INTRODUCTION

Conventional MRI is sensitive to physiologic motion such as cardiac contraction or respiration. View-ordering methods that match k-space sampling to motion during acquisition have been developed to suppress ghosting artifacts caused by respiratory motion. Recently it has been reported that motion blurring in coronary MRA can also be minimized at no cost of scan time through view ordering. To achieve this goal, however, a precise understanding of motion effects and their quantitative mechanism is crucial. The present study provides important insights into existing view-ordering methods and lays foundation for a more systematic approach towards finding an optimal solution.

METHODS

Cardiac motion effects in 2D coronary MRA were simulated in 8 heartbeats (32 echoes per heartbeat). The motion in each cardiac cycle was assumed to be linear with a motion range of ±5 pixels and include a mid-diastole rest period. It was also assumed that the time scale of sampling during readout is much shorter than the time scale of motion variation. Five basic view-ordering methods were investigated: sequential (seq), center-edge (ce), edge-center (ec), center-edge-center (cece), and edge-center-edge (ece). In each case, point spread function (psf) analysis was performed to characterize quantitatively the dependence of motion blurring on view ordering and motion direction. In particular, full width at half maximum of the psf was measured in both readout and phase-encoding directions (FWHM, FWHM,). These measures indicate the degree of local motion blurring. In addition, normalized energy disturbance (P) was calculated as a global measure of motion artifacts.

RESULTS

Figure 1 shows the resulting psf’s for cce, offset cce and ece view ordering for motion in readout direction (notice that the motion k-maps (first row) are the same function but shifted in frequency). Although the psf’s have the same magnitudes, their corresponding real and imaginary parts are substantially different. Also, the amount of oscillation changes with the shift. Table 1 shows extensive analysis results for five basic view orderings for motion in both readout and phase-encoding directions (FWHM is measured in pixel, and P is dimensionless). The results indicate that ece view ordering achieves the best results; furthermore, setting readout direction to be parallel with motion direction could improve image quality. Figure 2 demonstrates these observations on a phantom image degraded by simulated motion artifacts for different view orderings, when motion is in readout direction.

DISCUSSION & CONCLUSION

The simple example in Figure 1 clearly emphasizes the complex nature of the psf. Different view orderings could lead to psf’s with the same magnitudes but different real and imaginary parts, and different image qualities. Consequently, psf magnitude in general and FWHM in particular are not reliable measures of motion blurring as they are often used now. Results obtained through ece view ordering demonstrates that motion effects can be substantially reduced by minimizing motion at the k-space center and smoothly distributing motion over k-space. This strategy works best because MR signal is concentrated in the low-frequency region of k-space. Violating this strategy could lead to severe motion blurring (see cce in Figure 2). In coronary MRA, this implies that the center of k-space should be sampled during mid-diastole period when cardiac motion is minimal. Finally, setting readout direction to be parallel with motion direction during data acquisition could reduce motion blurring significantly without adding any complexities or scan time.

REFERENCES


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