Acquisition Strategy for 3D GRASE with a Sharp Point Spread Function Towards Whole Brain ASL Perfusion Mapping at 3T

Q. Qin[1,2], A. J. Huang[2,3], J. Hua[1,2], M. J. van Osch[4], and P. C. van Zijl[1,2]

[1]Radiology, Johns Hopkins University, Baltimore, Maryland, United States, [2]F.M. Kirby Center, Kennedy Krieger Institute, Baltimore, Maryland, United States, [3]Biomedical Engineering, Johns Hopkins University, Baltimore, Maryland, United States, [4]Radiology, Leiden University Medical Center, Leiden, Netherlands

INTRODUCTION: For cerebral blood flow (CBF) mapping using the arterial spin labeling (ASL) approach (1), perfusion signals (difference of label/control) depend on the tagging delays (2). Compared to 2D multi-slice (MS) acquisition, 3D ASL has the advantages of acquiring a large volume at an identical tagging delay and no destruction of tagged bolus destined for distal slices by acquiring proximal slices (3). Technical developments, such as background suppression (BS) (4) and pulsed continuous ASL (PCASL) (5), have enabled 3D whole brain ASL within a clinically accepted time window. 3D GRASE combines high sampling efficiency from EPI/Spiral read-outs with low sensitivity to B_0 field inhomogeneity from Fast Spin Echo (FSE) method and has become a natural choice for ASL (4-7). To reduce measurement time for each dataset, long echo trains (T_{acq}=300~500ms, (6-8)) with small number of segments or even single-shot methods are often employed, which is known to cause severe blurring along the FSE encoding direction due to T_2 decay. However, another undesired effect of this T_2 decay during acquisition that is often times overlooked is amplitude loss (9,10), which offsets the SNR gain from extended sampling duration. In this work, we evaluated different acquisition schemes for 3D GRASE, and demonstrated optimum strategy in whole brain ASL at 3T with a sharp point spread function (PSF).

THEORY: Fig.1(a) shows the PSF of T_2 decay during acquisition with different T_{acq}/T_2 ratios. With increasing T_{acq}/T_2 ratios, PSFs get both broader and lower, being normalized to the case without any T_2 decay. The amplitude loss at the center of PSFs is: $amplitude_{decay}=(1-\exp(-T_{acq}/T_2))/(T_{acq}/T_2)$ (EQ.[1]) (10) Fig.1(b). Blurring effect is indexed using full width half maximum: $FWHM_{decay}=0.55(T_{acq}/T_2)$ (EQ.[2]) (10) Fig.1(c). When centric profile order of *k*-space is used, SNR per unit time is proportional to the multiplication of both the amplitude loss (EQ.[1]) and the square root of T_{acq}. As plotted in Fig.1(d), this SNR efficiency function is 20% less at T_{acq}/T_2=4 compared to its maximum (around T_{acq}/T_2=1). Finally, lowering refocusing angles is known to generate both lower pseudosteady state (no relaxation) and longer effective T_2 with the T_1 effect (11). SNR efficiency for gray matter at 3T (T_1/T_2=1300/80ms), here taking into account the pseudosteady state in addition to $T_{2,eff}$ and T_{acq}, is compared between different refocusing angles Fig.1(e). Optimum SNR efficiency is at T_{acq}≈80ms with 180°. With longer T_{acq}(>250ms), lowering flip angle can produce similar sensitivity but with less blurring and lower SAR (11).

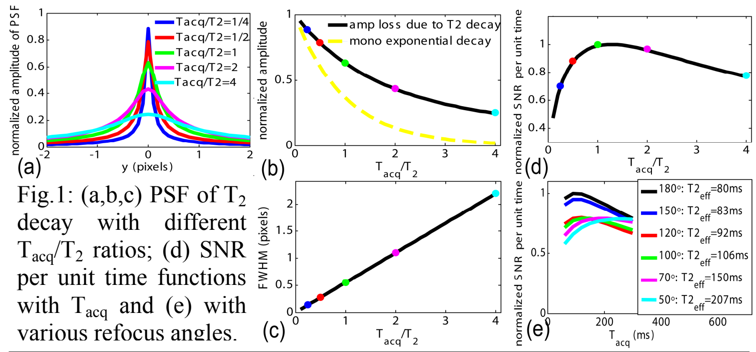

Fig.1: (a,b,c) PSF of T_2 decay with different T_{acq}/T_2 ratios; (d) SNR per unit time functions with T_{acq} and (e) with various refocus angles.

