Application of compressed sensing to minimize pulsation artifacts and distortions in high resolution time-of-flight imaging at 7 Tesla MRI

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TARGET AUDIENCE: Researchers interested in UHF-MRI, compressed sensing, and MRI-artifacts

PURPOSE: Ultra high field MRI is especially suited for high spatial resolution time-of-flight (TOF) MRA, enabling the visualization of the smallest intracranial arteries, such as the lenticulostriate arteries[1]. Furthermore, it might aid in the detection of small aneurysms and the differentiation of aneurysms from infindibula. Image quality of such angiograms at the level of the Circle-of-Willis is, however, frequently degraded due to pulsation artifacts (see Figure 1a). Cardiac gating can be used to minimize these artifacts, however, at the expense of scan-time (see Figure 1b). By acquiring TOF-angiograms at different gating intervals, subtle distortion of the vascular tree can also be appreciated (data not shown). We hypothesize that pulsation artifacts and distortion in high resolution TOF-images can be minimized by acquiring 3D-TOF data with a random k-line acquisition scheme, subsequently reordering of k-lines based on the cardiac cycle as deducted from synchronously sampled peripheral pulse unit (PPU)-signal, and compressed sense reconstructions of a separate angiogram for each cardiac phase, which can finally be combined into an artifact-free angiogram. Compressed sensing is in this approach not used to accelerate imaging sequences, but to isolate imaging artifacts arising from cyclic processes such as cardiac pulsations.

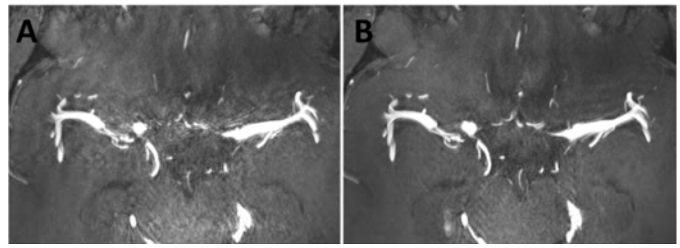

Figure 1: Pulsation artifacts in MRA
The original TOF-angiogram (a) shows clear pulsation artifacts around the vessels, which are substantially reduced when cardiac gating is applied (b). However at the cost of a twofold increase in scan-time.

METHOD: A fully sampled 3D human brain angiography dataset was acquired on a 7 T Phillips scanner using a 32-channel head coil and a 3D gradient echo sequence. K-space was collected using random order Cartesian sampling and the timing of each acquired line in k-space, relative to the R-wave, was recorded using the PPU of the scanner. The applied imaging settings were: matrix = 448 x 446 x 50, FOV = 180 x 170 x 25 mm^3, TR/TE = 23/6.4 ms, and flip angle = 30°. Six images were reconstructed, using L1-SPIRiT[2], from partial k-spaces corresponding to data acquired during 300 ms intervals of the cardiac cycle. The six intervals started at {100, 200, 300, 400, 500, 600} ms after the R-wave. To reduce memory footprint and reconstruction time, the 32 channels were reduced to 24 using coil compression[3]. The L1-SPIRiT reconstruction were performed using a POCS L1-SPIRiT algorithm[4] with 50 iterations, l1-regularization parameter = 0.005, 5 x 5 x 5 GRAPPA kernel, 25 auto-calibration frequencies, and Daubechies 4 wavelets as compressing transform. The fully sampled central part of k-space, used for auto-calibration and also in the reconstruction, contained data from the entire cardiac cycle. After L1-SPIRiT reconstruction, the six images were combined by taking their mean value. For comparison, an ordinary Fourier transform reconstruction was also performed.

RESULTS: Figure 2b shows the result of the L1-SPIRIT reconstruction and the flow artifact is reduced compared to Figure 2a. However, some flow artifacts remain and some stripe artifacts are introduced from the reconstruction.

DISCUSSION: The results show that the proposed method is a feasible solution to flow artifacts in TOF images. However, many future improvements to these results are expected. For instance, the remaining flow artifacts in Figure 2b are of relatively low frequency and likely due the use of central k-space data from the entire cardiac cycle. By denser sampling at the center of k-space the reuse of central k-space lines is no longer needed and the remaining flow artifacts can thus likely be further reduced. Comparison of the images reconstructed from different intervals of the cardiac cycle show evidence of cardiac pulsation induced distortions of the vascular tree. By taking the mean of these images, these distortions will blur the final result and more advanced combinations of these images might result in even sharper images.

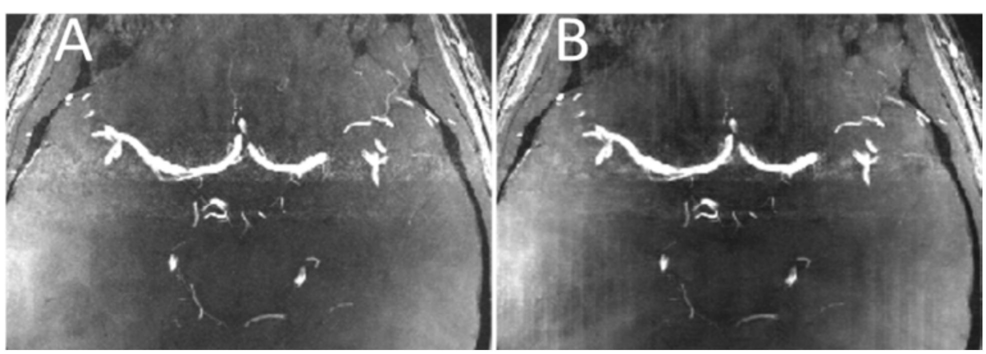

Figure 2: Flow artifact reduction with L1-SPIRiT
(a) Image reconstructed using ordinary Fourier transform. (b) Image reconstructed using the proposed method.

CONCLUSION: L1-SPIRiT in combination with random sampling and retrospective gating can be used to reduce flow artifacts in TOF imaging at 7 T.

REFERENCES: [1]Cho et al Stroke 2008;39:1604–1606, [2]Lustig et al MRM 2010;64:457-471, [3]Zhang et al MRM 2012; DOI 10.1002/mrm.24267, [4]Murphy et al IEEE-TMI 2012;31:1250-1262