Time-Resolved 3D Dynamic Contrast-Enhanced MR Angiography with Optimized Separate Auto Calibration Signal Lines

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INTRODUCTION: Time resolved 3D ("4D") dynamic contrast-enhanced MR angiography (DCE-MRA) [1] offers combined anatomic and hemodynamic information with fractional Gd contrast doses [2]. To achieve high temporal resolution while retaining high spatial resolution and having enough spatial coverage, DCE-MRA often utilizes k-space view sharing techniques combined with parallel imaging [3-5]. Time-resolved imaging with stochastic trajectories (TWIST [4,5])) is a view-sharing technique that undersamples the peripheral k-space region while acquiring central data with full sampling (Fig.1). With a conventional TWIST, the integrated auto-calibration signal (ACS) lines (i.e. ACS is integrated in every central data acquisition) are utilized to achieve high parallel imaging factors. In the current study, we propose to modify the conventional TWIST by using an optimized separate ACS lines to improve the image quality of the peak arterial enhancements.

METHODS: The TWIST method separates the k_y-k_z plane into 2 regions: an inner central region ***A*** and an outer peripheral region ***B***. The region A is defined by the percentage of *the total data points* in k_y-k_z plane (referred to as *A%*). The region B, on the other hand, is defined *by the sampling density* of B (referred to as *B%*). After an initial Prep phase, TWIST acquires full k-space data only at the beginning (Meas.#0 on Fig.1). From here on, the region A is fully sampled with each repetition, while the region B is sampled with reduced density (according to B%). To reconstruct 3D image data for each measurement, the missing portions of the region B are copied from the neighboring B acquisitions (Fig.1: example shows forward sharing with B33%).

With the conventional TWIST, the ACS lines for the parallel MRI are *integrated* in every dynamic acquisition, and this results in a non-accelerated sampling of the central k_y-k_z map in the region A (Fig.2 left). With the proposed approach, all of the ACS lines are acquired *separately* before the dynamic data acquisitions (Prep phase in Fig.1), allowing region A to be acquired with the full parallel acceleration (Fig.2, right). Not only it increases the effective acceleration (i.e. less redundancy in central data), same number of sampling points in region A (i.e. same temporal resolution) now covers larger central area in k_y-k_z map with the separate ACS than with the integrated ACS, and this improves the image quality since less data are shared (Fig.2). With the proposed scheme, it is crucial to acquire the optimal separate ACS lines that resemble the actual sequence acquisition data. To achieve this, the separate ACS lines are acquired by the identical RF pulse and gradients parameters as with the acquisition sequence. Also with a typical sequence flip angle (FA) for DCE-MRA at 3T amounts to 15-20 degrees, we choose a FA of 8 degrees for the separate ACS lines, where FA is high enough to have acceptable SNR for ACS and yet low enough to avoid noise enhancement. The size of the ACS lines is set at 24x24, which is optimal for the data quality and for the prep phase duration.

The sequence was implemented on a 3T scanner (TIM Trio, Siemens AG, Healthcare Sector, Germany) and tested in a series of 16 consecutive patients (8 each for the integrated and the separate ACS TWIST) and 1 volunteer (scanned with both techniques for visual comparison) under IRB regulations. The sequence parameters were: TR/TE 2.03ms/0.83ms, FA 15 deg, BW 710Hz/pixel, parallel acceleration 2x3, Partial Fourier 0.8, image matrix 170PE x 320RO, 176 slices, voxel res. 1.7x1.3x1.5mm^3, 1.5ml Gd contrast injection at 2ml/sec, 1.7sec temporal resolution, B20%, 22 measurements, and 48sec total acquisition time. For the integrated TWIST, region A was set at *8% or 9% k_y-k_z map coverage*. For the Separate TWIST, in order to match the temporal resolution with the integrated TWIST, A% was increased to *14% or 25.8% k_y-k_z map coverage*. The results were compared qualitatively on basis of subtracted MIPs and source images. Also differences in SNR of the peak carotid artery enhancement (SNR= (mean of carotid) / (SD of noise outside of patient)) were tested for statistical significance with t-test for independent samples.

RESULTS: Visual comparison (Fig.3) reveals the superior quality of the peak carotid arteries with the separate ACS TWIST. The separate ACS TWIST has significantly superior SNR than the integrated ACS TWIST (39.9 ± 4.9 vs. 24.1 ± 1.9, respectively, $p<0.01$).

DISCUSSIONS AND CONCLUSION: The DCE-MRA benefits from further improvements in spatial and temporal resolution because it may help characterizing pathologies that can only be detected with higher fidelity (e.g. parenchymal lesions). Though untested, one potential limitation with the proposed technique is with the longer acquisition time (e.g. 2+ minutes), where accumulated motion during the course of scanning may cause artifacts with the single ACS acquisition. With improved central ky-kz plane coverage and the image quality, TWIST with the optimized separate ACS lines is a promising approach for further advancements in the DCE-MRA.

