Improved Time-Resolved, 3D Phase Contrast Imaging through Variable Poisson Sampling and Partial Respiratory Triggering

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INTRODUCTION

Time-resolved 3-dimensional phase-contrast MR imaging (4D-PC MRI) has been shown to be an important tool in a wide variety of research applications, such as wall shear stress measurements [1], aortic pulse wave velocity measurements [2], and the investigation of flow patterns in the heart [3]. The adoption of this technique in routine clinical imaging is primarily hampered by two issues: The long scan time inherent in the acquisition and the resulting respiratory artifacts that come from free breathing during the study. Parallel imaging can be used to significantly reduce scan time [4], but undersampling patterns suitable for GRAPPA-like reconstructions often result in coherent artifacts in the final images. Here we demonstrate the use of variable density Poisson-disc/ellipse pseudorandom sampling [5] in conjunction with the compressed sensing L1-SPIRiT [6,7] parallel imaging reconstruction implemented on general purpose graphics processors (GPGPU) [8]. In addition, we have implemented a partial respiratory triggering approach to further reduce breathing artifacts with a minimal increase in scan time. This combined approach provides improved image quality and better artifact reduction within clinically viable acquisition and reconstruction times.

MATERIALS AND METHODS:

All imaging protocols were done at 3T 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. The Poisson-ellipse modification is used to produce anisotropic reduction factors in the ky×kz directions (Fig. 1). Respiratory triggering was implemented so that a user-specified initial fraction of the study was gated while the remainder of the acquisition would run continuously. These triggered data were collected around the center of (ky, kz) space. Respiratory compensation was used throughout the entire acquisition. A typical protocol involved imaging in the axial plane using a prototype 32 channel pediatric coil. Coverage was provided with 52, 2.4 mm thick slices and an in-plane field-of-view (FOV) of 24 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 repetition time (TR) and TE were 3.8 ms and 1.4 ms, respectively. In each R-R interval two pairs of (ky,kz) phase encodes were repeatedly acquired. For each (ky,kz) pair four sequential TRs were acquired with different flow sensitivities, and as a result the intrinsic temporal resolution of the data was 2*4*TR, or 30.4 ms. 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. In addition, the corners of (ky,kz) space were not acquired. To provide autocalibration data for L1-SPIRiT, a region of 24×20 central phase encodes in the ky×kz direction was fully sampled. With this prescription the total number of required (ky,kz) phase encoding pairs was 1323. Because two (ky,kz) phase encode pairs were acquired in each R-R interval, 662 heart beats were required to complete the scan. The first 30% of the scan was respiratory triggered using an acceptance window of 30%. With a subject heart rate of 96 bpm, the total scan time was approximately 12 minutes. The data were reconstructed using the L1-SPIRiT algorithm [6,7] using a GPU-enabled off-line reconstruction.

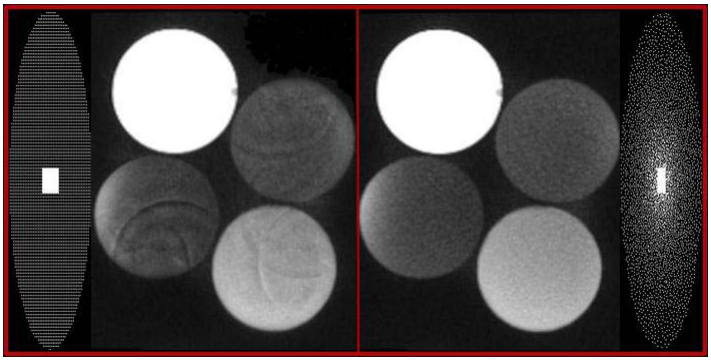

Figure 1: L1-SPIRiT reconstructions of data sampled with a 3x2 uniform rectangular grid sampling (left) and an equivalent 2.45x2.45 variable density Poisson-disc pattern (right). The uniform undersampling pattern manifests errors as coherent artifacts, while the variable density Poisson sampling produces incoherent white noise.

RESULTS

Figure 2 shows representative images from the above protocol used in during a free-breathing clinical examination of a 3 year old female. Partial triggering of the exam reduces the respiration artifacts and the L1-SPIRiT reconstruction produces high quality, low-noise images.

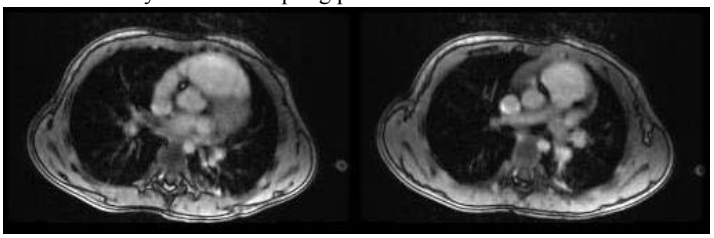

Figure 2: Axial images at the level of the aortic valve (left) and branch pulmonary arteries (right) from a partially triggered free breathing exam acquired using variable density Poisson sampling and an L1-SPIRiT reconstruction. Note the absence of significant respiratory artifacts.

CONCLUSION

Time-resolved 3D-PC MRI is becoming more clinically acceptable with the advent of parallel imaging. Variable density Poisson-ellipse sampling is well suited to provide large reduction factors with improved image quality compared to a traditional uniform subsampling. In addition, partial respiratory triggering provides some reduction of respiration artifacts with minimal increases in scan time.

REFERENCES

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