METHODS: Experiments were conducted on a 3T Philips scanner using body coil transmit and a 32-channel head coil receive (Invivo). 4 healthy subjects (26-46yrs) were enrolled with informed consent. The PCASL sequence was performed together with BS pulses as described in (12), with 1.6s tagging duration and 1.5s tagging delay. Saturation pulses were applied inferior to the imaging slab to mitigate inflowing unlabeled arterial blood (4,5).

Axial FOV=240x240mm^2; 60mm for 2DMS and 120mm for 3D along head-foot direction; acquisition resolution=3x3.2x4mm^3; in-plane reconstruction resolution= 1.9x1.9mm^2. 2DMS EPI scan used 35 EPI factors and 2.5 SENSE factors with a T_{acq}=21ms; 3D GRASE scans disabled SENSE, kept 19 EPI factors (y dir) (12.7ms for EPI readout gradient) and 16.7ms echo spacing, and with three different FSE factors (z dir)=4/9/18. These resulted in T_{acq}=67/152/303ms for each TR(4s) and 30/15/8 shots respectively. Bipolar gradients (b=1.2s/mm^2) were inserted before the first refocusing pulse to further suppress intravascular artifacts. Refocusing flip angle was kept 180° for these 3D scans with different T_{acq}. For the scan with T_{acq}=303ms, another scan was performed with the only change to 50° refocusing. Total measurement time was 4min40s with 35 averages for 2DMS and 1/2/4/4 averages for 3D scans respectively.

RESULTS AND DISCUSSION: Fig.2 displays normalized difference images with 3 orthogonal cross-sections, acquired with 2DMS and 3D GRASE using different T_{acq}. General findings: 2D MS had the least blurring in transverse plane (T_{acq}/T_2^*=21/40=0.5) but perfusion signal decreased in superior slices, similar as observed in (3,12). Blurring effect of 3D GRASE scans was more apparent with longer T_{acq} in all three views. 3D results with 67ms and 152ms T_{acq} had similar signal sensitivity, as predicted in Fig.1(d) with T_{acq}/T_2 ratio for gray matter at 3T close to be 0.9~1.8. 3D scan with T_{acq}=303 ms showed lower sensitivity. The one with 50° refocus angle, although not showing signal improvement, did show some blurring reductions, as expected from theory Fig.1(c,e).

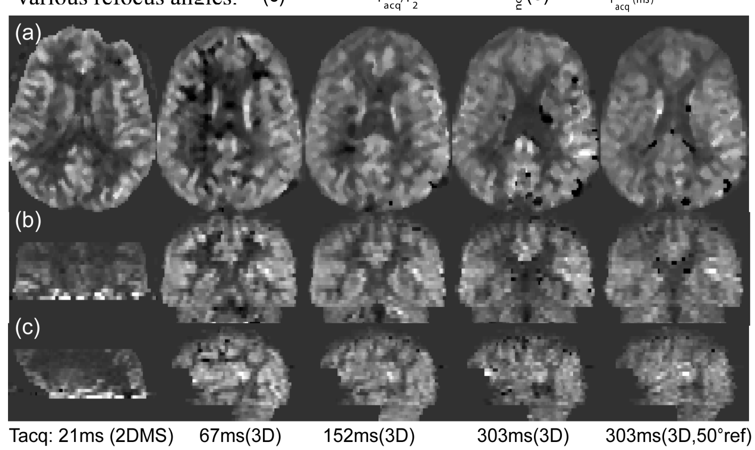

Fig.2: comparison of ASL difference images with different sampling durations T_{acq} at (a) transverse, (b) coronal and (c) sagittal views.

CONCLUSION: We have demonstrated that 3D whole brain ASL with high resolution can be obtained with a short echo train comparable to tissue T_2. A longer echo train does not provide gains of SNR efficiency yet is penalized with severe blurring. Parallel imaging can be enabled to shorten the number of shots yet keep the short echo train, such that neither resolution nor SNR per unit time is sacrificed and measurement time of each average is minimized to reduce motion sensitivity.

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