T2-weighted 4D-MRI with combined phase and amplitude sorting

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Target audience: Radiation oncologists, radiologists, medical physicists, MR scientists, and MR technicians who have interest in 4D MRI of the abdomen, abdominal cancer, and respiratory biomechanics of the abdomen.

Purpose: T2-weighted MRI provides excellent tumor-to-tissue contrast for target volume delineation in radiation therapy treatment planning. This study aims to develop a novel T2-w retrospective 4D-MRI phase and amplitude hybrid sorting technique for imaging organ/tumor respiratory motion.

Method and Materials: A 2D fast T2-weighted Half-Fourier Acquisition Single-Shot Turbo Spin-Echo (HASTE/SSFSE) MR sequence was used for image acquisition of 4D-MRI, with a frame rate of 2~3 frames/s. Respiratory signal was measured using external breathing monitoring devices. The combined sorting method sorts the images based on either the calculated phases or the amplitudes, as long as the amplitude of the image is in the amplitude range of a certain phase, it would be sorted to that phase, regardless of its inhalation or exhalation status. Besides, a result-driven strategy was applied to effectively utilize redundant images in case more than one image is collected for a certain bin at a certain slice location. This strategy, as showed in Figure 1, choosing the image with minimal amplitude difference with average amplitude for each bin on the average respiratory curve, will generate the most representative 4D-MRI. An important challenge of the proposed technique is to determine the number of repeated scans (N_R) required to obtain all phase information at each slice position, due to its sequential image acquisition scheme (in comparison with cine or helical image acquisition scheme). To tackle this challenge, we firstly conducted computer simulations using RPM respiratory signals of 29 cancer patients to derive the relationships between N_R and the following factors: number of slices (N_S), number of respiratory bins of the 4D-MRI (N_P), and starting phase at image acquisition (P_0). The hybrid sorting technique considerably diminishes the required scanning time compared with phase or amplitude sorting. To validate our technique, 4D-MRI acquisition and reconstruction were simulated on a 4D Digital Extended Cardiac-Torso (XCAT) human phantom[1] using derived parameters. 5 healthy volunteers were involved in an IRB-approved study to test this technique.

Result: Percentage of complete acquisition of all required phases (C_P) increases as N_R increases in an inverse-exponential fashion (C_P=100-98*exp(-0.28*N_R)], when N_P=10, fitted using 29 patients' data), as showed in Figure 2. The N_R needed for 4D-MRI (defined as achieving 95% completeness, C_P=95%, N_R= N_{R95}), is proportional to N_P (N_{R95}~2.86*N_P, r=1.0), but independent of N_S and P_0. Simulated 4D-MRI on the digital phantom showed a clear pattern of respiratory motion. Tumor motion trajectories measured on 4D-MRI were comparable to the average input signal, with a mean relative difference of 2.7±2.9%. Reconstructed 4D-MRI for healthy volunteers illustrated clear respiratory motion in all three planes, with minimal image artifacts, presumably due to breathing irregularity and incompleteness of data collection (95% collected only). The mean relative difference of critical structure trajectory in superior-inferior (SI) direction for 5 healthy volunteers is 11±7%, which is comparable to voxel size. A representative 4D-MRI of a healthy volunteer is shown in Figure 3.

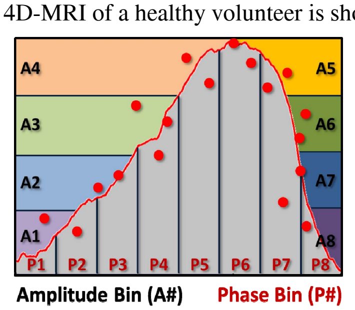

Figure.1 Using result-driven strategy to effectively utilize redundant images.

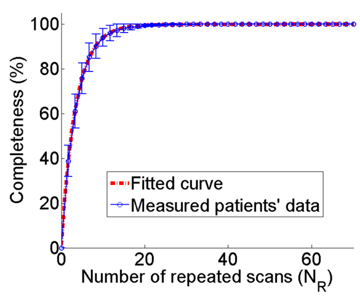

Figure.2. Inverse-exponential relationship between N_R and completeness (%)

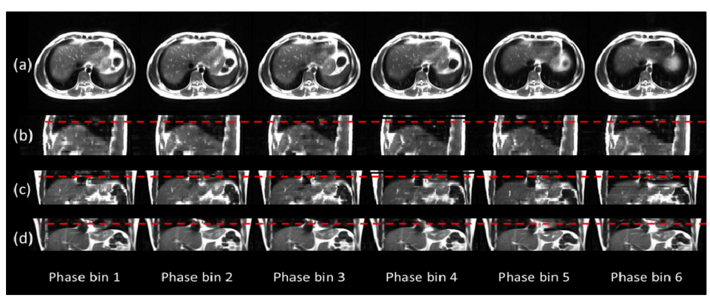

Figure.3. Reconstructed 4D-MRI for one represent healthy volunteer in axial (a), sagittal(b), coronal(c) view and comparison with cine in coronal view (d).

Discussion: The technique can potentially be applied to liver, pancreas and other abdominal tumors, even lung tumors, to reveal the respiratory tumor/organ motion. Compared to current clinical standard of 4D-CT imaging in radiotherapy, this technique will improve our ability to deliver radiation treatment to tumors and mitigate radiation-induced injury to surrounding healthy tissues, and ultimately improved treatment outcome.

Conclusions: A novel T2-weighted, retrospective, 4D-MRI technique based on phase and amplitude hybrid sorting has been developed and successfully tested in healthy volunteer. Future evaluation of the technique on patients is warranted.

Reference: 1. Segars, W. P., et al. "4D XCAT phantom for multimodality imaging research." Medical physics 37 (2010): 4902.