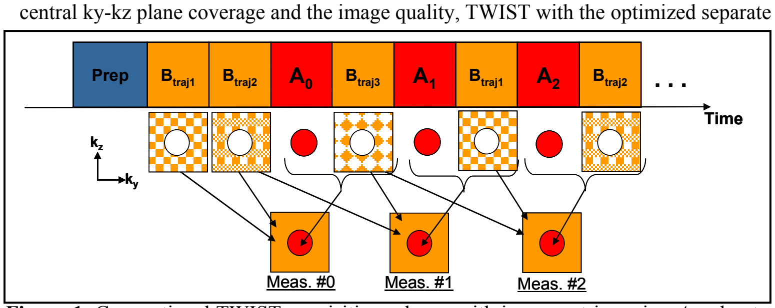

Figure 1: Conventional TWIST acquisition scheme with inner centric region *A* and outer peripheral region *B*. Region B is undersampled with different trajectories (=traj). In this example, forward sharing (i.e. filling in the missing portions from previous acquisitions) and with B33.3% (i.e. undersampled to the factor of 1/3) are illustrated.

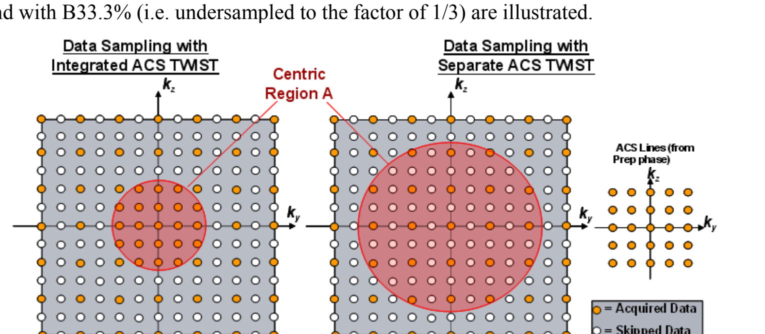

Figure 2: Comparison of the complete data sampling ky-kz maps of integrated vs separate ACS TWIST. In this example, an image matrix of 13x13 with acceleration factor 2x2 and reference data size of 5x5 is shown in illustration. For the same # of data points in central region *A* (in this case, 21), region *A*'s k_y-k_z coverage for the separate ACS TWIST is far superior as compared to that for the integrated ACS TWIST.

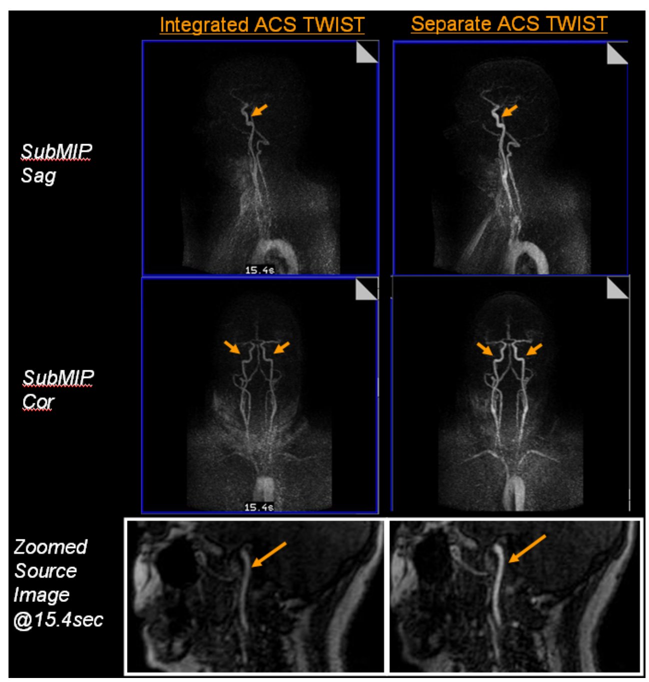

Figure 3: Integrated (left column) and separate (right column) ACS TWIST reconstructed images at the peak carotid artery enhancement (TT=15.4 sec). Subtracted MIP and the source images on the same volunteer with two identical injection profiles and essentially identical MRA parameters (other than A%) are shown. Carotid arteries (yellow arrow) show superior quality with the separate reference TWIST.

References: [1] Korosec FR, Frayne R, Grist TM, et al. Magn Reson Med, 1996;36:345-351. [2] Lohan DG, Tomasian A, Saleh R, et al. Invest Radiol, 2009; 44(4):207-217. [3] Fink C, Ley S, Kroeker R, et al. Invest Radiol., 2005;40:40-48. [3] Vogt FM, Eggebrecht H, Laub G, et al. Proc ISMRM, Berlin, 2007. [4] Song T, Laine AF, Chen Q, et al. Magn Reson Med, 2009;61:1242-1248.