Improved Temporal Resolution and Reduced Geometric Distortions using Interleaved 3D Spiral Acquisition for Arterial Spin Labeling Imaging

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INTRODUCTION

3D acquisition methods became popular in arterial spin labeling (ASL) imaging because of its SNR advantages as well as its low geometric distortions. Particularly, single-shot 3D gradient spin echo (GRASE) acquisition has demonstrated superb SNR advantages over 2D single-shot acquisition [1]. Segmented acquisition methods covering the entire *k*-space during multiple labeling periods are often preferred to reduce blurring along the slice encoding direction in 3D GRASE. However, applications of the segmented acquisition are limited to baseline perfusion imaging. Single segment acquisition, with which the entire *k*-space data is collected within a tag or a control period, is desired in the ASL applications that require high temporal resolution or multiple signal averages, such as, functional MRI, multiple post-labeling delay imaging, or vessel-encoded ASL. We propose an interleaved 3D spiral FLASH imaging method that collects the entire 3D *k*-space data quickly within a single labeling period, reduces geometric distortions, and increases the sensitivity to ASL signal due to shorter TE. We also investigated the trade-off between the number of interleaves and SNR benefit compared to the conventional 2D spiral imaging method.

METHOD

An interleaved 3D stack-of-spiral acquisition method (shown in Fig. 1) has been developed for FLASH ASL imaging. Spiral imaging is preferable for ASL imaging because the short TE offers higher sensitivity to ASL signal and rapid spiral acquisitions allows larger *k*-space coverage in a given time. Using the interleaved 3D spiral imaging it is possible to collect the entire *k*-space within a single labeling period (typically ~1sec) without using parallel or partial Fourier imaging when the number of interleaves were smaller than 7. Variable flip angle FLASH imaging [2] reduces blurring resulting from the T_1 recovery of the tagged blood signal along the slice encoding direction. Background suppression (BGS) [3] is necessary for 3D imaging with a long acquisition period to minimize physiological noises from the static tissue. Flow sensitive preparation was applied to suppress intravascular signal [3]. 3D imaging requires a single preparation whereas 2D imaging needs bipolar gradients per excitation which increase TE.

We compared the interleaved 3D spiral FLASH with the conventional 2D single-shot spiral gradient echo (GE) imaging from two healthy volunteers. Pseudo-continuous tagging scheme was used with 1.6s labeling duration and post labeling delays of 1sec and 1.2sec were applied for the 2D and 3D imaging, respectively. Two BGS inversion pulses were applied in 3D imaging at 1.15s and 0.35s before the first imaging excitation. The number of interleaves we tested were [1 2 4 6 8] with the initial flip angles of [16.4 11.6 8.2 6.7 6.3] degrees and [30 60 120 180 208] excitations were played within a TR (a labeling period). Imaging parameters include 64x64 matrix size and 24 slices for 2D and 64x64x30 matrix size for 3D, 4mm^3 imaging resolution, 20 tag/control pairs, 4sec TR, and 2min 40sec scan time. The 8 interleave acquisition had four slice encoding steps skipped and the homodyne reconstruction method was applied. The flip angles and the number of phase encoding steps were used to calculate the theoretical SNR. SNR and temporal SNR (tSNR) were measured in the gray matter and relative SNR and tSNR normalized to those from the 2D imaging were calculated in our analysis.

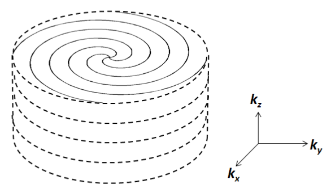

Fig. 1. An example showing spiral trajectories with 4 interleaves per slice encoding. The center k_{xy} plane is collected first and slice encoding steps follows in the centric order.

RESULTS

Fig. 2 shows the measured relative SNR and tSNR values normalized to the values from the 2D single-shot spiral. Close to the theoretical SNR value, 3D imaging schemes with one or two interleaves provided higher SNR values than the 2D imaging scheme. 3D FLASH imaging demonstrates lower geometric distortions compare to the conventional 2D single-shot spiral acquisition as shown in Fig. 3. The SNR of 6 and 8 interleaved 3D schemes was not sufficient to produce acceptable cerebral blood flow (CBF) maps under 3min scan time. Representative tSNR maps are shown in Fig. 4. Similar to the results shown in Fig. 3, one and two interleaved 3D imaging provided tSNR benefit as well as reduced spiral blurring.

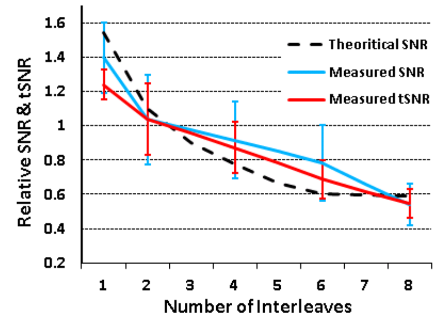

Fig. 2. The theoretical SNR and the measured relative SNR and tSNR. Error bars indicate standard deviations across subjects.

DISCUSSION

Rapid acquisition speed of 3D spiral imaging yields effectively high temporal resolutions for ASL imaging (=2TR). It was demonstrated that the proposed interleaved 3D spiral FLASH imaging can take advantage of 3D imaging, such as improved SNR and reduced geometric distortions, while keeping high temporal resolution as with 2D imaging. Our experiment showed that the relative SNR values were generally lower than the relative tSNR values. This may be interpreted as the proposed 3D imaging is more sensitive to physiological contaminations since a long acquisition period is needed following volume excitation. Applying more than two BGS inversion pulses may reduce the physiological contamination and improve tSNR. The potential application area of the proposed acquisition method is broad since one can control the trade-off between SNR (or tSNR) and geometric distortions. For example, 1) the single interleaf scheme would be preferred when high temporal and SNR are desired. 2) Two or four interleave scheme may be suitable for fMRI study emphasizing temporal and/or frontal lobes where the geometric distortions are severe. 3) More than 4 interleave schemes may be useful for an animal study which requires low geometric distortion and high spatial resolution but allows a long scan time.

REFERENCES

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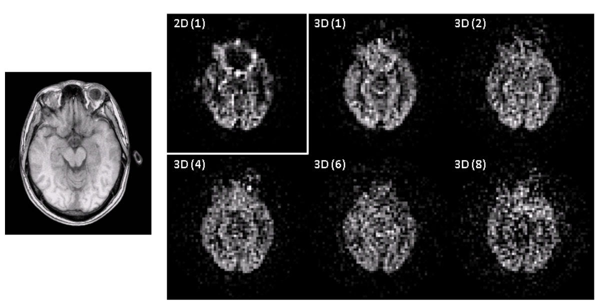

Fig. 3. CBF maps with the 2D single-shot spiral GE and the proposed interleaved 3D FLASH methods. A single slice was chosen where the spiral blurring is typically severe. The image in left shows an anatomical reference of the images.

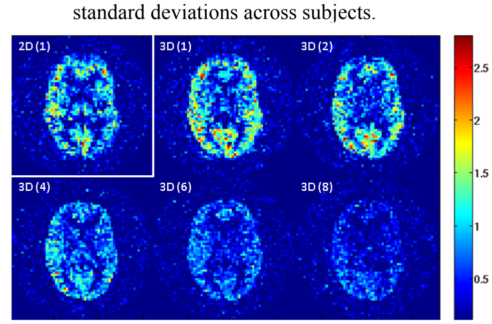

Fig. 4. tSNR maps from a representative subject. For simplicity, a single slice containing deep gray matter regions is shown. The numbers in () indicate the number of interleaves.