Probabilistic planning for liver SBRT

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Purpose/Objective: Treatment planning for Stereotactic Body Radiation Therapy (SBRT) of liver tumours is often challenging due to large respiratory motion and a close vicinity of OARs such as great vessels and duodenum. In such cases a section of the PTV is edited to spare nearby OARs. We evaluated a PTV-less probabilistic planning technique which directly incorporates respiratory motion and other geometric uncertainties of the GTV in the dose optimization process. An improved balance between OAR exposure and the confidence of proper target dosage is expected, as well as a more efficient planning procedure since less human interaction is required.

Materials and Methods: Four liver SBRT plans (3x20 Gy prescription) for which clinical planning had been problematic due to OAR constraints were re-planned using an in-house developed research plug-in for Pinnacle (version 9.100). The plug-in combines the tumour trajectory extracted from the 4D planning CT (~1 cm amplitude for this case) with the Gaussian distribution of random errors (0.25 cm) into a dose blurring kernel, and incorporates a Gaussian distribution of systematic errors as GTV offsets (0.34 cm). Our probabilistic objective assumes shift invariance and aims for a set confidence (e.g. 90%) of GTV minimum dose. Clinical and probabilistic plans were compared using in-house software that accurately simulates the effects of motion and uncertainties on an optimized dose distribution by explicitly sampling three daily errors for each systematic error (10000 were simulated), and 100 positions along the breathing trajectory for each daily error. OARs were evaluated via a traditional DVH.

Results: In three out of four cases the probabilistic plan showed a clear clinical benefit compared to the conventional plan. In two cases the clinical PTV coverage was lowered to spare the great vessels and duodenum, here probabilistic planning significantly increases GTV coverage, while maintaining a low enough dose on the OAR (e.g. Fig. 1). In a third case a higher dose to the great vessels was tolerated in the clinical plan in favour of getting proper PTV coverage. Using probabilistic planning we were able to reduce the great vessel dose while still reaching 90% target dose confidence. In the fourth case all clinical constraints were met both in the clinical and probabilistic plan.

Conclusions: Probabilistic planning can make a valuable contribution to treatment planning in those cases in which it is difficult to meet all clinical criteria.

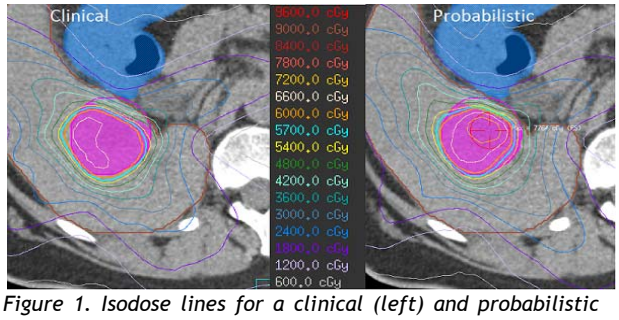

Figure 1. Isodose lines for a clinical (left) and probabilistic (right) plan. Due to the overlap of the duodenum (blue) with the PTV (pink line), clinical optimization was done only on the dashed part of the PTV, leading to reduced GTV dose confidence (99% of the volume received 87.5% of the dose with a probability of 90%). Probabilistic planning did not use a PTV, and led to sufficient GTV coverage (99% of the volume received 95% of the dose with a probability of 90%) while still sparing the duodenum.

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Normal lung tissue reaction to stereotactic body radiation therapy

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Purpose/Objective: Stereotactic body radiation therapy (SBRT) is becoming the standard of care for early stage lung cancer patients. Toxicity data of lung injury after SBRT remains sparse. Our work evaluated toxicity by analyzing lung density changes for lung cancer patients that underwent SBRT.

Materials and Methods: From 2003 to 2009, 63 patients received SBRT treatments in 3-5 fractions for a total median dose of 54Gy (range 30-60Gy). RT-induced lung density changes were evaluated after registration of the planning CT with post-RT CT scans acquired at 3, 6, 12, 18, and 24 months after treatment. A comprehensive dose-response analysis was performed including 1) CT number (HU) changes as a function of dose, 2) spatial analysis of lung fibrosis location, and 3) correlation of lung tissue changes with clinical end-points. We generated patient specific dose-response curves (DRC) by binning voxels into 10Gy dose bins, calculating the average HU for each dose bin, and evaluating the HU change as a function of dose. Spatial analysis was performed by contouring regions of fibrosis and analyzing the centroid movement of the fibrosis volume relative to the gross tumor volume (GTV) centroid. Airway or vessel branches inside the lung were paired on the pre- and post-RT scans to guide the spline based deformable registration of the lung. Regional density increases were classified as local lung collapse or fibrotic based on the local volume changes calculated using the deformation field Jacobian.

Results: DRCs exhibited a linear HU increase up to 35Gy and a plateau beyond 35Gy. The response of the 4-5fx (high toxicity risk) and 3fx (lower toxicity risk) groups were notably different as the 4-5fx group experienced HU changes twice the increase seen in the 3fx group. The average radial movement of fibrosis centroids relative to the GTV centroids was 2.6 cm with movement greater than 5 cm occurring in 11% of patients questioning the direct exposure of the fibrotic tissues to high doses. 30% of patients with a large fibrotic tissue displacement showed concurrent local lung volume contraction (according to the Jacobian) compatible with radiation-induced regional lung collapse.

Conclusions: The current study presents a comprehensive dosimetric, spatial, and clinical analysis of lung density changes after SBRT. In addition to characterizing dose response after SBRT, we demonstrate certain unexpected observations including a dose-response plateau at 35Gy and fibrosis volume travel outside of the high dose region. Our clinical analysis suggests some of these abnormalities may be explained by regional lung collapse due to high SBRT doses to the proximal airways. Although current clinical toxicity rates with SBRT are low, as treatments become more aggressive, toxicity rates will increase and better prediction of lung response will be needed. Our work presents important data towards the mechanical and clinical understanding of lung injury after SBRT.