Improved Temporal Resolution in Phase-Contrast MRI with Non-Interleaved Velocity Encodings

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Introduction

Phase-contrast MRI measurements of epicardial coronary artery flow holds great promise for functional assessment of the coronary arteries[1]. High temporal resolution is required [2], due to both the rapid motion of the heart as well as rapid changes in the coronary artery flow waveform. Another important requirement for coronary flow measurements is that the acquisition time should be less than a single manageable breath hold of 15 to 30 seconds. This requirement is often achieved by employing segmented k-space acquisition. Phase contrast MRI requires two velocity encodings for each line of k-space to measure blood velocity in a selected direction. The positive and negative velocity encodings for a given segment are typically interleaved, + – + – + – + –, (for 4 views-per-segment, VPS) producing a temporal window of 2*VPS*TR, which can lead to motion blur. The advantage of interleaving the velocity encodings is that the pair of images are closely registered, since the two reconstructed + and – velocity-encoded images cover the same temporal span (offset by a single TR), thus are very close to being identical frames in the heart cycle. We propose the use of non-interleaved velocity encodings, + + + + – – – –, producing a shorter temporal window of VPS*TR for each of the two velocity-encoded images, thus reducing blurring of the lumen and improving the accuracy of the flow velocity measurements. The disadvantage of non-interleaved velocity encoding is that the two reconstructed images now have a temporal separation of 4*TR. The resultant pair of velocity-encoded images will thus have less artifact due to motion and flow, but will require spatial registration prior to phase subtraction.

Methods

Imaging was performed on a 1.5T GE Echospeed scanner (General Electric, Milwaukee, WI). A computer-controlled flow pump was used to deliver constant flow of 20 ml/sec through a phantom consisting of a 6mm tube embedded in gelatin. The phantom was mounted on a motion platform and attached to a motor-driven cam using a 4 meter rigid plastic rod. The motor and the scanner were triggered by the flow pump, thus synchronizing the motion and the acquisition. The flow tube was oriented right-to-left in the bore, and sagittal phase-contrast images at 4 VPS were acquired with both interleaved and non-interleaved velocity encoding. 26 frames were acquired over a 1sec simulated heart cycle with 80mm displacement. Other parameters included 256x256 matrix, 20cm field of view, 8mm slice thickness. Interleaved velocity encoded images were reconstructed on the scanner, while the non-interleaved data was transferred to an offline computer for subsequent analysis using Matlab (Natick, MA). After spatial reconstruction of the positive and negative velocity encoded images, a correlation-shift technique was employed in which the user places a rectangular region-of-interest (ROI) around the flow tube lumen on the first frame of the positively encoded image and a spatial correlation is performed with the negatively encoded image, which is then shifted to register the two images. The ROI is then automatically propagated to subsequent frames until the complete data set is registered. Phase-differencing is then performed to produce the final velocity map. Flow was calculated by placing an elliptical ROI encompassing the apparent lumen of the flow tube in each frame.

Results

Figure 1 illustrates the motion blur present in the interleaved velocity encoding images, and the significant reduction of blur in the non-interleaved velocity encoding images. Figure 2 presents the calculated flow for both scans.

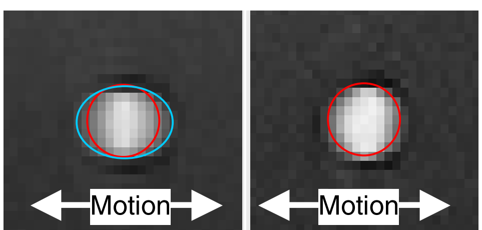

Figure 1. Standard interleaved velocity encodings (left) exhibit significant motion blur, with the apparent lumen shown in blue. The shorter acquisition window for the non-interleaved encodings (right) produces much less blur and more accurate flow measurements. The true lumen size is shown in red in both images.

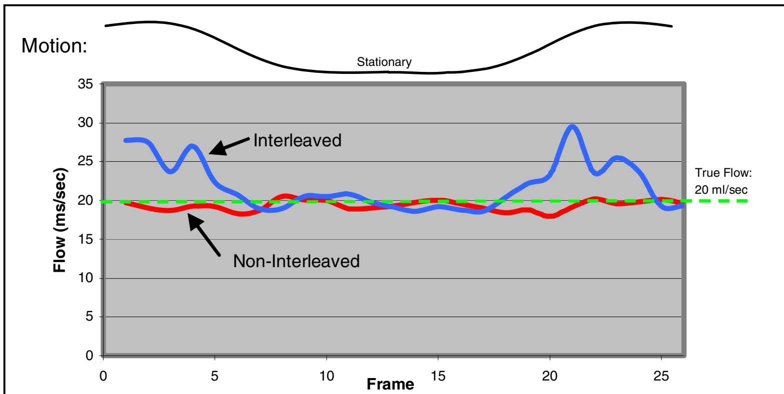

Figure 2. The error due to motion blur in the standard interleaved scan (blue) is evident during the period of motion. Non-interleaved velocity encoding (red) has less error during times of large motion. The actual flow is shown in green.

Discussion

While this new technique requires an additional step, that of registration of the positive and negative velocity encoded images, the execution of that step is readily incorporated into the analysis procedure for flow imaging, since placement of ROIs is already required. This new technique may hold significant promise for accurate measurement of flow in the coronary arteries, especially the more challenging right and circumflex coronary arteries.

References

1. Hundley et al. Circulation. 1999;99:3248-3254.
2. Hofman et al. J Magn Reson Imaging. 1994;8:568-576.