Image quality characterization in Time-Resolved 3D CE-MRA

Yijing Wu[1], Kevin M Johnson[1], Jane H Maksimovic[2], Charles A Mistretta[1], and Patrick A Turski[2]
[1]*Medical Physics, University of Wisconsin, Madison, WI, United States,* [2]*Radiology, University of Wisconsin, Madison, WI, United States*

TARGET AUDIENCE: Accelerated imaging and reconstruction techniques.

PURPOSE: Time-resolved 3D contrast-enhanced MR angiography (CE-MRA) often requires highly accelerated imaging to achieve clinically required temporal and spatial resolutions. Recently developed non-linear reconstruction schemes, e.g. compressed sensing (CS) and HYPR, offer substantially greater acceleration than past methods but are unfortunately inherently object dependent and difficult to characterize with traditional linear methods. Subsequently, exemplary results in simplified digital phantoms do not translate clinically. In this work, we investigate the use of a highly realistic fractal based digital imaging phantom for accurate characterization of several non-linear reconstructions (CS, HYPR, and CS-HYPR)[1~2].

METHODS: A 3D digital fractal phantom was first generated utilizing seeding vessels (3 arterial, 1 venous) and a high resolution perfusion map generated by segmented gray and white matter. Resolution independent arterial and venous vascular trees were subsequently generated a stochastic branching guided by a hemodynamic cost of branching pattern. This provided a highly precise time of arrival (TOA) map for each point in the tree which was convolved with a gamma-variate function to generate images at each TR. K-space data at each TR was generated utilizing simulated coil sensitivities from typical 8-chanel coil geometry and inverse Fourier transform. Relevant acquisition parameters were accounted for simulated acquisition including: undersampled 3D radial acquisition (VIPR) with bit-reverse projection ordering, 256^3 matrix, and 13,920 total projections. Data were reconstructed using traditional gridding and L1-norm regularized SENSE[3] with low, medium, and high regularization levels. In addition, four image sets were generated by applying HYPR to each time series of images. Twenty time frames were reconstructed for each dataset with 696 projections per frame.

Image quality of the reconstructed images was quantitatively assessed using four metrics: (1) RMSE of the angiographic structure; (2) vessel sharpness; (3) TOA of veins; and (4) time of departure (TOD) of arteries. An angiographic mask was generated by thresholding truth images and dilated the result with 3x3x3 kernel. The mask was applied to images prior to RMSE calculations to reduce background weighting. Vessel sharpness was evaluated by measuring the full-width at half-maximum (FWHM) of the line profiles drawn at seven vessels (four arteries and 3 veins) with diameters range from 1~7mm. TOA of veins was used to detect possible early enhanced venous structures, defined as the time when the intensity of a medium venous structure (~3mm) reach 15% of the peak signal of a large arterial structure (~6mm). Similarly, TOD of arteries was used to detect possible prolonged arterial signal and defined as the time when the signal intensity of medium arterial structure (~3mm) reach 30% of the peak signal of a large venous structure (~7mm). Image quality of the reconstructed images was also qualitatively graded by a blinded radiologist using the following criteria: frame at which first venous structure is clearly visible; residual arterial enhancement on late phases; vessel sharpness; ability to visualize small vessels; residual artifacts; and overall impression.

RESULTS AND DISCUSSION Figure 1 shows image comparison at an arterial (top) and a venous (bottom) phase. CS shows significant vessel blurring at low regularization and vessels sharpen with high regularization. HYPR processing reduced vessel blurring and HYPR processing of CS with medium regularization had comparable dynamic phases and spatial resolution to truth images. Figure 2 shows an enlarged view of the venous phase from Figure 1. As demonstrated in Figure 3, the conspicuity of small vessels diminishes with high regularization despite high overall vessel sharpness. RMSE of the angiographic structure calculation shows that all the CS-HYPR with different regularization levels have similar error (7~8.8%) and are all smaller than the gridding method (14.7%). RMSE from CS methods with low, medium and high regularization levels were 15.2%, 13.6% and 9.1% respectively. TOA and TOD values were within 2 frames for all the CS and CS-HYPR series. HYPR alone resulted in a large error of 6 frames in both. In qualitative reading, CS-HYPR with low and medium regularization weightings were the best image quality compared to the true images.

