4DCT image-guidance for SBRT

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Purpose:

To investigate changes in target volume (gross tumor volume, GTV; planning target volume, PTV), respiration target motion trajectory and motion envelope over 3 to 5 fraction SBRT for primary lung and liver cancer.

Methods:

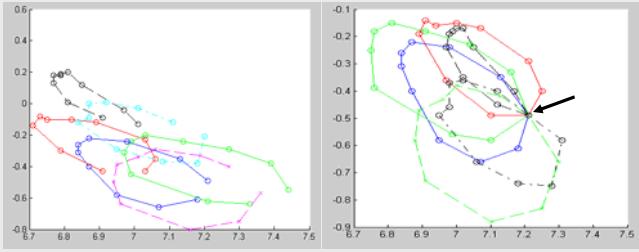
Seventeen patients underwent 4DCT simulation, and repeat 4DCT imaging for SBRT image-guidance (64 re-4DCT; 1-5 re-4DCT/patient, median 5). Target volumes were individually delineated in the following CT data sets: free-breathing (FB), 10 respiratory phases (0-90%), maximum intensity projection (MIP), minimum intensity projection (MinIP), and average intensity projection (AveIP). We analyzed the pattern of target motion and motion changes over time. We also analyzed target volume changes over time, and assessed if typical SBRT planning target volumes (PTV_{FB}: GTV_{FB} + 5 mm axial, 10 mm cranio-caudal; PTV_{MIP}: ITV_{MIP} + 5 mm) would encompass the motion envelop during the SBRT course.

Results:

GTVs were stable (+/- 20%) over a course of SBRT in 13 patients; 2 tumors did shrink by up to 39%, while 2 tumors increased in size by up to 31%. Shape of the motion trajectory was characteristic for individual patients over the SBRT course in 15/17 patients, while maximum respiration target centroid displacement was more variable. Motion trajectories approximated a motion plane in 13/17 patients; 2 cases studied showed a complex three-dimensional motion profile, while 2 cases demonstrated somewhat erratic motion. Inter-individually, motion trajectories varied widely. The simulation derived PTV_{MIP} and PTV_{FB} were larger than respective volume calculations in control 4DCT studies in 69%, and 68.4%, respectively, indicating that the target motion envelope at simulation was larger than during the SBRT course. However, in 21.4%, and 29.9% of controls, the PTV_{FB} and PTV_{MIP} derived from simulation 4DCT studies were smaller than control CT derived PTVs by up to 75%, with individually associated loss of motion envelope coverage. The respective motion envelope coverage by the clinically utilized PTV_{MIP} was better than 90%. While the PTV_{FB} provided similar coverage, the respective volumes differed from PTV_{MIP} by up to 70% (mean 106%).

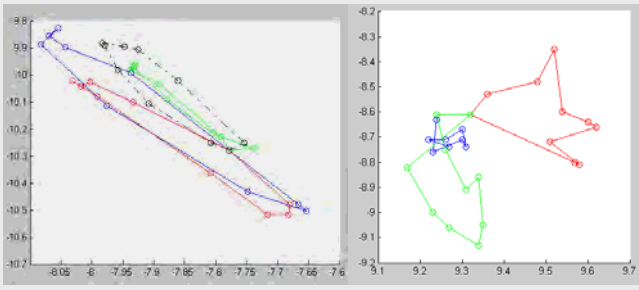
Conclusion:

In this preliminary analysis, 4DCT image-guidance assessed changes in target motion over time were observed in the majority of patients. Individually, significant changes in respiratory target motion were observed that prompted adaptive re-planning to minimize the risk of target miss (n=2) or allowed for significant normal tissue sparing (n=2). Changes in target motion were randomly observed early and late in the SBRT course, and were individually not predictive of motion during the following fraction.



Upper left figure: Motion trajectories of a stage 1 NSCLC during SBRT simulation (blue), and subsequent 5 fraction SBRT 4DCT image-guidance (centroid motion depicted relative to stereotactic frame coordinates). The trajectories appear similar in shape, indicating a relatively constant motion pattern. Tumor motion assumes roughly a planar motion pattern.

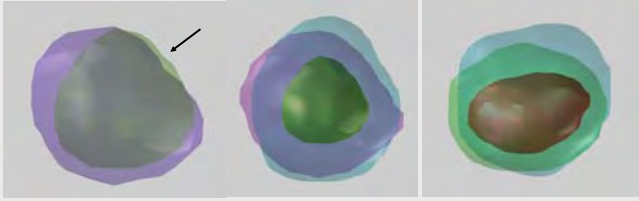
Upper right figure: Same tumor trajectories as left but following image-guided alignment optimization according to tumor centroid position in the 0% reconstructed breathing phase (arrow). While the basic breathing pattern appears characteristic, a resulting ITV and PTV would differ between studies.



Additional lung tumor motion trajectories

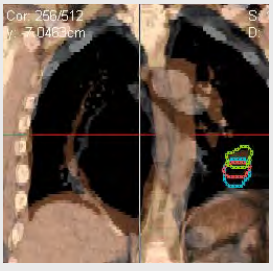
Upper left figure: Motion trajectories of a lung metastasis during SBRT simulation (blue), and subsequent 3 fraction SBRT 4DCT image-guidance (centroid motion depicted relative to stereotactic frame coordinates). Maximum centroid motion displacement shows variability, while the underlying motion pattern remains constant.

Upper right figure: Motion trajectory of a lung metastasis. Here a rather erratic motion pattern with large motion displacement variations between image-guidance 4DCT studies is observed.



Upper left figure: Free-breathing scan derived GTV (green), and 4DCT derived ITV (purple) delineated based on back to back acquired CT studies in the same patient. As assumed, the GTV does not represent the entire motion envelope. Interestingly, the 4DCT derived ITV does not fully encompass the free-breathing CT derived GTV either (arrow)!

Middle and right figures: Depicted are two target volumes (ITV) derived from 4DCT MIP reconstructions (middle figure in green; right figure in red). The respective PTV_{MIP} represents a 3D extension of the ITV by 5 mm (middle figure in blue, right figure in green – not depicted to scale!). A corresponding PTV_{FB}, derived from target delineation and extension based on a separate free-breathing CT scan acquired immediately before the 4DCT image acquisition, overlaps largely with the PTV_{MIP}, but encompasses differing amounts of normal tissues than the PTV_{MIP} (left figure: PTV_{FB} in purple is smaller than PTV_{MIP}; right figure: PTV_{FB} in blue is larger than PTV_{MIP}).



Left figure: Extreme case of ITV variability in two 4DCT studies acquired for SBRT image guidance (the red volume represents the simulation CT derived ITV).

Such significant variations in ITV position and/or volume may be observed in about 15% of lung tumor cases treated.

In our limited institutional experience, we observed 4 similar cases since July 2007. While 3 tumors were located in the lower lobes, one tumor was located in the middle lobe. In the case presented, adaptive re-planning was performed based on each new 4DCT study.