The Effect of Time-Resolved K-Space Sampling on Contrast-Enhanced MRA: A Method to Optimize Imaging Parameters

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Introduction

MR angiography (MRA) has emerged as an alternative to digital subtraction angiography (DSA). Time-resolved angiography with stochastic trajectories (TWIST) has been shown to enable high spatial and temporal resolution imaging [1]. The choice of k-space sampling parameters offered by TWIST has a profound impact on image quality, such as blurring, ringing artifacts, and signal loss in small vessels. Optimization of these parameters remains a significant challenge. We propose an objective framework for analysis of TWIST k-space sampling strategies that is based on computer simulated four dimensional MRA phantom.

Methods

A dynamic blood vessel signal was derived from a real contrast enhanced peripheral MRA study. A phantom was constructed to simulate variable diameters of vessels as shown in the leftmost section of Fig. 3. Two voxel sizes: VS1= 0.8×1.0×1.0mm and VS2= 0.8×1.4×1.4mm were simulated by varying the matrix size while keeping a fixed acquisition time of 10sec. Read out direction was kept the same. K-space was divided into two regions shown in Fig.1: A – a fully sampled central region, and B – partially sampled peripheral region. Region B was decomposed in N disjoint trajectories: Bi (i = 1, 2, …N). In a dynamic acquisition, the k-space is assumed to be sampled in a fashion: A, B$_1$, A, B$_2$, A, B$_3$,… Sampling is specified by two parameters: pA – fraction of K-space taken by A; and pB = 1/N, or *sampling density* in region B [1]. For VS2, we have assumed the matrix size of 206×512 with 80 partitions and four (pA, pB) scenarios (0, 0.5), (0.08, 0.50), (0.39, 0.25), (0.50, 0) shown in Fig. 1. For VS1, the matrix size was 300×512 with 112 partitions and the (pA, pB) scenarios were (0, 0.25), (0.04, 0.25), (0.18, 0.10), and (0.25, 0). Profiles across vessel were extracted from maximum intensity projection (MIP) images [2]. For each scenario, relative errors between true and reconstructed TWIST images were computed and used as an objective measure of sampling strategy.

Results

Fig. 2 plots measurements of ringing artifacts (a,c) and error in measured vessel diameter (b, d) for VS1 (a, b), and VS2 (c, d). An optimal combination of pA and pB are (0.04, 0.25) and (0.08, 0.50) respectively. Subsequent inspection of VS1 scenarios revealed that larger errors were associated with significant signal drop and blurring in small vessels. Fig. 3 compares the true phantom with the results from scenarios one to four for VS2. The second scenario (0.08, 0.50) demonstrated lowest ringing artifacts and blurring and best description of small vessels. Overall, we observed that for smaller vessels, higher sampling density (pB) is more important than the size of A (pA), while for larger vessels, larger pA gave better accuracy of diameter resolving ability. In a clinical case (Fig. 4a, 4b) using 10ml Gd at 2ml/sec and TWIST with (pA, pB) (0.08, 0.50), TR/TE/ 3.0/1.0, TA 9.77sec, FOV 338×450×112mm, and true voxel size 0.9×1.6×1.4mm, resulting images demonstrate vascular details that are superior to a 12 sec 30ml full dose non-TWIST bolus chase image (Fig. 4c).

Conclusions

We studied the effect of time-resolved undersampling on MRA vessel ringing artifacts and diameter measurement accuracy using a 4D vascular phantom. Optimal undersampling parameters were applied in a clinical case and demonstrated the utility of the simulation, with further validation studies underway. The proposed framework can be applied to other clinical applications.

