Subtraction in View-Shared 3D Contrast-Enhanced MRA

E. A. Borisch[1], C. R. Haider[1], R. C. Grimm[1], and S. J. Riederer[1]
[1]Radiology, Mayo Clinic, Rochester, MN, United States

INTRODUCTION

The use of a pre-contrast reference image, referred to as a mask, to suppress background signal and improve output contrast-to-noise ratio (CNR) through subtraction is common in contrast-enhanced MR angiography. It is critical that this operation be performed to optimize output image quality. As has been previously reported [1-3] it is advantageous to use complex subtraction for this removal operation. In this work we extend this discussion to the optimal selection of the mask for the case of 3D time-resolved view-shared reconstructions, using the CAPR sequence [4] as an example.

METHODS

The desirable characteristics of complex subtraction, covered previously [1-3], continue to be relevant in the context of accelerated parallel imaging enabled through multiple coils. In the reconstruction of accelerated parallel acquisitions, the memory required for the reconstructed volume is frequently smaller than the set of input data, leading to a natural desire to move subtraction (which requires storage and manipulation of a reference volume) to the end of the reconstruction process in an attempt to conserve resources. If each step in the reconstruction process is linear, the subtraction operation can be performed at various points during the process. However, performing subtractions on the final magnitude reconstructions as a post-processing step can lead to substantially different results [1], as can performing a partial-Fourier (homodyne) processing step prior to subtraction. [2]

During a time-resolved view-shared acquisition, each section of k-space experiences a unique history, or magnetization state at the beginning of readout, as well as potentially being updated (re-acquired) at differing rates. Examples of this include Keyhole, TRICKS, and CAPR acquisitions. In these situations, multiple options are available with respect to the combination of k-space data sets to use as the input values for a reconstructed time frame. As shown in Figure 1 for a 4-fold view-shared (N4) CAPR acquisition, the initial acquisition (Fig. 1a) consists of the center of k-space and a set of PR-like vanes. Subsequent acquisitions (Figs. 1b-d) fill in additional vane sets, while acquiring a new center of k-space each time. As the sequence repeats (Figs. 1e-h), new k-space samples replace prior centers and corresponding vane sets.

When performing subtraction in this situation, a simple choice for a mask is to select the earliest (pre-contrast) "complete" representation of the sampled k-space, Figure 1(d) in this example. This mask would then be subtracted (in complex space and pre-homodyne as noted above) from subsequent frames to create a "digitally subtracted" MR time series. We report here that this is likely a non-optimal choice in any system where acquisition occurs faster than the spin system's history decays. Due to this effect, subtracting the center of Figure 1(d) from the center of Figure 1(g), for example, is subtracting two acquisitions that, while occupying the same logical k-space locations, and imaging a presumed static volume, have differing magnetization histories leading up to their acquisition, and consequently deterministically different results. The proposed subtraction method uses history-matched regions of k-space for subtraction: the center of Figure 1(c) would be subtracted from the center of Figure 1(g), for example.

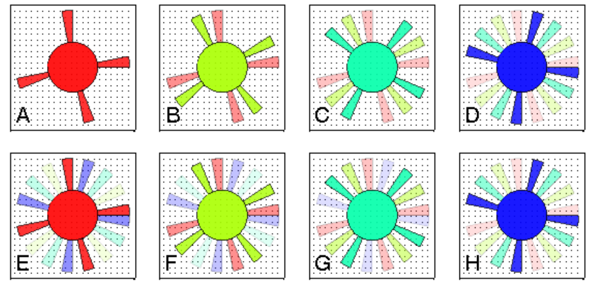

Figure 1: Example CAPR (N4) Pattern Evolution (k_y-k_z plane)

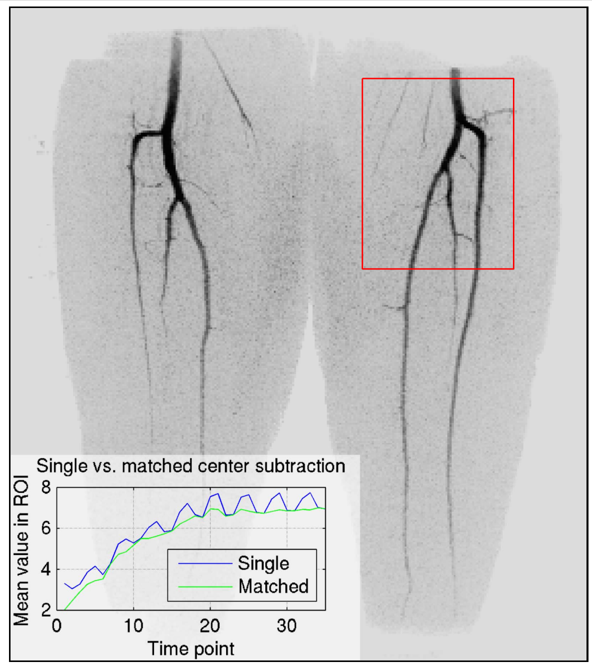

Figure 2: Mean value in ROI over time

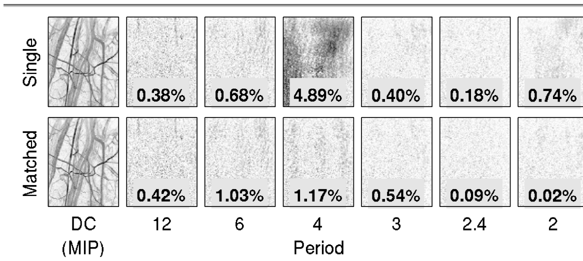

Figure 3: Mean intensity projection of frequency bands (last 12 frames)

RESULTS

The impact of using a single mask can be seen in Figure 2. The mean value of the signal in the (3D) ROI identified in Figure 2 by the red outline is plotted in as a function of time for the case of a single mask (blue line.) Arrival of contrast over the course of the exam is visible. More striking is the signal modulation in time with a periodicity of four image updates. This modulation is primarily attributed to the selection of a single mask whose center section, in three out of every four time points, consists of k-space acquired with a differing magnetization history than the most recent center. As an alternative, the subtraction mask can be "matched" to the update frame. This is achieved by storing N copies of the center of k-space, one for each of the various histories; N=4 in this case. Using the centers in Figures 1(b-e) – 1(a) is discarded, and primarily serves to "initialize" the state of the system – four different subtraction masks are constructed. The resulting masks are then matched with the latest acquisition center during subsequent reconstructions, leading to the improved tissue uptake curve shown in green in Figure 2. Figure 3 shows, for both the single and matched cases, the results of taking the Discrete Fourier Transform (DFT) of the ROI volume through time for the final (approximately static) twelve update volumes and comparing the signal in the resulting frequency bands, labeled by their period. The labeled percentages in Figure 3 indicate the ratio of the average intensity in the band to the average intensity at DC.

DISCUSSION

When applying subtraction to a view-shared reconstruction, as previously reported, it is critical to perform the subtraction in the complex sense, and not as a post-processing step using magnitude-only data. We have shown that, in the context of a view-shared reconstruction, it is also necessary to appropriately select the mask data from the available sets, taking care to select regions with similar acquisition history to the newly acquired input data.

REFERENCES

[1] Wang Y., MRM 1996. [2] Hoogeveen, R.M., MR Imaging 1999. [3] Naganawa A., JMRI 1999. [4] Haider C.R., MRM 2008.