Novel approaches to estimating time-dependent dose variations in lung radiotherapy: Time-resolved Monte Carlo simulations, scintillator dosimetry, and simulations of anatomical changes - DTU Orbit (29/09/2019)

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Lung cancer is one of the most common cancer diagnoses worldwide, unfortunately with patients suffering from poor prognosis. There is therefore a pressing need for improving treatment outcome and this is being widely addressed in the implementation of more complex treatment techniques, where radiotherapy of lung cancer patients is becoming more and more patient specific with a treatment delivery that is guided by the monitoring of the respiratory motion. However, ensuring high quality of complex radiotherapy in a heterogeneous anatomy such as the thorax is a challenging task. Additionally, the treated geometry is time-dependent and subject to both inter- and intra-fractional variations affecting both tumor position and material density distribution.

The work presented in this thesis has been motivated by the need to improve methods for estimating and verifying the dose delivered during motion managed radiotherapy of lung cancer patients. A major factor contributing to dose deviations in lung radiotherapy is inter-fractional variations. Anatomical changes such as pleural effusion, atelectasis and tumor shrinkage occur over the course of treatment and manifests in the form of density alterations also within the irradiated volume. By estimating the dosimetric effect of systematically simulated anatomical changes a foundation for assessing the need for adaptation of the treatment plan was established. The method was applied to a set of treatment situations of different complexity. In general the results demonstrated the need for patient- and treatment-specific investigation of the dosimetric effect caused by anatomical changes.

While inter-fractional changes often occur randomly over the course of treatment, the respiratory-induced intra-fractional motion is more predictable but in the same time also more challenging as any change in motion will influence the delivered dose immediately during irradiation. Addressing the questions of when, where and possibly why dose deviations occur requires methods for both accurate measurements and calculations where the dynamic motion of both the treatment beam configuration and the heterogeneous patient anatomy is taken into account. This study has therefore also focused on the development of tools for time-resolved scintillator measurements and accurate Monte Carlo dose calculations in a thoracic-like geometry.

An in-house developed dynamic thorax phantom was demonstrated to enable time-resolved plastic scintillator dosimetry during reproducible respiratory-like motion. Furthermore this dosimetry setup, mimicking radiotherapy in a patient-like geometry, was used as a basis for initial validation of a novel approach to time-resolved Monte Carlo simulations also developed during the current project. With the implementation of the Monte Carlo simulations into an automated workflow the tools were furthermore made accessible by minimizing the user interaction.

Based on the work carried out in the thesis it was concluded that there is a need for estimating dose variations in time-dependent heterogeneous geometries. Tools addressing this issue, both by measurements and dose calculations, were developed and demonstrated to be reliable. These tools were observed to have great potential to be used in a quality assurance program for dosimetric verification of complex treatment delivery techniques in radiotherapy of lung cancer patients.

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