Evaluation of the Effects of Dose on 4DCT-Calculated Lung Ventilation

Introduction: Ventilation imaging using 4DCT would make it easy to use lung functional information in radiation therapy (RT) treatment planning to spare normal functional lung volumes. Deformable image registration (DIR) along with ventilation algorithms are used to derive ventilation from 4DCT scans. This study uses the optical flow (OF) DIR method (1) and the ΔV (2) ventilation calculation algorithm to evaluate the effects of radiation treatment dose on lung ventilation.(3, 4)

Methods: 4DCT data sets before and after RT from three patients are used in this study. The after RT scans were performed on patients who came back for treatment to a different region of the lung. They were acquired at 26, 3 and 6 months after RT for patient A, B and C, respectively. Optical flow is applied to register an image acquired near end inspiration to an image acquired near end expiration to estimate ventilation. The ΔV method, which is a direct geometrical calculation of the volume change, was used to calculate the local lung expansion or contraction. This volume change serves as an index of regional lung ventilation.

In order to address the uncertainties in the ventilation image calculation process and to reduce the effects of CT noise on ventilation a 3 × 3 × 3 voxel spatial averaging of the resulting ventilation images was performed to generate the final ventilation images. Furthermore, the images were normalized based on the volume coverage in the accumulative ventilation-volume histogram for the lung to remove the effects of breathing differences from before and after RT. In order to quantitatively compare the ventilation images both sets had to have the same coordinate system. The ventilation image is defined in the exhale phase therefore we registered the exhale data sets and applied the registration transformation to the ventilation map. For each patient the post RT exhale CT was registered to the pre RT exhale CT using deformable registration.

Planning dose and ventilation were superimposed on the CT volume (Fig 1a) to produce 3D dose-ventilation-volume surfaces similar to Fig 1b. Integrating the surface in Fig 1b over dose reduces the 3D surface to a 2D histogram that is easier to interpret (Fig 1c, and Fig 1d).

Results: For lung tissue regions receiving more than 20 Gy, a decrease in ventilation was observed in the three subjects. Patient A showed an increase in ventilation for regions receiving a dose smaller than 20 Gy, whereas patients B and C did not show any change for these regions. Mean ventilation within the 20 Gy region (Fig. 1e) for patient A was 0.57 before RT and 0.51 after RT, 0.54 before and 0.48 after RT for the 30 Gy region (Fig. 1f). Mean ventilation for the 20 Gy region for patient B was 0.49 before RT and 0.47 after RT, for the 30 Gy region mean ventilation was 0.49 Gy before and 0.45 Gy after RT. Patient C’s mean ventilation for the 20 Gy region was 0.54 before RT and 0.50 after RT, for the 30 Gy region mean ventilation was 0.54 before RT and 0.49 after RT.

Conclusions: Lung ventilation prior to and following radiation therapy can be measured by using 4DCT and image registration techniques. In a preliminary application of this approach for three patients, changes in ventilation were observed with a weak correlation between ventilation change and dose. The observed effects of dose on ventilation may be real or may be due to the limited patient sample size. More data points will enable us to make a stronger conclusion on the changes of ventilation for patients undergoing radiotherapy treatment.
Fig 1: Ventilation analysis for a representative patient. (a) dose and ventilation superimposed on the CT image, (b) dose-ventilation-volume surface, (c) volume-ventilation histogram for voxels receiving more than 20 Gy, (d) volume-ventilation histogram for voxels receiving more than 30 Gy, (e) mean ventilation within the 20 Gy isodose volume, and (f) mean ventilation within the 30 Gy isodose volume.

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