Sparse Sampling Phase Contrast Imaging of the Aorta

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Target Audience: This work is relevant to investigators interested in the feasibility of applying compressed sensing in cine aortic phase contrast imaging.

Purpose: Compressed sensing or sparse sampling MRI has been shown to be very promising in achieving extremely fast scan times while still resulting in clinically diagnostic image quality. One particular area of interest is 2-D phase contrast flow imaging due to its potentially lengthy scan times when desiring higher spatial resolution and low heart rates. The purpose of this study is to determine the feasibility of applying sparse sampling in high resolution phase contrast imaging by comparing quantitative flow results between sparsely sampled images with to a typical fully sampled clinical acquisition.

Methods: All scans were acquired on a clinical Philips 3.0T system (R3.2.1 software) on a single volunteer with known aortic regurgitation. Each cardiac triggered phase contrast acquisition was acquired at 0.8 x 0.8mm in plane resolution with a 6mm slice thickness, TE/TR = 5.5/15ms, FA = 10 degrees, VENC=200 cm/s, 35 cardiac phases, and 3 signal averages. A total of four scans were acquired (one fully sampled and three sparsely sampled prospectively at 45, 36, and 30%). An offline computer with internally custom developed software based on Kim et al. [2] reconstructed the sparse images. Velocity encoding was done in 2 opposite directions, and the phase difference in the two resulting images ($image_1$ and $image_2$) were obtained for flow quantification. The difference image ($image_{diff}$ = $Image_2$ – $image_1$) only contained flow information and was more sparse due to the background structures canceling out. Thus, it could be reconstructed more reliably than images encoded in a single direction. The flow was then obtained from phase($image_1$+$image_{diff}$)-phase($image_1$), with $image_{diff}$ reconstructed from the difference of k-space data. Region of interest analysis was performed on the ascending aorta.

Results: Figure 1 shows the phase images with different random sampling schemes. Figure 2 shows the flow curves for each data acquisition. All curves exhibit the same flow characteristics. Furthermore, all curves clearly show the flow regurgitation at the 250ms time point. The 36% sampling scheme exhibits the closest curve characteristics compared to the fully sampled dataset. Table 1 lists selected quantitative values for all acquisitions. The maximum flux values for under-sampled images are slightly lower than the fully sampled acquisition. Again, 36% sampling showed the closest agreement to the fully sampled data. Between the 30% sampling and fully sampled data, there is a 6%, 14%, and 3% underestimation of stroke volume, max flux, and average velocity, respectively.

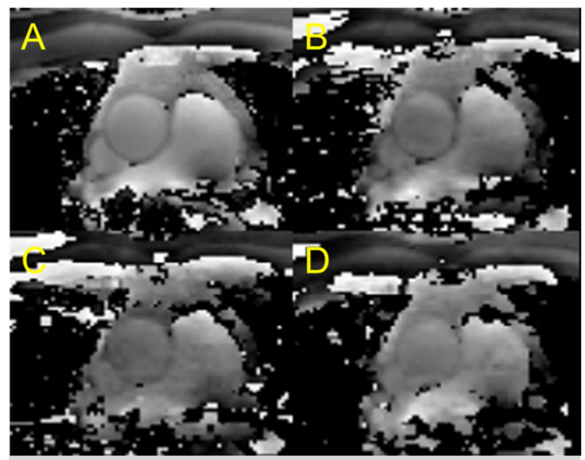

Figure 1: Comparison of (A) fully sampled, (B) 45% sampling, (C) 36% sampling, and (D) 30% sampling phase images

Discussion/Conclusions: Even though there is noticeable image quality degradation in the sparser acquisitions, the quantitative values and flow curve characteristics from the sparsely sampled images are in very close agreement with fully sampled data. Surprisingly, 36% acquisition had better agreement with the fully sampled data than 45% acquisition. This could be due to a number of reasons such as physiologic fluctuations between scans, cardiac triggering inconsistencies, and heart rate variability. The lower quantitative values at 30% sampling is most likely due to the insufficient sampling resulting in an underestimation of values. However, at the sampling rate of 36%, the flow measurements fall within 10%, which is an acceptable error in flow quantitative analysis [3]. Certain values in the 45% and 30% under sampled data are outside the 10% error range. Because the reason for this variability is unclear, more investigation is needed to determine the actual causes. This study has shown that sparse acquisition MRI is feasible in high resolution phase contrast imaging. Investigations on more volunteers and specific patient populations are needed. Furthermore, further testing is required to determine optimal k-space sampling schemes and compress sensing accelerations.

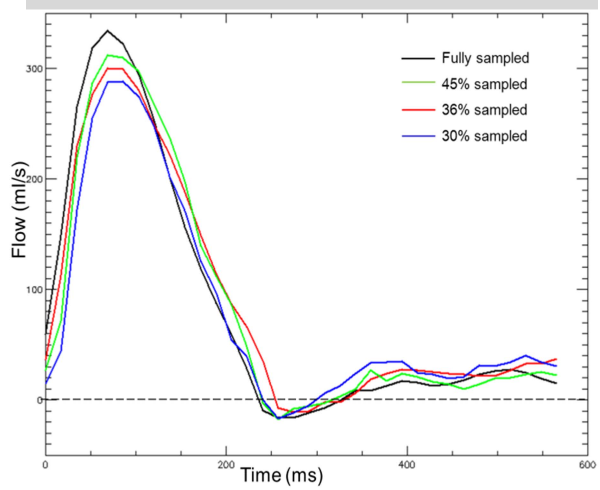

Figure 2: Comparison of flow curves

implementation.

Acquisition %	Acquisition time (mm:ss)	Stroke Volume (ml)	Max flux (ml/s)	Min flux (ml/s)	Average Velocity (cm/s)
100	4:40	48.8	334.7	-16.1	8.88
45	2:06	51.5	300.1	-10.8	9.90
36	1:41	48.5	312.0	-17.7	9.28
30	1:24	45.9	288.5	-16.4	8.67

Table 1

[1] Sparse MRI: The application of compressed sensing for rapid MR imaging. Lustig M, Donoho D, Pauly JM. Magn Reson Med. 2007 Dec;58(6):1182-95.
[2] An Interior-Point Method for Large-Scale l_1-Regularized Least Squares. Kim SJ, Koh K, Lustig M, Boyd S, Gorinevsky, D.IEEE. 2007 Dec;1(4):606-617.
[3] Cardiovascular flow measurement with phase-contrast MR imaging: basic facts and Lotz , Meier C, Leppert A, Galanski M. Radiographics. 2002 May-Jun;22(3):651-71.