Comparison of the Uniform and Golden Angle Projection Reconstruction Schemes Using a Dynamic Sampling Simulation

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INTRODUCTION

Adaptive sampling of k-space allows dynamic images to be reconstructed at various spatial and temporal resolutions from the same dataset. In a typical PR (projection reconstruction) adaptive scheme, projections are chosen based on a uniform angular distribution. However, this method restricts the reconstruction to specific temporal resolutions that correspond to "commensurate" projection numbers (a set of projections that have equal angular coverage of k-space). A more flexible approach is to choose successive projections based on the golden angle, $\varphi = (3-\sqrt{5})/2 * 360° \approx 137.5°$, which fills in k-space with projections that, at any point in time, have a relatively uniform angular distribution [1]. In both cases, aliasing artifacts resulting from a highly undersampled k-space introduce substantial jittering and deviations in contrast-uptake curves. Until now, there has been no quantitative assessment of the accuracy of the golden angle approach in measuring contrast-kinetic parameters. Using a dynamic simulation with enhancing lesions based on the Tofts model [2], we quantitatively compared the reconstructed values to simulated true curves in the uniform and golden angle sampling schemes.

METHODS

We developed a dynamic simulation in which phantom lesions enhanced over time while 3D k-space was sampled. The center object in the phantom (as shown in Fig.1a) had an enhancing ring with K^{trans} and *ve* (Tofts model parameters) of 0.35 min^{-1} and 0.43 [2] to model characteristics of malignant breast tumours. K-space was sampled in-plane (*kx-ky*) with uniform and golden angle projections. A concentric acquisition scheme was used to acquire slices in the *kz* dimension. For both schemes, images were reconstructed with commensurate projections (multiples of 16 derived from the uniform angle method consisting of eight sets of 16 projections) and non-commensurate projections (other than multiples of 16). Direct Fourier summation was used to reconstruct all images in order to eliminate the inaccuracies of the gridding procedure. Contrast-enhancement curves were fitted using the least squares method to obtain values of K^{trans} and *ve* as well as the mean-squared errors (mse).

RESULTS & DISCUSSION

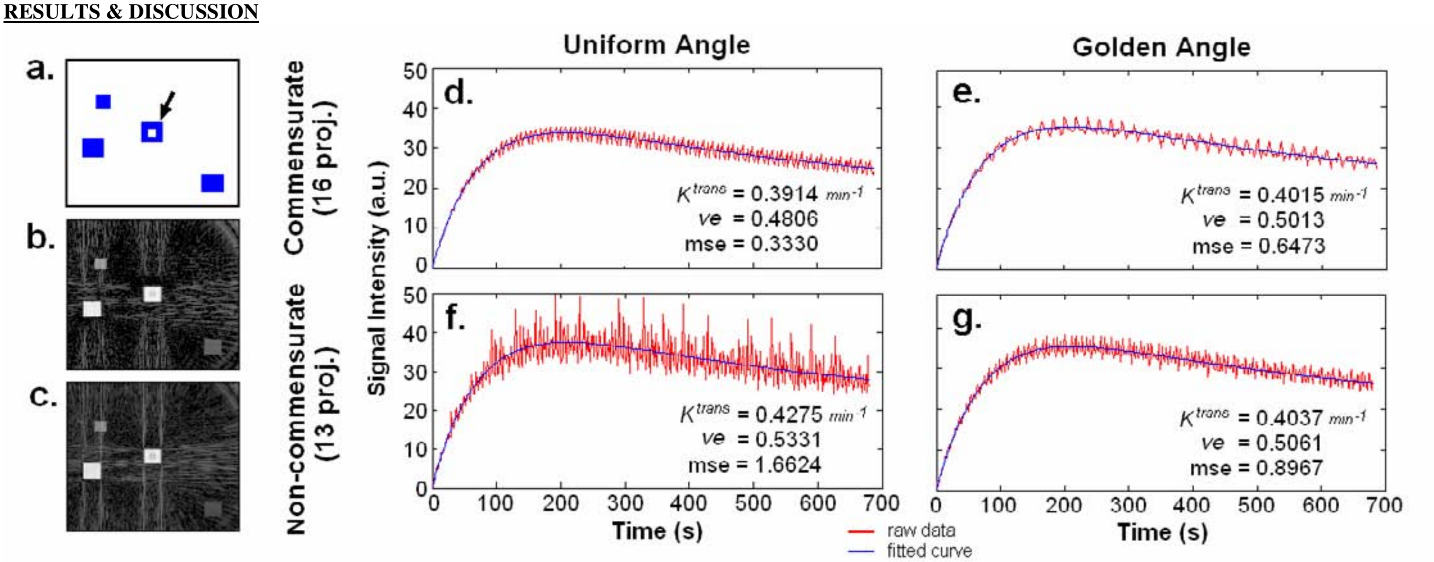

Fig 1. (a) Diagram showing the lesion positions for the middle *z*-slice of the simulation phantom, with the object in the centre (indicated by the arrow) exhibiting malignant ring-enhancement over time. All dynamic curves pertain to this object. (b,c) High resolution 128-projection 256x256 images of the uniform and golden angle reconstructions, respectively. (d,e) Time-curves reconstructed with a commensurate projection number (16 projections) for the two sampling methods. (f,g) Time-curves reconstructed with a non-commensurate projection number, illustrating the case of 13 projections for both sampling methods.

High-resolution images show that the image quality of the golden angle scheme (Fig.1c) is able to match that of the uniform projection approach (Fig.1b) for the same number of (128) projections. In terms of temporal kinetics, while the efficacy of the uniform angle approach degrades at non-commensurate reconstructions (any projection number other than the commensurate), the golden angle technique results in more precise measures of signal intensities (mse = 0.8967) compared to the uniform angle method (mse = 1.6624), as shown for the case of 13 projections in Figs.1f and 1g, and maintains similar values of K^{trans} and *ve*. The uniform angle approach has the best results (mse = 0.3330) only at commensurate reconstructions (16 projections). On the other hand, the golden angle technique surpasses the uniform angle case at all other non-commensurate (including 13 projection) reconstructions.

CONCLUSIONS

A greater flexibility of image reconstruction can be achieved by incrementing every projection according to the golden angle. This highly adaptive approach allows one to reconstruct images from the same dataset at essentially any temporal and spatial resolution. By quantitatively assessing the temporal jittering caused by undersampling artifacts, this simulation showed that on average, the golden angle technique had substantially less contamination due to artifacts compared to the uniform angle approach.

REFERENCES:

[1] Song HK, et al. Proc. ISMRM 2006, Seattle, p.3364.
[2] Tofts et al. Magn Reson Med. 1995 Apr;33(4):564-8.