allowing finer optimization of imaging parameters. However, the unequal angular spacing between contiguous views (albeit only a small deviation) may affect image quality (increased streaking). A more systematic study remains to be carried out to assess the relative performance of the various techniques.

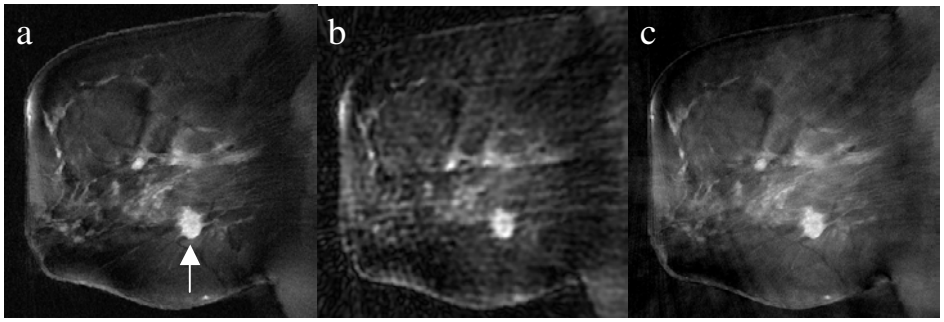

Fig. 1 (a) High spatial resolution image (512 points x 384 views, 2:00 minute temporal resolution). (b) High temporal resolution image (128x48, 15 sec resolution). (c) Temporally filtered image series with high spatial and high temporal resolutions (512x384, 15 sec resolution).

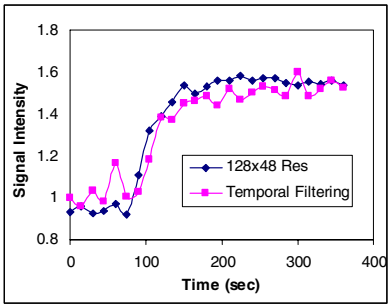

Fig. 2 Plot of the enhancement curves for the lesion in **Fig. 1** (arrow).

Conclusion

Incrementing the view angles of a PR sequence by the golden angle permits high level of flexibility in spatial and temporal resolution during image reconstruction. Multiple combinations of temporal and spatial resolutions could be reconstructed from a single data set, and with temporally selective data filtering, both high spatial and high temporal resolution images could be achieved in a single time series. The technique may be valuable for a 3D dynamic contrast-enhanced exam of the breast in which the assessment of both lesion architecture and contrast kinetics are important for tumor characterization.

References:

(1) Song HK, et al., *Magn. Reson. Med.*, **46**:503-509 (2001).
(2) Song, HK, et al., *Magn. Reson. Med.*, **44**:825-832 (2000).
(3) Barger AV, et al, *Magn. Reson. Med.*, **48**:297-305 (2002).
(4) Song, HK, et al., *Magn. Reson. Med.*, **52**:815-824 (2004).
(5) Winkelmann S, et al., Proc. ISMRM 2005, Miami, p. 2196.