A New Encoding Scheme for Single-shot 3D GRASE to Double Slice Coverage

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Introduction: Single-shot 3D GRASE sequence is a popular MRI acquisition method for arterial spin labeling (ASL) perfusion imaging (1). A major limitation of 3D GRASE is the through-plane blurring caused by T_2 decay as a result of an extended acquisition window. Full brain coverage with minimum blurring artifacts is difficult to achieve without using either parallel imaging or multi-shot acquisitions along the slice encoding direction. While parallel imaging may be used for reducing the echo train length, this scheme is inefficient due to the additional dead time associated with each new refocus RF pulse. With a standard 8-channel phased-array coil, it is difficult to accelerate directly along the slice encoding direction (k_z) due to the lack of coil sensitivity variation along k_z. We demonstrate here that parallel imaging can be used, however, to increase spatial resolution along k_z. In this study, we modified the 3D GRASE sequence to acquire 2 k_z encodes within a single partition to achieve twice the slice coverage in a single-shot. Normally, this will increase the acquisition window by a factor of 2. Instead, we perform a 2× acceleration along k_y to maintain the acquisition window length. This version, referred to as 3D zGRASE, was tested in ASL studies and yields image quality similar to a 2-shot 3D GRASE.

Materials & Methods: A series of oscillating k_z "blips" is used in each partition of 3D zGRASE to switch back and forth between the two adjacent k_z encoding positions, as shown in Figure 1. For instance, the first 4 k-space lines in each partition follows the acquisition pattern: [k_x= +G_x, k_y=n, k_z=m], [k_x= –G_x, k_y=n, k_z=m+1], [k_x= +G_x, k_y=n+1, k_z=m], [k_x= –G_x, k_y=n, k_z=m+1], where +/–G_x indicates the direction of the readout gradient, n and m indicate phase (k_y) and slice encoding (k_z) indices, respectively. To compensate for the time used to encode a second k_z position in each partition, we employ self-referenced GRAPPA (2) with an acceleration factor of 2. Temporal encoding (3), achieved by toggling the readout gradients (G_x) polarity during successive frames, is used to remove the misalignment of echoes acquired during positive and negative G_x (3). A centric-out slice ordering is implemented to minimize echo time (TE) for optimized perfusion sensitivity. The image reconstruction consists of two stages: calibration and reconstruction. In the calibration stage, k-space data from two successive frames are re-organized into two datasets with opposite readout polarities, I^+ and I^-. I^+ and I^- are coherently combined to form I_{ref} after estimating and correcting for the phase errors caused by the echo misalignment (3). The parallel reconstruction coefficients are then obtained by calibrating GRAPPA on I_{ref} after performing a 1D FFT along k_z. In the reconstruction stage, k-space data from an individual frame is firstly re-organized to establish the correct k_z order. As a result of the acquisition pattern, the even and odd slices have the opposite readout directions. The echo misalignments between odd and even slices are corrected using the estimated phase error values obtained from calibration. A 1D FFT is applied along k_z to employ slice encoding. GRAPPA is then used to reconstruct each slice using the coefficients from the calibration stage. A final 2D FFT is used to transform the GRAPPA reconstructed data to image space. While 2 temporal frames of data are necessary for constructing the reference image, the 3D zGRASE method is still a true single-shot method because each excitation samples a full set of k-space necessary for image reconstruction.

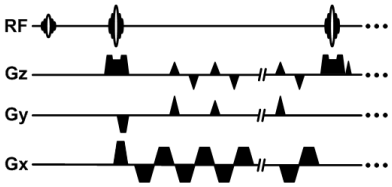

Figure 1. 3D zGRASE pulse diagram.

Q2TIPS-FAIR (4, 5) with background suppression (6) was used to acquire in-vivo perfusion weighted images on a GE 1.5T scanner (TwinSpeed, GE Medical Systems, Milwaukee, WI) with a standard 8-channel phased array coil. Three healthy volunteers (age 24 – 28) were imaged with informed consents. The acquisition parameters for 3D zGRASE include: image matrix size = 60×80, in-plane FOV = 210×280mm, through-plane FOV = 135mm, 9 partitions ($k_{z,max}$ = 13) was acquired with 9/13 partial Fourier encoding yielding a total of 27 slices (2*$k_{z,max}$ + 1). 2-shot 3D GRASE images were acquired for comparison. TE =33.7 ms and the total imaging time = 3.2 minutes are identical between the two methods.

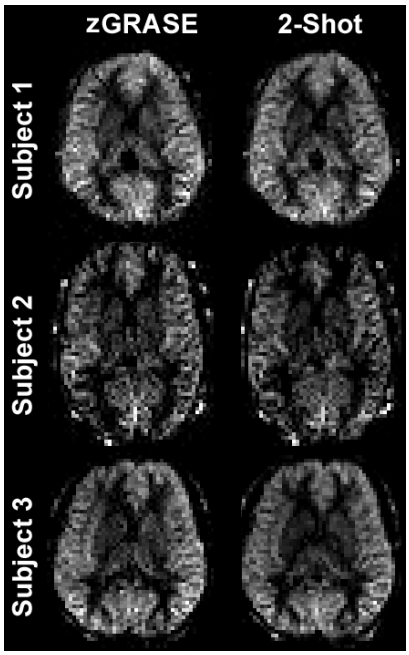

Figure 2. Perfusion weighted images acquired with 3D zGRASE and 2-Shot 3D GRASE.

Results: Perfusion weighted images acquired from all three subjects are shown in Fig 2. The images are similar between 3D zGRASE and 2-shot 3D GRASE, both revealing detailed anatomical structures and showing good perfusion signal in deep gray matter. Full brain coverage can be seen in the reformatted views (Fig 3). The amount of T_2-induced through-plane blurring was comparable between the two methods. This result suggests that full brain coverage can be achieved in a single-shot without trading off for image quality or perfusion sensitivity in comparison to the multi-shot method. Improved slice coverage is achieved here at a cost of SNR compared to conventional single-shot 3D GRASE. However, it does not appear to adversely affect the perfusion image quality.

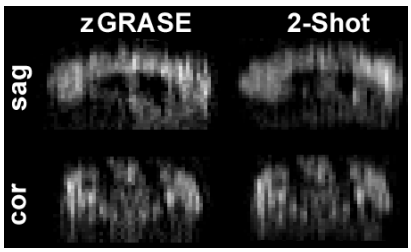

Figure 3. Reformatted sagittal and coronal views of the perfusion weighted images to show full brain coverage.

Discussion: Multi-shot encoding is often used in conventional 3D GRASE to improve slice coverage. As a result, the temporal resolution of the multi-shot method is proportionally reduced by the number of shots used. In this study, we have shown a new encoding scheme to double the slice coverage in a single-shot 3D GRASE with image quality comparable to a 2-shot 3D GRASE. The new technique 3D zGRASE, which provides full brain coverage without compromising for T_2 blurring and temporal resolution, has a strong potential for functional ASL studies. Since the number of actual partitions needed for encoding n slices is less than n/2 (with partial Fourier encoding), 3D zGRASE can be used to minimize T_2 induced through-plane blurring in conventional ASL imaging. In addition, as a single-shot technique, 3D zGRASE is less susceptible to motion errors than the multi-shot technique.

References: 1) Günther et al. MRM, 2005. 54: 491. 2) Grisworld et al. MRM, 2002. 47(6): 1202. 3) Hoge et al. MRM, 2010. *In press.* 4) Wong, EC, et al. MRM, 1998. 39:702. 5) Kim, SG and Tsekos, NV. MRM, 1997. 37:425. 5) Lawrence et al. MRM, 2005. 53:735.