Respiratory motion based dynamic keyhole reconstruction for real-time thoracic MRI

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Purpose: Real-time patient imaging is utilised in interventional radiology and cancer radiotherapy in order to continuously monitor the region of interest.[1] Magnetic resonance imaging (MRI) is an ideal candidate for medical applications due to (1) excellent soft tissue contrast, (2) non-ionizing radiation and (3) recent developments of radiation therapy systems combined with MRI[2]. However, thoracic imaging in conventional MRI requires a long scan time.[3,4], which is also insufficient for real-time motion tracking. Dynamic keyhole reconstruction method has been previously demonstrated to improve MR images in the presence of respiratory motion with healthy subjects.[5] This study aims to demonstrate that the dynamic keyhole method can achieve better image quality and faster image acquisition with lung cancer patients for real-time thoracic MRI.

Methods: To investigate the improvement of image quality and acquisition time, eight MR-image datasets from three lung cancer patients were reconstructed using the dynamic keyhole method. For thoracic imaging, the T2-TrueFISP (True fast imaging with steady state precession) MR pulse sequence in Siemens Skyra 3T scanner was employed and parameters were TR/TE = 308.71/1.32 ms, FOV = 380 ×380 mm^2, pixel size = 1.48 × 1.48 mm^2 and image matrix = 256 × 256. There were 512 coronal images in each dataset acquired for 158 s. Respiratory signals were obtained on (1) abdomen using real-time position management system (Varian) during MRI scan and (2) diaphragm using 2D coronal images. In this study, the dynamic keyhole method utilized respiratory signals to match the peripheral region of k-space to the dynamic keyhole region of central k-space data (see Figure 1). Full k-space data are sorted into a library based on their respiratory displacement and the sorted data are then placed in a full respiratory cycle without duplicates,(see Figure 1(a)). Real-time acquisition is started with different keyhole sizes except for peripheral region retrieved from the sorted data in the closest respiratory displacement in Figure 1(b). Reconstruction is then performed with peripheral and central k-space stream, shown in Figure 1(c). In order to investigate the efficacy of the dynamic keyhole method, it was compared to currently utilized reconstruction methods: conventional keyhole[6] and zero-filling[7], in a reconstruction simulation. Reconstruction performance was quantified by (1) comparing image quality of the three reconstruction methods to an original image (full k-space), (1) comparing the required number of reused phase encoding lines (an indication of image acquisition time) across the different reconstruction methods, and (2) keeping the number of phase encoding lines fixed across the three reconstruction methods (fixed at 220 of 256 phase encoding lines) to compare the resultant image quality. The reconstructed images in points (1) and (2) were also compared to an original image (full k-space).

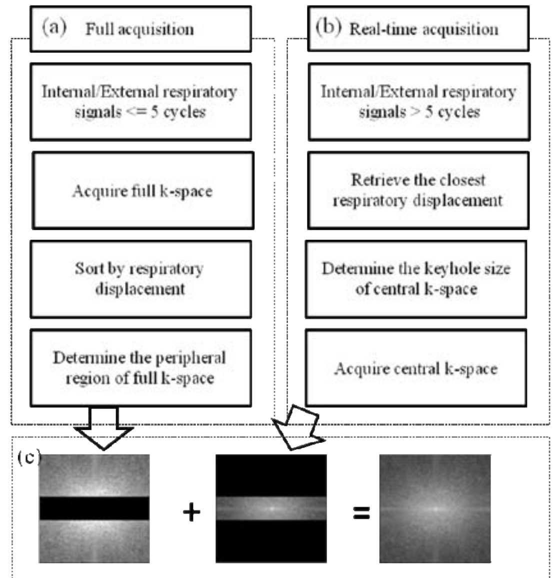

Figure 1. *The dynamic keyhole method: (a) The full acquisition, (b) The partial acquisition and (c) reconstruction.*

Results and Discussion Figure 2 shows the three reconstructed images compared to the original image. A larger peripheral region indicates a smaller keyhole size, corresponding to faster imaging. The image quality across the three reconstruction methods was compared using 220 of 256 phase encoding lines for peripheral k-space region, shown in Figure 3. The reconstructed image by the dynamic keyhole method using 220 peripheral phase encoding lines has minimal difference in terms of image quality as well as tumor delineation (shown as the redline outline in Figure 3), demonstratively superior to the zero-filling and conventional keyhole methods. The average number of phase encoding lines reused in peripheral region across the three methods during central data acquisition and is shown in Table 1. The dynamic keyhole method reused an average of 222±18 of 256 (86%) lines in peripheral region compared to 166±4 of 256 lines (65%) in the zero-filling method and 186±16 of 256 lines (73%) in the conventional keyhole method. There was a difference in the average of 6 peripheral phase encoding lines between the respiratory signals in the dynamic keyhole method (p-value 0.10).

