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Potential for Sensitive Cardiac Substructure Sparing Using MR-Guided Radiation Therapy

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staying as the mainstream in clinical practice. The purpose of this study is to explore the potential of using 4DCT information to remove motion-induced errors in 3D PET/CT images.

Materials/Methods: A novel iterative image-to-image (III) reconstruction algorithm was developed. Specifically, a motion-blurred PET image was considered as a weighted average of PET images acquired at different respiration phases. PET images at each phase were assumed to be deformed from a virtual reference image. Image-intensity-based B-Spline registrations were performed on 4DCT from the end-inhale to the other phases. Resultant deformation maps were used to establish a set of composition equations between the virtual reference image and the blurred PET image. A maximum likelihood estimation maximization (MLEM) algorithm was used to solve these equations. The solution of these equations was smoothed by minimizing total gradient variations before generating the virtual reference image. A 10-phase 4D dataset with the resolution of 3.64×3.64×3.24 for PET and1.37×1.37×2.15 for CT was acquired from a lung cancer patient and used to benchmark the computed results. Different from previous studies, the III-reconstruction was performed in the image space, so there is no any tracking device or sorting operation required during the PET image acquisition.

Results: For the blurred PET, III-reconstructed PET and PET0 (which is the 4D-PET at the end-inhale phase), their relative SUV_{peak} are 10.2, 12.7 and 12.8, and SUV_{max} are 9.2, 12.5 and 13.1. With PET0 taken as the baseline, the III-reconstruction reduced the motion-induced error from 20.3% to 0.8% for SUV_{peak}, and from 29.8% to 4.6% for SUV_{max}. The mean SUV difference between the III-reconstructed PET and PET0 was 1.8% in the tumor region, and 13.2% over the whole image domain. Large differences between the two PET images were located mainly in the chest wall where ribs were mis-registered about 6 mm due to discontinuous motion between the ribs and lungs. The III-reconstruction algorithm was also applied to the 4DCT image. Image contrast ratios for the blurred 3DCT, III-reconstructed CT, and CT0 are 1.8, 3.7 and 4.0, respectively.

Conclusion: The III-reconstruction method can be used to correct motion-induced errors in SUV_{max} and SUV_{peak} and improve image contrasts in free-breathing PET and CT images. This method does not require sorting projection data, thereby reducing financing cost and clinical burden. Further investigation of this reconstruction method is warranted.

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Potential for Sensitive Cardiac Substructure Sparing Using MR-guided Radiation Therapy

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Purpose/Objective(s): Mounting evidence suggests that cardiac substructures are highly radiosensitive. However, these structures are not typically considered in treatment planning because they are not readily visualized on treatment planning CTs (TPCTs). This work sought to evaluate the potential of integrating soft tissue contrast provided by MR-guided radiation therapy for highly effective cardiac substructure sparing.

Materials/Methods: A retrospective evaluation was conducted of 10 patients (11 lesions) in the upper thoracic region treated at varied breathing states (4 end-exhalation, 6 end-inhalation, 1 free-breathing) on a 0.35T MR-linac. A hybrid MR/CT cardiac substructure segmentation atlas propagated 13 cardiac substructures to TPCTs. Contour modifications were performed by radiation oncologists using registered 0.35T MRIs to elucidate substructures. Clinical step and shoot IMRT treatment plans were reoptimized to reduce substructure doses while maintaining target coverage and sparing other organs at risk. Monte Carlo dose calculations were performed on the TPCTs. Equivalent dose conversion to 2 Gy fractions (EQD2, $\alpha/\beta = 2$) was used for dosimetric assessment including mean heart dose (MHD) and left ventricular volume receiving 5Gy (LV-V5). Dose to 0.03 cc ($D_{0.03cc}$, a surrogate for maximum dose) and mean doses were evaluated for the left anterior descending artery (LADA), coronary arteries, and ventricles. As metrics of plan complexity, total monitor units (MUs) and treatment time were evaluated between planning approaches. Plans were evaluated for beam arrangement modification to further improve sparing.

Results: Cardiac sparing plans reduced the MHD (0.8 ± 0.7, range: 0.1 to 2.5 Gy). Reoptimized cardiac sparing plans reduced $LADA_{mean}$ and $LADA_{0.03cc}$ (4.8-51.1% and 0.1 to 14.4 Gy, respectively). $LV_{0.03cc}$ was reduced >1 Gy for 7 patients while large reductions (>7%) in LV-V5 were observed in 4 cases. Left atrial mean dose was equivalent/reduced in all sparing plans (mean reduction 1.1 ± 1.4 Gy). The left main coronary artery was better spared in all cases for mean dose and $D_{0.03cc}$. A left lung cancer patient exhibited >10 Gy reduction in $D_{0.03cc}$ to the LV, heart, left atrium, and pulmonary veins with sparing. Negligible increase in estimated delivery time was found with reoptimized plans (0.1 ± 1.3 min) with 7/11 plans having <100 MU change. New beam arrangements for preferential cardiac sparing were possible for 4 patients, leading to further reductions of dose metrics.

Conclusion: By introducing cardiac substructures into treatment planning in the setting of MR-guided RT, an opportunity is presented for more effective sparing. Similar delivery times and MUs were observed between planning strategies**, suggesting limited increase in plan complexity with cardiac sparing**. Validation in a larger cohort with appropriate margins offers potential to reduce radiation-related cardiac toxicities.

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