Evolution of Image Quality in View-Shared Time-Resolved 3D CE-MRA

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INTRODUCTION: With the recent advent of parallel acquisition with acceleration factors of R≥4 it is often assumed in time-resolved 3D contrast-enhanced MR angiography (CE-MRA) that k-space is fully sampled during passage of the contrast bolus. However, this is often not the case, such as at the leading edge of an enhancing vessel or for early-enhancing time frames in a series. These frames can often be important in, say, distinguishing arterial from venous structures. Another constraint can occur if the acquisition time must be limited by some other factor, such as the need to move the patient table in multi-station peripheral MRA to keep pace with the advancing contrast bolus. These effects can be further complicated if view sharing is used to provide an enhanced frame rate. In each of these cases the resultant k-space undersampling will reduce image quality, either by decreasing vessel signal, decreasing vessel sharpness, or increasing undersampling aliasing artifacts [1].

In many Cartesian time-resolved 3D CE-MRA techniques such as TRICKS [2], CAPR [3], and TWIST [4] the k_Y-k_Z phase encoding plane is segmented into a single lowpass center region and N highpass regions. A time frame consists of sampling the center region and one of the N highpass regions and view sharing previous measurements of the other N-1 highpass regions. Importantly, there are multiple ways to segment the k_Y-k_Z plane to yield a target frame time. The precise segmentation can greatly influence how angiogram quality evolves with view sharing and thus determine the quality of a time frame with incomplete k-space sampling. In this work we quantitatively study the effects of different phase-encoding plane segmentations, or sequences, on image quality. We demonstrate a fundamental tradeoff between vessel signal and sharpness that should be taken into consideration when performing time-resolved 3D CE-MRA.

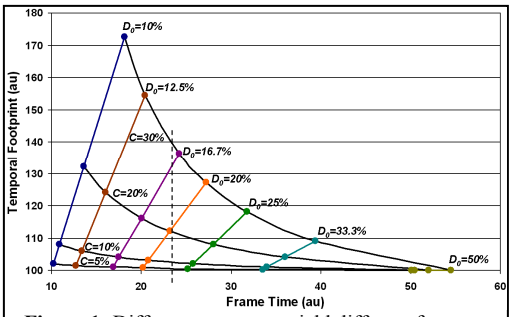

Figure 1: Different sequences yield different frame times and temporal footprints. For a given frame time (e.g., vertical dashed line) there are a number of sequences that can be used.

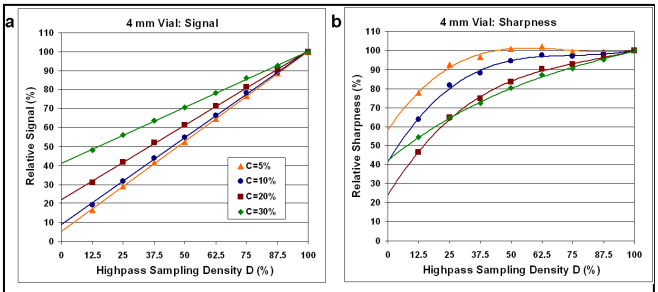

Figure 2: 4mm vial (**a**) signal and (**b**) sharpness for various C and D.

