Reduction of Respiration Artifacts in 3D Phase Contrast Imaging with Intermittent Fat Saturation

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INTRODUCTION

Time-resolved 3-dimensional phase-contrast MR imaging (4D-PC MRI) is becoming a valuable tool in the clinic for comprehensive cardiac examinations [1-3]. However, the long scan time that is typically required results in motion artifacts from respiration that can limit anatomic visualization. Navigator gating and respiratory compensation can be used to reduce these effects but result in even longer scan times. Because the lipid signal is very bright and tends to originate from close to the chest wall, we hypothesize that the elimination of this signal will reduce the severity of the resulting respiration artifacts. Prior work on fat-water separation in PC imaging has used a dual echo acquisition in conjunction with a non-linear reconstruction [4]. This approach has the advantage of being relatively immune to B0 inhomogeneity but at a cost of a doubling in undersampling in order to keep the scan time fixed. In addition, because the lipid signal is not suppressed during the acquisition it can still produce artifacts in vessels of interest. Here we demonstrate that the inclusion of an intermittent fat saturation pulse in a Cartesian 4D-PC acquisition can reduce the severity of the respiration artifacts and improve vascular visualization with no acquisition time penalty.

MATERIALS AND METHODS:

All imaging protocols were done at 1.5T using Signa scanners (GE Healthcare, Milwaukee, WI, USA). The sequence was a 3D spoiled gradient-recalled echo (SPGR) phase contrast sequence modified to collect k-space data using a variable density Poisson-disc/ellipse pseudo-random sampling pattern [5]. In each R-R interval a block of N pairs of (ky,kz) phase encodes were repeatedly acquired. Each (ky,kz) pair required the collection of four sequential repetition times (TRs) with different flow sensitivities, and as a result the intrinsic temporal resolution of the data was N*4*TR. Fat suppression was enabled by inserting a chemical saturation pulse and spoiler at the beginning of each block of N (ky,kz) pairs. At 1.5T this adds approximately 10 ms to the intrinsic temporal resolution while leaving the overall scan time unchanged. Respiratory compensation was used throughout the entire acquisition. A typical protocol involved imaging in the axial plane using an 8 channel pediatric coil. Coverage was provided with 60, 3 mm thick slices and an in-plane field-of-view (FOV) of 32 cm. The in-plane resolution consisted of a matrix of 256 points in the readout direction and 192 phase encodes. A fractional echo was used to reduce the echo time (TE), and the typical TR and TE were 4.9 ms and 1.9 ms, respectively. Typically N=4 pairs of (ky,kz) phase encodes were acquired in each R-R interval leading to an intrinsic temporal resolution of 78 ms without fat saturation and 88 ms with fat saturation. Gadofosveset contrast had been given for an MRA, and thus was present for the 4D-PC acquisition. After the completion of the study the data were retrospectively interpolated into 20 cardiac phases distributed equally across the R-R interval.

Parallel imaging compressed sensing was performed in the phase and slice direction using a total reduction factor of 2×2. With this prescription and a typical heart rate of 80 bpm the total scan time was on the order of 6 minutes. The data were reconstructed using the L1-SPIRiT algorithm [6] using a GPU-enabled off-line reconstruction.

RESULTS

Figures 1 and 2 show representative images from the above protocol used during free-breathing clinical examinations. It can be seen that the fat suppression was successful at removing most of the lipid signal from the imaging volume. This in turn leads to fewer respiration artifacts across the vessels of interest and greater clarity in the visualization of the anatomical structures.

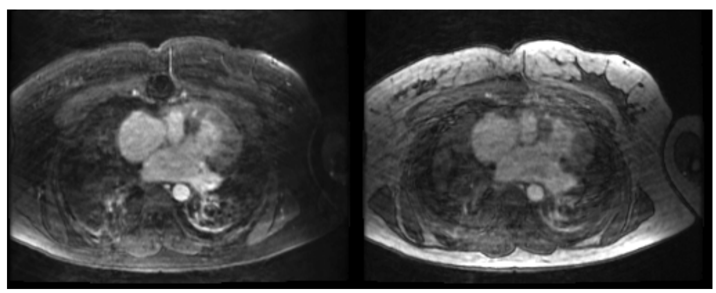

Figure 1: L1-SPIRiT reconstructions of data sampled with a 2x2 reduction factor. Fat saturation was used in the acquisition of the image on the left, while no saturation was done for the image on the right. The elimination of the lipid signal greatly improves the delineation of the cardiac chambers as well as producing a more consistent vascular signal.

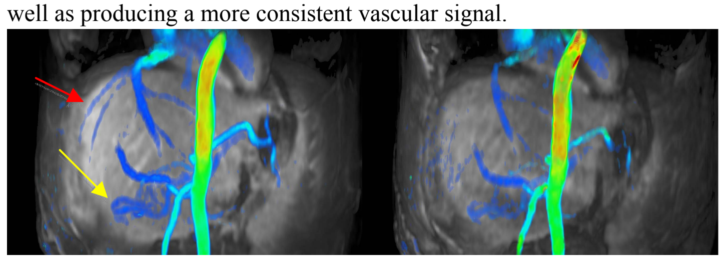

Figure 2: Volume-rendered coronal slabs from an exam with fat saturation (left) and without (right). The fat-suppressed images better depict the pancreaticoduodenal collateral vessels related to portal vein occlusion (yellow arrow) and delineate the right lobe hepatic veins (red arrow) more clearly. Respiratory artifacts on the non-suppressed images blur out these vessels.

CONCLUSION

Respiration artifacts are a necessary consequence of the long scan time inherent in 4D-PC acquisitions. We have shown that the use of an intermittent fat saturation scheme can reduce these artifacts and improve vessel delineation with no increase in scan time. Removing the lipid signal from the imaging volume also makes segmentation easier during data processing. Fewer artifacts across areas of flow also should reduce measurement variability and improve flow estimation. We intend to investigate this hypothesis in the near future.

While fat saturation pulses are subject to failure in areas of B0 inhomogeneity, this generally occurs just over a small fraction of the imaging volume. The intermittent nature of the saturation minimizes SAR effects while producing only a moderate increase in the temporal resolution of the data. At 1.5T this is on the order of 10 ms, but at higher field strength this time penalty will be even less due to the shorter time necessary for chemical saturation pulses.

REFERENCES

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