CONCLUSION The temporal blurring of HYPR and signal loss from the small structure of CS limit the performance of these two reconstruction schemes. Quantitative image metrics and qualitative grading analysis demonstrate that CS-HYPR is able to overcome the disadvantages of both methods and provide the most accurate reconstruction images to the truth. These highly realistic digital phantom and quantitative image quality metrics provide an evaluation method for highly accelerated imaging techniques and non-linear reconstruction schemes.

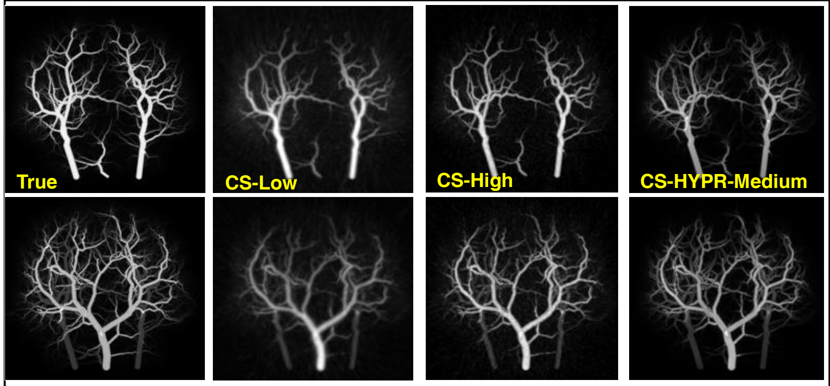

Figure 1 Image comparison at an arterial frame (upper row) and venous frame (lower row). From left to right: true image, CS with low and high regularization weightings, and CS-HYPR with a medium regularization.

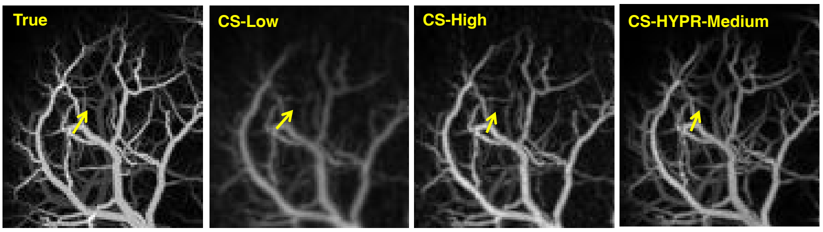

Figure 2 Enlarged view of the upper left section of the venous phase in Fig.1. CS with high regularization starts to loose signals on some small vessels as shown in arrows.

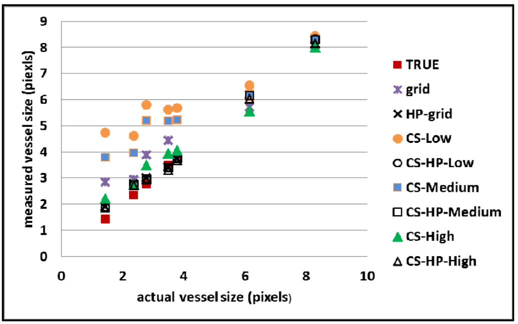

Figure 3 FWHM as quantitative comparison of vessel sharpness to the truth. All the measurements from HYPR images (black markers with different shapes) are close to the truth (red squares). Measurements from the regular gridding and CS (show as yellow) have different errors depends on the regularization weighting.

REFERENCES 1. Lustig et al, MRM, 2007;58(6):1182-1195. 2. Wu et al, ISMRM 2012 P2863. 3. Pruessmann KP, et al, MRM 2001;46:638-651.