Entropic model for dose calculation in external beam radiotherapy and brachytherapy

Purpose

This work is dedicated to development of a completely new Grid-Based Boltzmann Solver (GBBS) for the transport and energy deposition by energetic particles and x-rays in human tissues. The entropic closure and structured mathematical formulation provide an efficient framework enabling calculations of the delivered dose with an accuracy comparable to Monte Carlo (MC) codes in a strongly reduced computational time and without any special processing power requirement.

Methods

In contrast to discrete ordinates angular discretization methods, such as Acuros®, the entropic model is based on a reduced number of moment equations for the electrons and photons closed with Boltzmann's H-theorem. Keeping a good accuracy of calculations, the algorithm can simulate different treatment techniques such as the external radiotherapy even in presence of magnetic field (e.g., MRI-guided radiotherapy), brachytherapy or intra-operative radiation therapy. The model has been compared with the full MC simulations by using the code PENELOPE and showed a good accuracy and performance for different materials and geometric structures.

The validation procedure consisted in simulating dose distributions in complex numerical phantoms including a large number of heterogeneity shapes and materials such as bone, lung and air. For both, brachytherapy and external beam radiotherapy, simulations based on CT scans and using the real phase-space of the source, have been performed. Several examples are shown in the Appendix.

Results

The code will be capable of calculating three-dimensional dose distributions with 1 mm^3 voxels without statistical uncertainties in a few seconds instead of several minutes like PENELOPE. In brachytherapy applications the calculated dose distributions significantly differ from the ones calculated with the TG-43 approximations, thanks to a more accurate account for the material inhomogeneities and strong density gradients. For both applications the entropic model shows an excellent agreement with PENELOPE calculations within the 1%/1mm gamma-index criterion.

Conclusions

Comparisons with the MC simulations demonstrates an excellent accuracy and efficiency of the model. Thanks to the significantly reduced computational time and its accuracy, this model is a promising candidate to become a real-time dose calculation algorithm.