Max CAPR: High Temporal and Spatial Resolution 3D CE-MRA With Scan Times Under Five Seconds

C. R. Haider[1], J. Huston III[1], N. G. Campeau[1], J. F. Glockner[1], A. W. Stanson[1], and S. J. Riederer[1]

[1]Radiology, Mayo Clinic, Rochester, MN, United States

Introduction. Time-resolved sequences for MRA generally exploit a temporal-spatial correlation to provide high frame rates. In view-shared sequences an underlying assumption is that the information content of high spatial frequencies is slowly varying throughout the duration of the exam. This allows the small subset of low spatial frequencies associated with image contrast to be updated frequently to provide high temporal fidelity, while higher spatial frequencies are sampled less frequently to provide high spatial resolution. These techniques can provide image update times sufficiently small to allow for dynamic imaging of contrast bolus passage [1-3]. However, as the "temporal footprint," defined as the duration over which any views used in image formation, is increased in an effort to improve spatial resolution or SNR, the chances also increase for non-idealities such motion artifact or blurring, waning contrast levels, and rapid venous enhancement to occur and cause reduced overall image quality. It was hypothesized in this work that a non-view-shared 3D CE-MRA time-resolved sequence can provide 1 mm isotropic spatial resolution with a sub-five second frame time using 40-fold k-space undersampling for bilateral imaging of the calves with high diagnostic image quality.

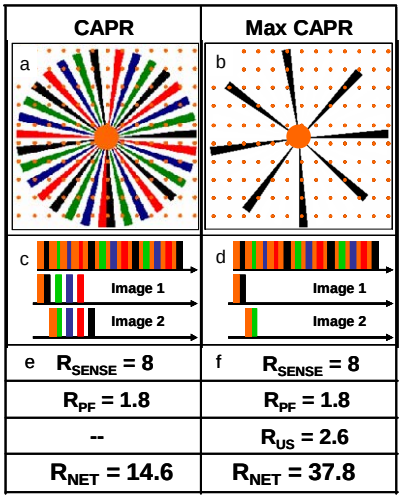

Fig. 1. Comparison of CAPR vs. Max CAPR

Methods. ***k-Space Sampling:*** Max CAPR is based on the previously described CAPR technique [3], and the two are compared in Fig. 1. The sampling patterns of the k_Y-k_Z phase encoding planes are shown in (a-b) in which orange dots represent full k_X echoes oriented perpendicular to the page, sparsely shown for clarity. The intersection of this Cartesian grid of echoes with the colored patterns is sampled during the acquisition. For each CAPR image (a), sampling includes the central orange region and four annular sets of spokes, and for each new image in the time series the center and one vane set are updated (c). The net acceleration for CAPR, R_{net} = 14.6, shown in (e), is derived from the combination of partial Fourier (R_{PF} = 1.8) and 2D SENSE (R_{SENSE} = 8). The net acceleration does not include elimination of sampling the corners of k-space or any temporal acceleration from view sharing. With Max CAPR (b, d, f) only a single vane set is used for each image, resulting in additional acceleration due to k-space undersampling (R_{US} = 2.6), yielding a net acceleration of R_{net} = 37.8. The playout of views of Max CAPR matches that of CAPR (d vs. c), but only one vane set is used for image formation; there is no sharing of vane sets from image to image. The robustness of undersampled vanes in 3DFT acquisition is akin to that observed in undersampling in projection reconstruction imaging [4].

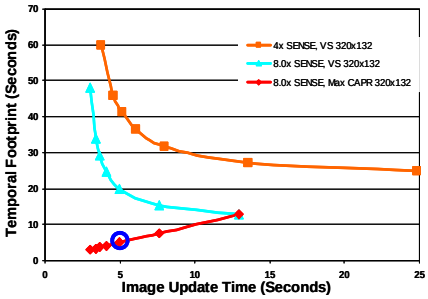

Fig. 2. Temporal footprint vs. frame time.