METHODS: ***Segmentation parameters.*** The above-described sequences can be characterized by the size of the center region (C) and initial sampling density of the highpass region (D_0). C is defined as the ratio of the diameter of the center region to that of the fully-sampled k_Y-k_Z plane. D_0 is defined as 1/N, and the progressive view sharing that occurs in an image sequence is modeled as a linear increase in D up to D=100%. ***Temporal parameters.*** The time to fully sample k-space with C=100% is assigned to be 100 arbitrary units (au). This case corresponds to a fully-sampled k-space each time frame. The frame time and temporal footprint [3] of a given sequence are calculated relative to this C=100% case based on its relative number of acquired views. ***Specific hypotheses.*** (i) For a given frame time, sequences with shorter temporal footprints will produce sharper angiograms more rapidly. (ii) For a given frame time, sequences with longer temporal footprints will have higher signal in early time frames. (iii) The benefits of larger C are less pronounced when imaging smaller vessels. ***Phantom experiments.*** The measured k-spaces of fully-sampled images of vial cross-sections with diameters of 4, 6, and 12 mm were masked to simulate generic time-resolved sequences over a broad range of C, D_0, and D values. The signal (peak vial magnitude) and sharpness (maximum slope of vial edge) of the undersampled vial images were assessed relative to the fully-sampled reference. ***In vivo studies.*** 3D time-resolved CE-MRA calf studies acquired using two different CAPR sequences (I: C=21%, D_0=12.5%; II: C=10%, D_0=20%) in combination with 8× 2D SENSE that yielded the same 2.5 sec frame time with 1.0 mm isotropic sampling resolution were evaluated. Vessel signal and sharpness were measured in consecutive time frames starting with contrast arrival and ending with complete view sharing for several target arterial segments. Results were grouped and averaged according to vessel size.

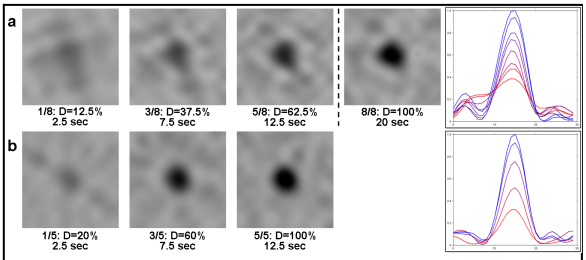

Figure 3: Select time frames of *in vivo* vessel cross-sections acquired using sequences (**a**) I and (**b**) II. Line profile plots show the signal evolution over all time frames.

RESULTS: Figure 1 shows a plot of temporal footprint vs. frame time for various combinations of C and D_0. Increasing C extends both the frame time and temporal footprint. Decreasing D_0 reduces the frame time but extends the temporal footprint. The reported times (in au) for each sequence will scale as imaging parameters such as y-z resolution, TR, and acceleration R are altered. Figure 2 shows plots of vial signal and sharpness for select C and D for the 4 mm vial. Use of larger C yields higher signal for a given D up to full sampling (a). However, this is offset by lower sharpness (b). As D increases, both signal and sharpness improve for a given C. For larger vials, a given C yields higher signal and lower sharpness (data not shown). Figure 3 shows example *in vivo* cross sections of arteries imaged with sequences I (a) and II (b). Signal and sharpness improved more rapidly for sequence II on account of its shorter temporal footprint (12.3 vs. 18.7 sec). The averaged vessel groups show similar trends (data not shown).

DISCUSSION: We have demonstrated, for the first time, how vascular image quality evolves in view-shared time-resolved 3D CE-MRA. For a target frame time (e.g., dashed line in Figure 1) there is a choice between sequences with shorter temporal footprints (smaller C, higher D) that rapidly build up signal vessel and sharpness and those with longer temporal footprints (larger C, lower D) that provide higher signal in early time frames. Selection of the most appropriate sequence depends on the application. For example, fluoroscopic tracking [5], which enables real-time tracking of the contrast bolus in multi-station 3D bolus chase MRA, requires a short frame time (≤2.5 sec), and has a short acquisition time window (<15 sec), benefits from sequences that provide rapid evolution of image quality. On the other hand, high temporal fidelity imaging [6], in which visualization of contrast bolus progression is paramount, would benefit from sequences that provide higher initial signal. Higher image acceleration (e.g., R>8 2D SENSE vs. R=8 used here) will benefit all applications by enabling both larger C and higher D to be acquired in a given frame time.

[1] Pipe JG, MRM 2000. [2] Korosec FR, MRM 1996. [3] Haider CR, MRM 2008. [4] Lim RP, JMRI 2010. [5] Johnson CP. MRM 2010. [6] Haider CR, MRM 2010.