Artifact Reduction in Time-of-Flight Imaging at 7 T using Temporally Resolved Compressed Sensing

Anders Garpebring[1,2], Maarten J. Versluis[1,3], and Matthias J. P. van Osch[1,3]

[1]CJ Gorter Center for high field MRI, Leiden University Medical Center, Leiden, Zuid-Holland, Netherlands, [2]Radiation Sciences, Umeå University, Umeå, Sweden, [3]Radiology, Leiden University Medical Center, Leiden, Zuid-Holland, Netherlands

Targeted audience: Researchers interested in UHF-MRI, compressed sensing, and MRI-artifacts

Purpose: High resolution time-of-flight (TOF) angiograms are frequently degraded due to pulsation artifacts (see Fig. 1a). Previously we have shown using simulations the feasibility of removing the pulsation artifacts using Compressed Sensing (CS) and a random k-line acquisition scheme with retrospective reordering of k-lines based on the cardiac cycle as deducted from synchronously sampled peripheral pulse unit (PPU)-signal[1]. In this study we have used in vivo data to test the applicability of this method and to investigate if CS can be used to reconstruct time-resolved TOF angiograms obtained from ultra-high field MR imaging.

Methods: A TOF angiography dataset was acquired on a 7 T Philips scanner using a 32-channel head coil and a 3D gradient echo sequence. The applied imaging settings were: matrix $= 256 \times 256 \times 128$, FOV $= 180 \times 180 \times 45$ mm^3, TR/TE = 13/6 ms, and flip angle = 30 °. The data were acquired on a Cartesian grid in random order and with more dense (and redundant) sampling at the k-space center. A total of 48482 lines were acquired and the timing of each line relative to the R-wave was recorded using the PPU of the scanner. The data were reconstructed by first binning the data into 10 cardiac phases and then reconstructing using slice-by-slice spatio-temporal CS in combination with SENSE[2]. The c-SALSA algorithm[3] was used to solve the l1-optimization problem and the associated noise level parameter and augmented Lagrangian penalty parameter were adjusted manually for optimal performance. To reduce the computational load coil compression[4] was used to reduce the number of coils from 32 to 8. The compression transform was only applied in the temporal dimension where the Fourier transform was used. Coil profiles were obtained from a fully sampled 32 x 32 matrix at the center of the (not binned) k-space and the sum-of-squares image was used for normalization of the coil profiles. For comparison, a fully sampled k-space was also acquired in sequential order using the same sequence

Fig. 1 **(a)** Fourier reconstructed image. **b** Image reconstructed using CS (averaged over all 10 time points). **(c)** and **(d)** Vessel intensity changes drastically between cardiac phase 3 and 9, see Fig. 2 below for definition of heart phase numbers.

settings as for the randomly sampled data. This data was reconstructed using ordinary Fourier transform reconstruction and combined into a single image using the sum-of-squares method.

Results: Fig. 1a and b show one slice reconstructed using CS and Fourier transform reconstruction, respectively. Clear pulsation artifacts can be seen in the image obtained using ordinary Fourier reconstruction while the artifacts are removed in the CS reconstruction. The ability to capture temporal intensity changes is illustrated in Fig. 1c and b corresponding to frames at the systolic and diastolic phases, respectively. In Fig. 2 the temporal intensity variations over the cardiac cycle are plotted for a vessel (indicated by arrows in Fig. 1c,d) and a ROI in static tissue.
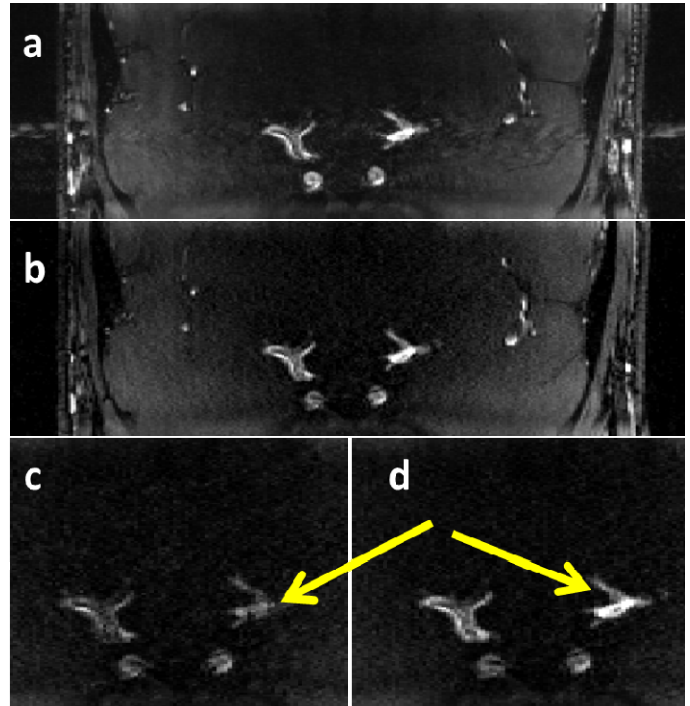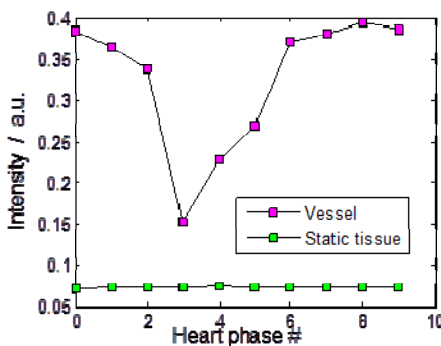

Fig 2. Intensity versus heart phase number in the vessel indicated with a yellow arrow in Fig. 1c,d and in a ROI in static tissue.

Discussion: The results of this work confirm that spatio-temporal CS can be used to remove pulsation artifacts in TOF-MRA at 7 T. By resolving the temporal changes the cause of the artifacts is removed and since temporal changes occur in such a small number of voxels the images are highly compressible using e.g. a temporal Fourier transform. The random order of the sampling also helps since it makes the pulsation non-periodic relative to k-space line index. As an added bonus to the removal of the artifact, intensity changes and vessel motion can be tracked with potential applications in e.g. the neck region where vessel motion may blur angiograms. The noise level in the obtained images were somewhat higher than expected, from simulations (data not shown). A likely cause of the higher than expected noise level is the very simple coil profiles used and continued future work will focus on improving the SNR through e.g. usage of better coil profiles.

Conclusion: This work shows that CS can be used to remove the pulsation artifacts that otherwise seriously can degrade the image quality of TOF angiograms obtained from ultra-high field MR imaging. As an additional benefit intensity variations and motion of vessels can be monitored dynamically.

References: [1]Garpebring A, et al. ISMRM 21, 2013. p2625. [2]Liu B, et al. ISMRM 16, 2008. p3154. [3]Afonso M.V. et al. IEEE TIP 2011 20(3):681-95. [4]Zhang, T. et al. MRM 2013 69(2):571-82.