Conclusion The The dynamic keyhole method using respiratory signals has been demonstrated to reconstruct MR images with a considerably smaller amount of central phase encoding lines, with minimal image intensity loss on the tumor compared to other currently available reconstruction methods. These results suggest that the dynamic keyhole method could be a desirable technique for MRI-guided radiotherapy that requires real-time MR monitoring in the thoracic region.

References [1] P. Keall, *et al.* Med Phys **33**, 3874(2006). [2] B. Raaymakers, *et al.* Physics in medicine and biology **54,** N229 (2009). [3] E. Tryggestad, *et al.* Med Phys **40**, 1712 (2013). [4] T. Bjerre, *et al.* Phys Med Biol **58**, 4943(2013). [5] D. Lee, *et al.* AAPM (2012). [6] J. Vaals, *et al.* JMRI **3**, 671(1993). [7] R. Yang, *et al.* Radiographics **30**, 185 (2010).

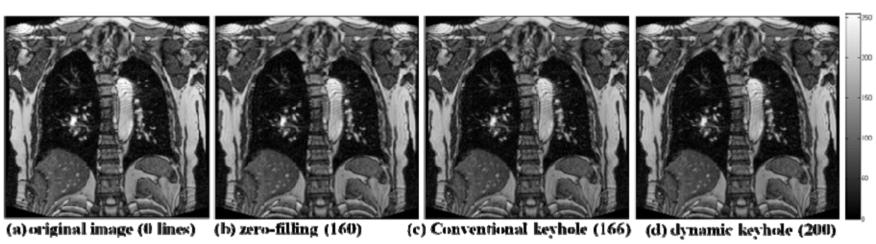

Figure 2. *Reconstructed images using the different phase encoding lines of peripheral region were compared to original image: (a) Original image, (b) zero-filling reconstructed image (160 peripheral and 96 central lines), (c) conventional keyhole reconstructed image (166 peripheral and 90 central lines) and dynamic keyhole reconstructed image (200 peripheral and 56 central lines).*

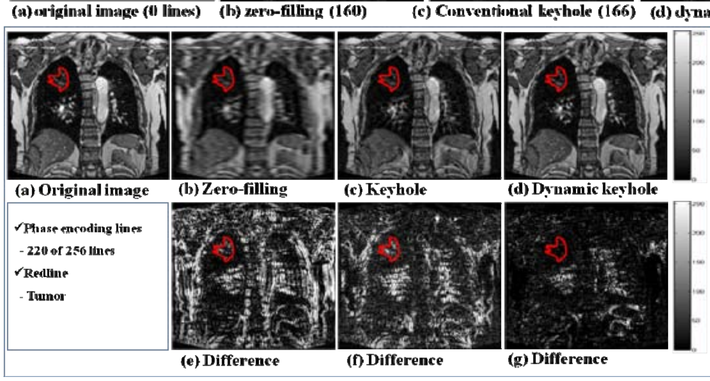

Figure 3. *Reconstructed images using three methods: (b) the zero-filling, (c) conventional keyhole, and (d) dynamic keyhole. The difference between (a) original image and reconstructed images is displayed on (e), (f) and (g).*

Table 1. *The average of peripheral region to achieve the same image quality and the standard deviation (STD) and paired Student t-test p-values (Internal denotes internal signals and External denotes external signals).*

Methods	Signal types	Mean ± STD (Phase encoding lines)	p-value
Zero-filling	Internal/External	166±4 (65%)	0.45
Conventional keyhole	Internal	186±16 (73%)	0.08
	External	178±10 (70%)	
Dynamic keyhole	Internal	222±18 (86%)	0.10
	External	218±16 (85%)	