Application of Monte Carlo to Four-Dimensional radiotherapy

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ABSTRACT

The Monte Carlo method is generally accepted to be the most dose calculation accurate method, especially in the presence of sharp heterogeneities such as those found in lung tumor geometries. Dose calculation accuracy for lung targets, however, is limited not just the presence of heterogeneities, but also by the fact that the target position is changing with time due to respiratory motion. To account for temporal changes in the target position, the concept of four-dimensional (4D) radiotherapy has been developed. 4DRT is the explicit inclusion of the temporal changes in anatomy during the imaging, planning and delivery of radiotherapy. This work describes the combination of 4DRT with Monte Carlo dose calculations with the goal of achieving accurate dose calculations for moving target volumes in heterogeneous media.

The 4D treatment plan was developed on a 4D CT scan. The 4D CT scan was created by acquiring a series of eight 3D CT image sets at different respiratory phases, and using deformable image registration to map each CT to the end-inhale respiration phase. Contours drawn on the end-inhale CT were then automatically transferred to the CT data sets at the other respiratory phases. Similarly, the treatment plan developed on the end-inhale CT image set was automatically applied to the 3D CT image sets at each respiratory phase using the same the beam arrangement and dose prescription as for the end-inhale plan. The Monte Carlo dose calculation was performed on each of the N (=8) treatment plans and 3D image sets with 1/N fewer particles per calculation than would have been used for a typical 3D plan. Using the deformable mapping, the dose distribution from each respiratory phase was mapped back to the end-inhale CT image set and added to the dose distributions from the other phases. This resulted in a statistical uncertainty in the merged dose distributions equivalent to that of a typical 3D plan. With this method, the 4D calculation time is similar to that for a 3D calculation. Overall, Monte Carlo dose calculation for 4D RT of lung tumors can result in higher dose accuracy because it properly accounts for both the electronic disequilibrium conditions due to the tissue heterogeneities and patient motion. Furthermore, for Monte Carlo, the dose calculation time is independent of the number of 3D CT image sets used in the calculation process, unlike other algorithms for which the calculation time scales linearly with the number of 3D CT image sets used for calculation.