Impact of Geometric Uncertainties on Dose Calculations for Intensity Modulated Radiation Therapy of Prostate Cancer

by

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Abstract

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Intensity-modulated radiation therapy (IMRT) uses non-uniform beam intensities within a radiation field to provide patient-specific dose shaping, resulting in a dose distribution that conforms tightly to the planning target volume (PTV). Unavoidable geometric uncertainty arising from patient repositioning and internal organ motion can lead to lower conformality index (CI) during treatment delivery, a decrease in tumor control probability (TCP) and an increase in normal tissue complication probability (NTCP). The CI of the IMRT plan depends heavily on steep dose gradients between the PTV and organ at risk (OAR). Geometric uncertainties reduce the planned dose gradients and result in a less steep or "blurred" dose gradient. The blurred dose gradients can be maximized by constraining the dose objective function in the static IMRT plan or by reducing geometric uncertainty during treatment with corrective verification imaging.

Internal organ motion and setup error were evaluated simultaneously for 118 individual patients with implanted fiducials and MV electronic portal imaging (EPI). A Gaussian probability density function (PDF) is reasonable for modeling geometric uncertainties as indicated by the 118 patients group. The Gaussian PDF is patient specific and group standard deviation (SD) should not be used for accurate treatment planning for individual patients. In addition, individual SD should not be determined or predicted from small imaging samples because of random nature of the fluctuations. Frequent verification imaging should be employed in situations where geometric uncertainties are expected. Cumulative PDF data can be used for re-planning to assess accuracy of delivered dose. Group data is useful for determining worst case discrepancy between planned and delivered dose. The margins for the PTV should ideally represent true geometric uncertainties. The measured geometric uncertainties were used in this thesis to assess PTV coverage, dose to OAR, equivalent uniform dose per fraction (EUD_f) and NTCP.

The dose distribution including geometric uncertainties was determined from integration of the convolution of the static dose gradient with the PDF. Integration of the convolution of the static dose and derivative of the PDF can also be used to determine the dose including geometric

uncertainties although this method was not investigated in detail. Local maximum dose gradient (LMDG) was determined via optimization of dose objective function by manually adjusting DVH control points or selecting beam numbers and directions during IMRT treatment planning. Minimum SD ($SD_{min)}$ is used when geometric uncertainty is corrected with verification imaging. Maximum SD (SD_{max}) is used when the geometric uncertainty is known to be large and difficult to manage. SD_{max} was 4.38 mm in anterior-posterior (AP) direction, 2.70 mm in left-right (LR) direction and 4.35 mm in superior-inferior (SI) direction; SD_{min} was 1.1 mm in all three directions if less than 2 mm threshold was used for uncorrected fractions in every direction.

EUD_f is a useful QA parameter for interpreting the biological impact of geometric uncertainties on the static dose distribution. The EUD_f has been used as the basis for the time-course NTCP evaluation in the thesis. Relative NTCP values are useful for comparative QA checking by normalizing known complications (e.g. reported in the RTOG studies) to specific DVH control points. For prostate cancer patients, rectal complications were evaluated from specific RTOG clinical trials and detailed evaluation of the treatment techniques (e.g. dose prescription, DVH, number of beams, bean angles). Treatment plans that did not meet DVH constraints represented additional complication risk. Geometric uncertainties improved or worsened rectal NTCP depending on individual internal organ motion within patient.