Uniform Spinning Sampling Gradient EPR Imaging

David H. Johnson, Rizwan Ahmad, Alexandre Samouilov, and Jay L. Zweier

Davis Heart and Lung Research Institute, Wexner Medical Center, The Ohio State University, Columbus, Ohio

ABSTRACT

The goal of this study was to improve the quality and speed of electron paramagnetic resonance imaging (EPRI) acquisition by combining a uniform sampling distribution with the spinning gradient acquisition. The historical Equilinear Spinning Sampling (ESS) spinning gradient acquisition was compared to our new Uniform Spinning Sampling (USS) acquisition, which more uniformly distributes points over the acquisition hemi-sphere. USS images had higher SNR (85.9 vs 56.2) and lower mean-squared error than ESS images in both phantoms and the isolated rat heart model of cardiac ischemia. Future work will include spectral-spatial spinning gradient acquisitions with a uniform distribution.

INTRODUCTION

A challenge in performing in vivo EPR imaging experiments is the relatively long acquisition time required to acquire a sufficient number of projections to resolve the spatial distribution of the probe. Acquisition time constraints include limited signal to noise ratio, respiratory or cardiac motion, and magnetic field stability. To address these challenges, the spinning magnetic gradient technique was developed to rapidly acquire nearly limitless numbers of projections in a very short amount of time [1,2].

The following properties are desirable for for the spinning gradient acquisition.

1) Uniform weight for every point on the hemi-sphere
2) Continuous first derivative of the magnetic field gradients
3) Entire distribution known for any number of points without needing lengthy computations

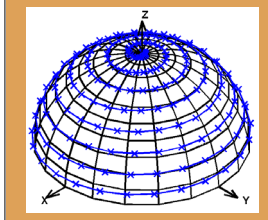
EPRI Coordinate System: φ is the azimuthal angle, and θ is the elevation angle.

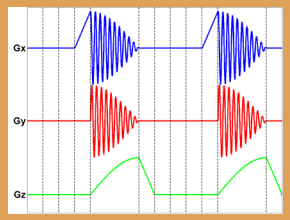
$$G_X = \cos(\varphi)\cos(\theta)$$
$$G_Y = \cos(\varphi)\sin(\theta)$$
$$G_Z = \sin(\varphi)$$

METHODS

The historical Equilinear Spinning Sampling distribution has a well-known bias of acquiring too many projections near one axis, which wastes approximately 30% of the acquisition time [2]. We propose a new method, called Uniform Spinning Sampling, which provides a uniform distribution of projections in a spinning gradient acquisition via an arcsin transformation of the elevation angle [3].

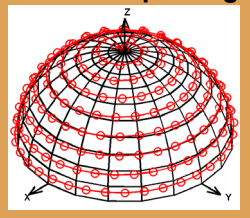
Equilinear Spinning Sampling (ESS)

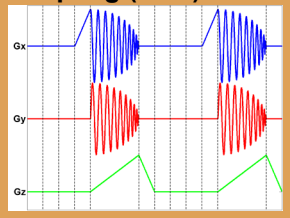




$$\left.\begin{aligned}\varphi_i &= \frac{\pi}{2}\frac{i-1}{N-1}\\ \theta_i &= -4R\left(\frac{\pi}{2}-\varphi_i\right)\end{aligned}\right\} i=[1,..N]$$

Uniform Spinning Sampling (USS)





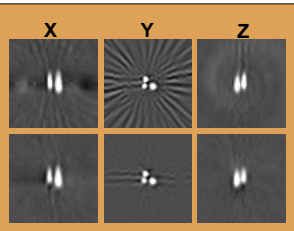
$$\varphi_i = \arcsin\left(\frac{i-1}{N-1}\right)$$
$$\theta_i = \varphi_i\sqrt{2\pi N}$$

PHANTOM IMAGING

A resolution assessment phantom was constructed from three 100 µl capillary tubes each containing 5 mg lithium phthalocyanine (LiPc). Projections (N=1,024) for both ESS and USS were acquired in 64 seconds using a home-built 1.2 GHz EPR imaging system. The acquisition parameters were: 64 points per projection, 2.5 G/cm gradients, 450 G center field with a 15 G sweep width, 0.089 mT modulation at 100 KHz.

Side view

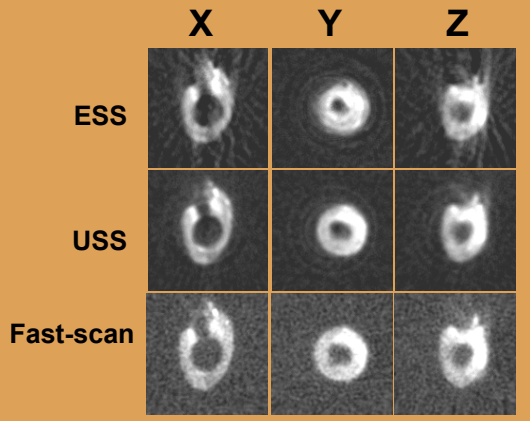
Top view



The phantom images showed radial streaking artifacts in ESS slices along the Y orientation. Streaking artifacts were supressed in USS in all orientations. USS images had lower mean-squared error (0.82) than ESS images (1.95), as compared to a reference image.

CARDIAC IMAGING

An isolated rat heart was infused with a suspension of PBS, calcium, and 20 mg/ml lithium octa-n-butoxynaphthalocyanine (LiNc-BuO). Cardioplegia was induced, and the heart was held in ischemia while USS, ESS, and fast-scan projections were acquired, as above except 2.3 G/cm gradients were applied over 2.5 minutes.



Isolated rat heart

The cardiac images showed superior SNR in USS images was observed as compared to ESS images (85.9 vs 56.2). Both spinning gradient acquisitions had higher SNR than a reference fast-scan acquisition with the same acquisition time (33.1).

DISCUSSION AND CONCLUSION

The spinning gradient acquisition has the potential to produce a nearly unlimited number of projections very quickly, and the USG distribution makes each projection contribute equally to the image reconstruction. This results in a reduction of image artifacts and a boost in SNR. SNR for USS images did not vary with gradient orientation, in contrast to ESS images. The additional efficiency provided by a uniform distribution allows faster EPR imaging experiments to be conducted, which could be useful for characterizing myocardial infarctions and measuring redox kinetics. When combined with variations in gradient amplitude, fast spectral-spatial EPR imaging will be possible with the spinning gradient acquisition.

REFERENCES AND ACKNOWLEDGEMENTS

[1] Deng et al. J Magn Reson 2004; 168(2):220-7.
[2] Deng et al. J Magn Reson 2007; 185(2):283-290.
[3] Johnson et al. Magn Reson Med 2013 (in press).

This work was supported by NIH R01 EB004900, and the first author was supported by NIH F32 EB012932.