Experiments: Max CAPR was adapted for bilateral 3D CE-MRA of the calves. A fast GRE sequence on a 3T MR imager (GE Signa, V14.0) with an eight-element receive coil were used in the coronal imaging plane with parameters: TR/TE = 5.85/2.7 msec; flip angle 30°; BW ±62.5 kHz; FOV 40x32x13.2 cm^3; sampling matrix 400x320x132; resulting in acquired 1 mm isotropic spatial resolution. A SENSE acceleration factor of R = 8 (R_Y = 4, R_Z= 2) was used for all acquisitions. Intravenous contrast administration was Multihance® contrast injected at 3 mL/s followed by 20 mL of saline at 3 mL/s. The sequence was run continuously for typically 90 sec, with the first frame used as a mask for subtraction.

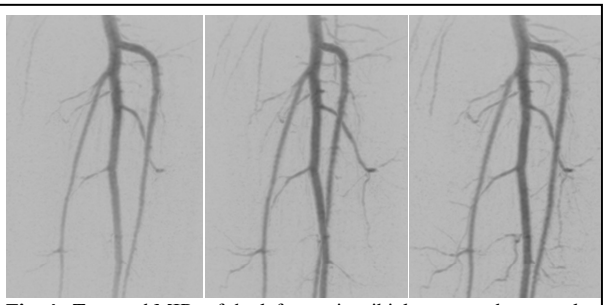

Fig. 4. Targeted MIPs of the left anterior tibial artery and peroneal artery origins from study of Fig. 3 showing progressive filling.

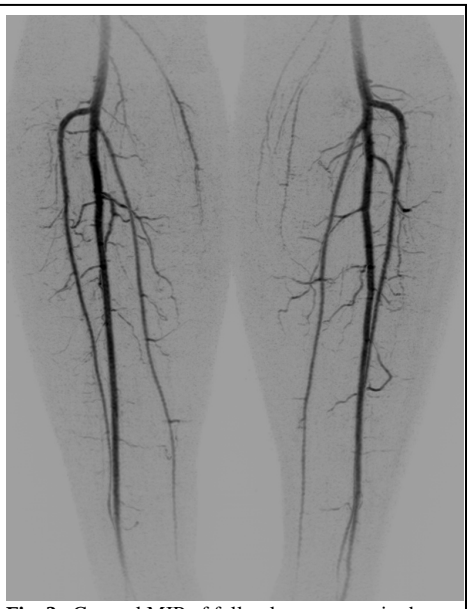

Fig. 3. Coronal MIP of full volume as acquired using Max CAPR. 4.9 sec acquisition time.

Temporal Footprint: The additional undersampling acceleration allowed by the removal of vanes not acquired in the same image update time equates the temporal footprint and image update time in Max CAPR. The results shown here have a total acquisition time per frame equal to 4.9 seconds. No additional views from outside of a given image update are included in a reconstruction.

Results. Fig. 2 compares the temporal footprint vs. image update time for view-shared (orange, cyan curves) and Max CAPR (red line). The circled point is for the acquisition used here. Figs. 3 and 4 are representative in vivo results using Max CAPR from a single volunteer. Fig. 3 is an A/P MIP acquired during the arterial phase. Fig. 4 shows the origins of the left anterior tibial and peroneal arteries at different time frames. The intrinsic spatial resolution of the method permits visualization of the progressive enhancement of small muscular branches. In spite of sampling the k_Y-k_Z plane using only one vane set comprised of just eight vanes, in none of the images are any artifacts apparent due to this radial undersampling.

Conclusion. We have demonstrated 1 mm isotropic resolution time-resolved 3D CE-MRA of the calves with an acquisition time per unsubtracted image of under 5 sec. We believe that these are the shortest times yet demonstrated for results of this quality. Reducing the acquisition time to match the image update time eliminates all influence of undesirable phenomena occurring during neighboring frames on a given frame.

References. [1] Korosec MRM 36:345 (1996); [2] Hadizadeh Radiology 246:205(2008); [3] Haider MRM 60:749(2008); [4] Peters MRM 43:91(2000)