References

[1] T. Song, et. al, ISMRM 2007, pp 402. [2] H. K. Song, et. al, MRM, vol 52, pp 815-824, 2004.
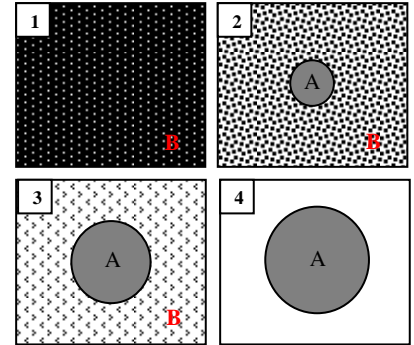
Fig. 1. A varied from 0 to 0.5, B varied from 0.5 to 0 across four scenarios. The total acquisition time was the same. A and B were the center area and periphery area of the K-space (ky-kz plane).
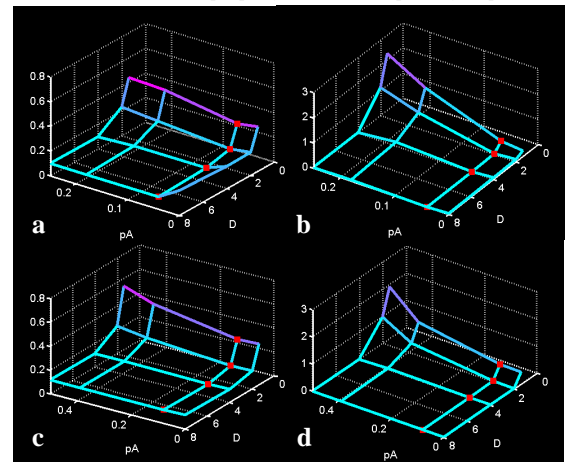

Fig. 2. (a,c) are ringing artifacts; (c, d) are relative errors in measured diameter. (a, b) are VS1 and (c, d) are VS2.
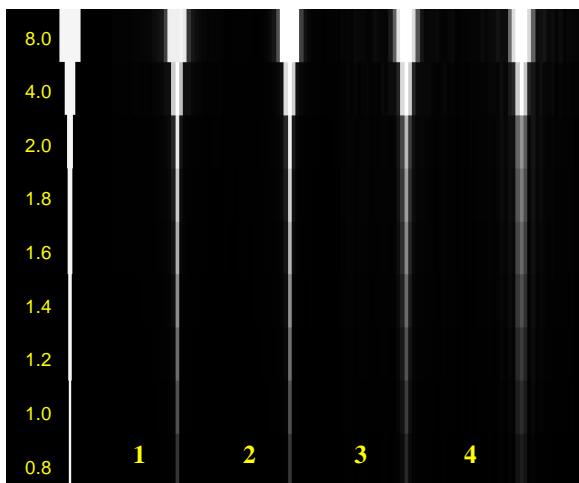

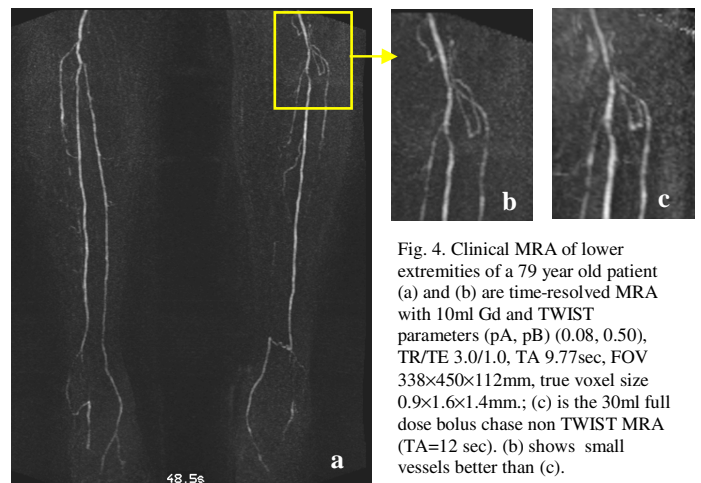Fig. 3. MIP of truth (diameters are in mm) and scenarios 1-4 (Fig 1) with increasing pA.

Fig. 4. Clinical MRA of lower extremities of a 79 year old patient (a) and (b) are time-resolved MRA with 10ml Gd and TWIST parameters (pA, pB) (0.08, 0.50), TR/TE 3.0/1.0, TA 9.77sec, FOV 338×450×112mm, true voxel size 0.9×1.6×1.4mm.; (c) is the 30ml full dose bolus chase non TWIST MRA (TA=12 sec). (b) shows small vessels better than (c).